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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VOL. 1

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To Arlene, Stewart

and Clifford

Volume 1

contents

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.

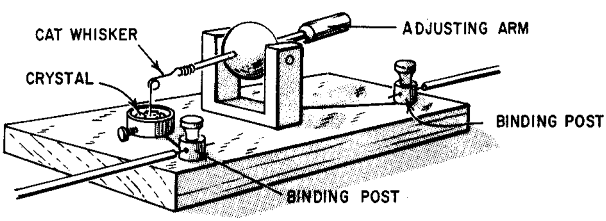


Fig. 101. *The crystal detector has a long history. The drawing shows a detector that was popular many years ago.*

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

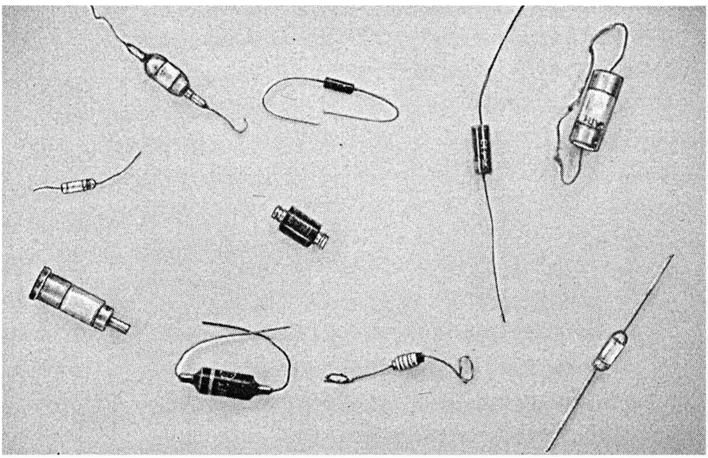


Fig. 102. *Crystal diodes are manufactured in a variety of shapes.*

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

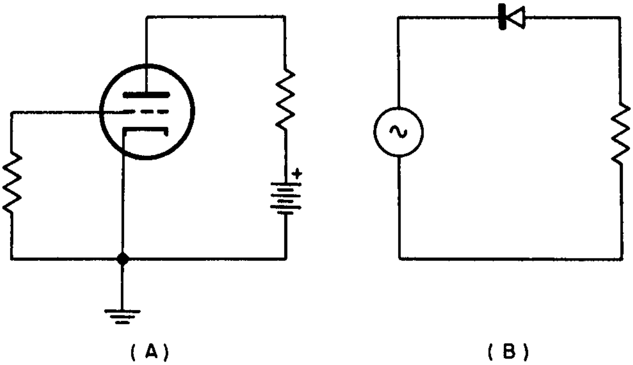


Fig. 103. *Electrons can move through a vacuum (A). They can also be made to move through a solid (B).*

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

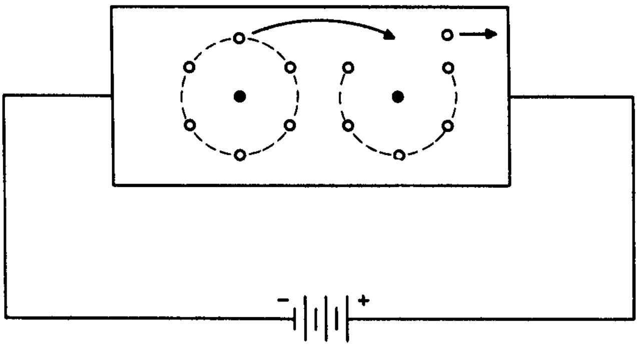


Fig. 104. *Electrons move from one atom to the next.*

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

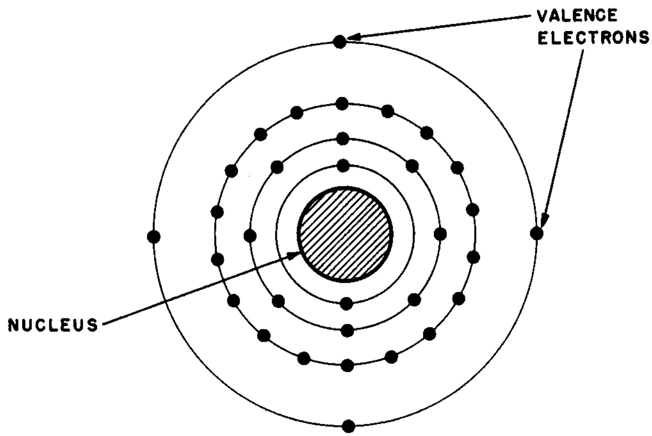


Fig. 105. *The germanium atom. The four valence electrons are the ones we are interested in.*

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

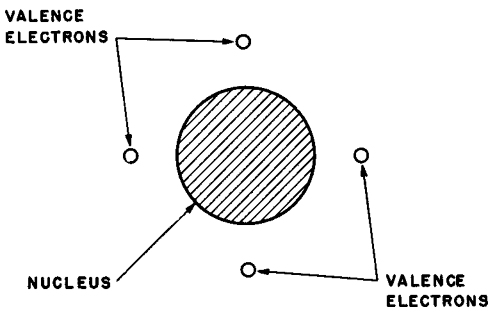


Fig. 106. *Simplified version of the germanium atom. The valence electrons are the ones that will work for us.*

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.

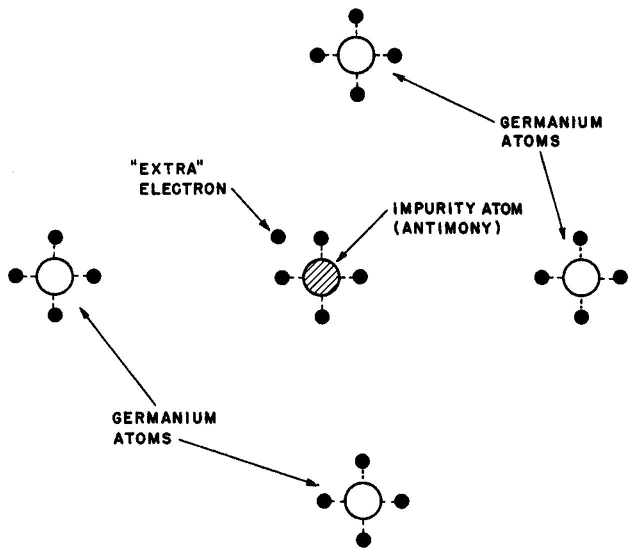


Fig. 107. *N-type germanium is formed by adding an "impurity" that contains excess electrons.*

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

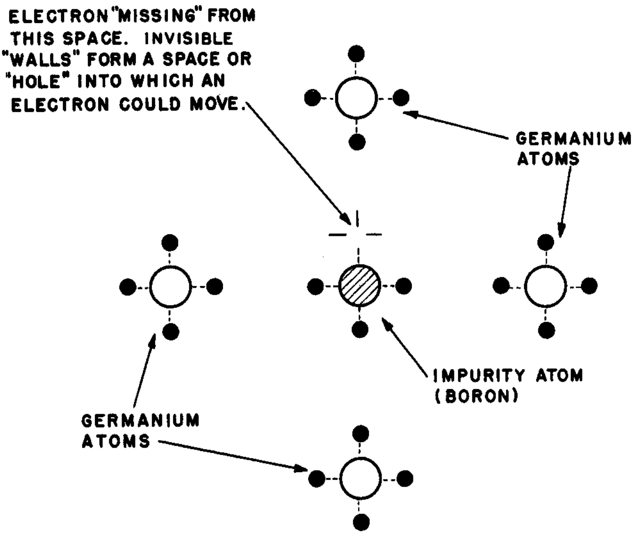


Fig. 108. *P-type germanium is formed by adding an "impurity" that has a shortage of electrons.*

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

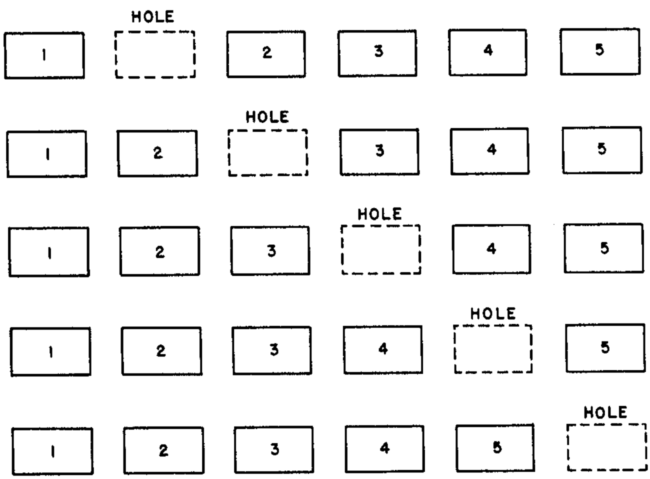


Fig. 109. *Each block represents a freight car. The vacant space or "hole" can be made to move back by changing the positions of the cars.*

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

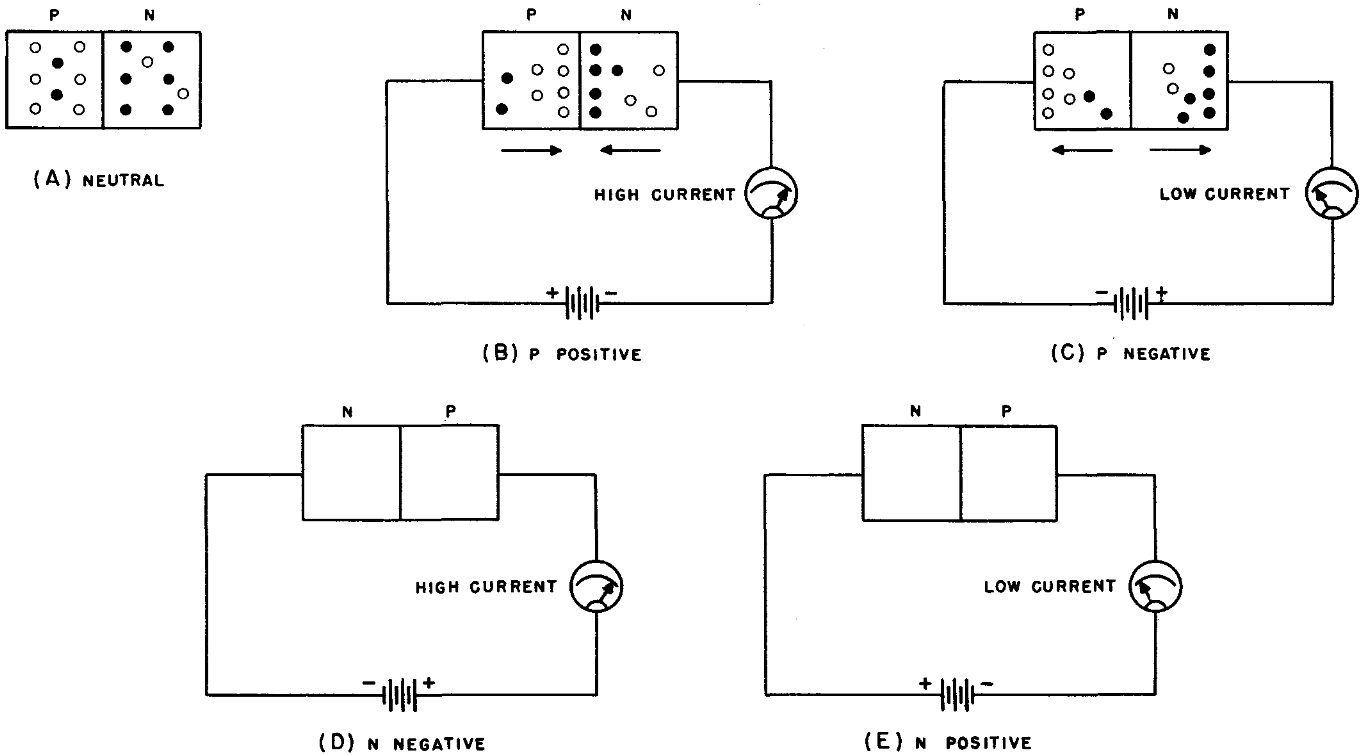


Fig. 110. *When the p-n diode is properly biased, a "high" current flows.*

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

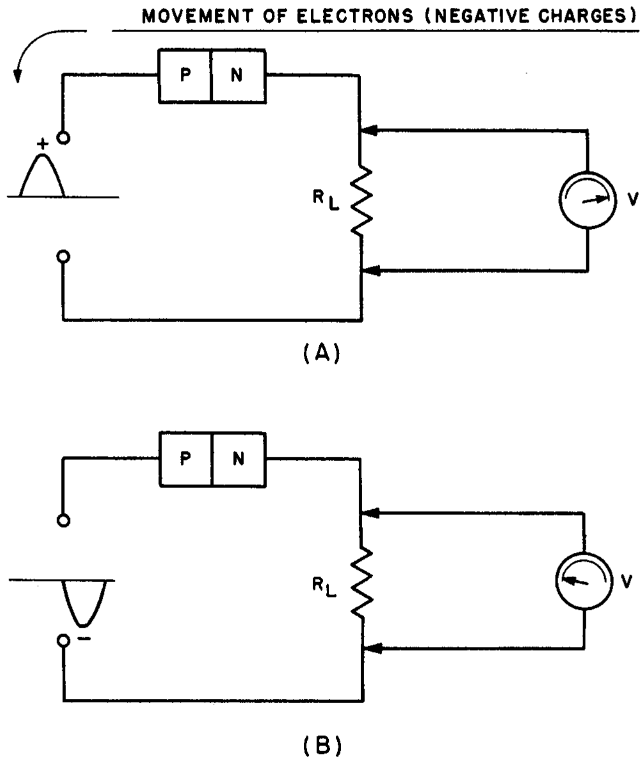


Fig. 111. *A p-n diode acts as a rectifier for an ac voltage.*

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

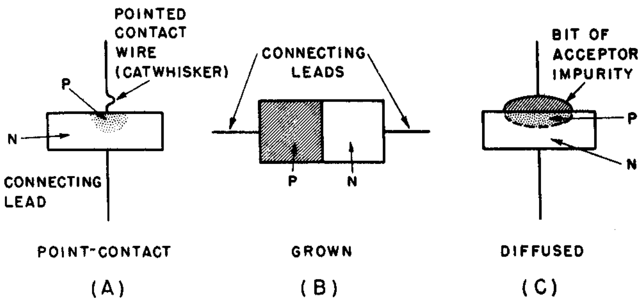


Fig. 112. *The p-n "sandwich" can be made in many ways. The point-contact type, is practically obsolete.*

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-

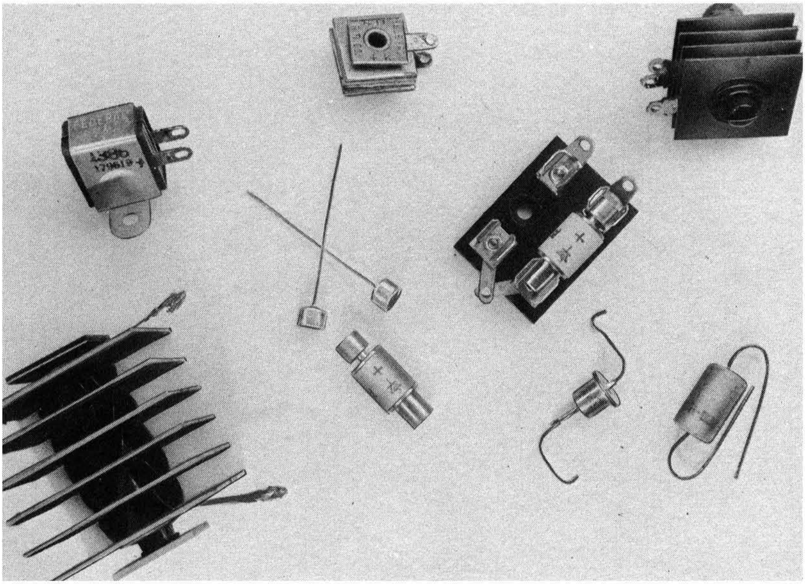


Fig. 113. *Semiconductor rectifiers used to supply dc for radio and television receivers.*

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

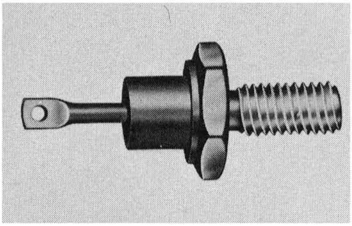


Fig. 115. *Both silicon rectifiers and Zener diodes are mounted in this type of case.* (International Rectifier Corp.)

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

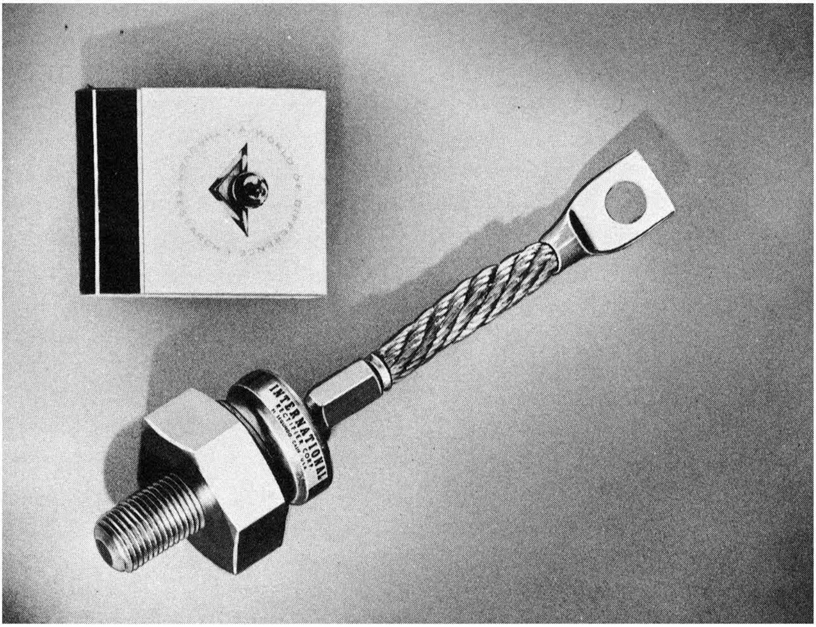


Fig. 116. *This silicon rectifier is a variety than can handle 70 to 250 amperes at 50 to 500 piv.* (International Rectifier Corp.)

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

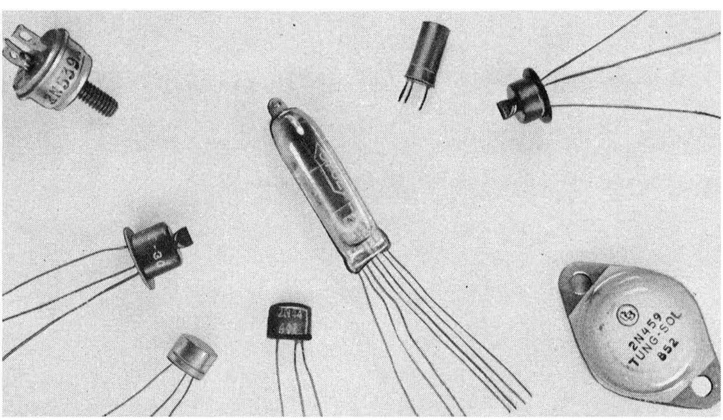


Fig. 117. *Compared to subminiature tubes, transistors still look small.*

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

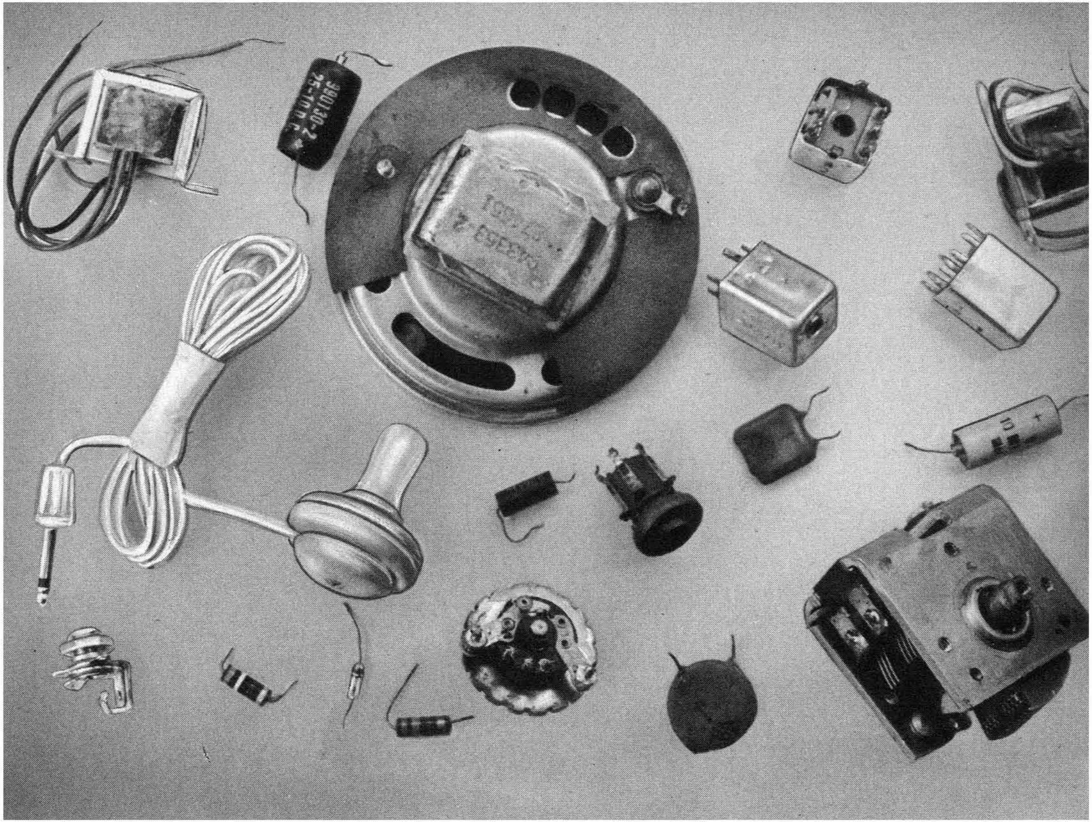


Fig. 118. *A 2½ inch speaker is shown with many of the major components of a transistor receiver.*

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

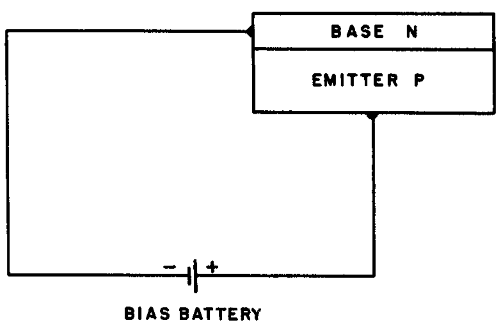


Fig. 201. *The emitter injects current carriers (holes) into the base.*

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

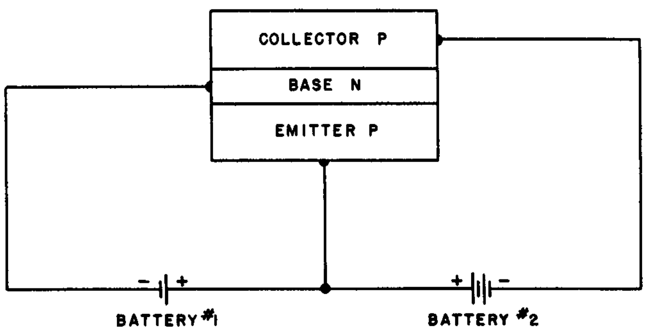


Fig. 202. *The transistor consists of an emitter, base and collector.*

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

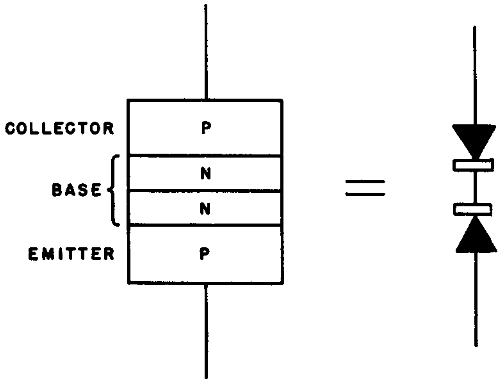


Fig. 203. *If the n-region of the transistor is sliced in half (theoretically), it will form two diodes placed back to back.*

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.

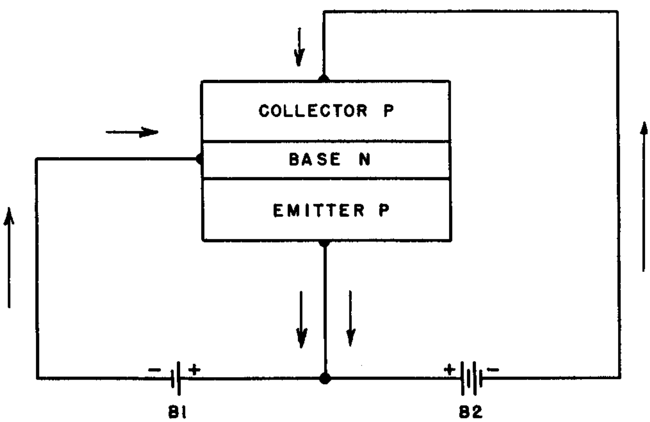


Fig. 204. *Most of the carriers (holes) go to the collector and form the collector current. A few of the carriers flow in the base-emitter circuit. The arrows indicate electron movement external to the transistor.*

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

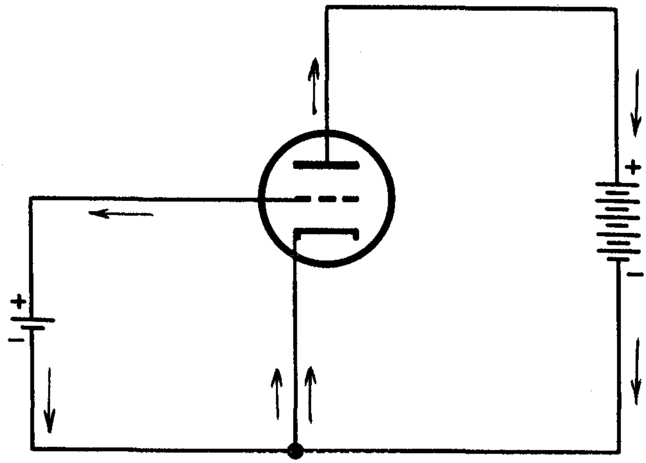


Fig. 205. *The triode transistor can be compared to a triode vacuum tube. Arrows show paths of electron flow.*

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

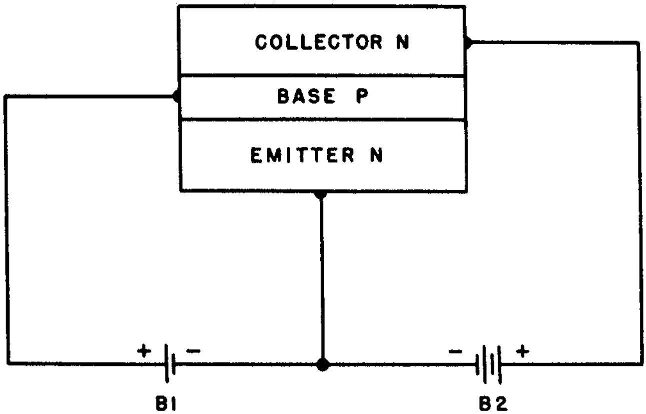


Fig. 206. *In the n-p-n transistor, the negative terminal of bias battery, B1, is connected to the emitter.*

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

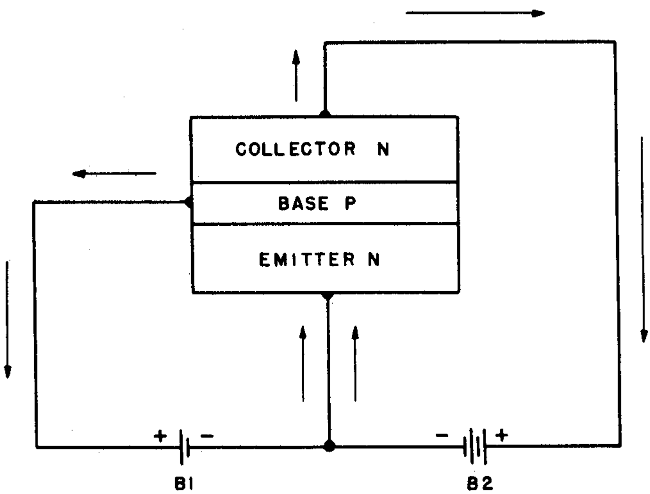


Fig. 207. *Electron flow in the n-p-n transistor circuit.*

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.

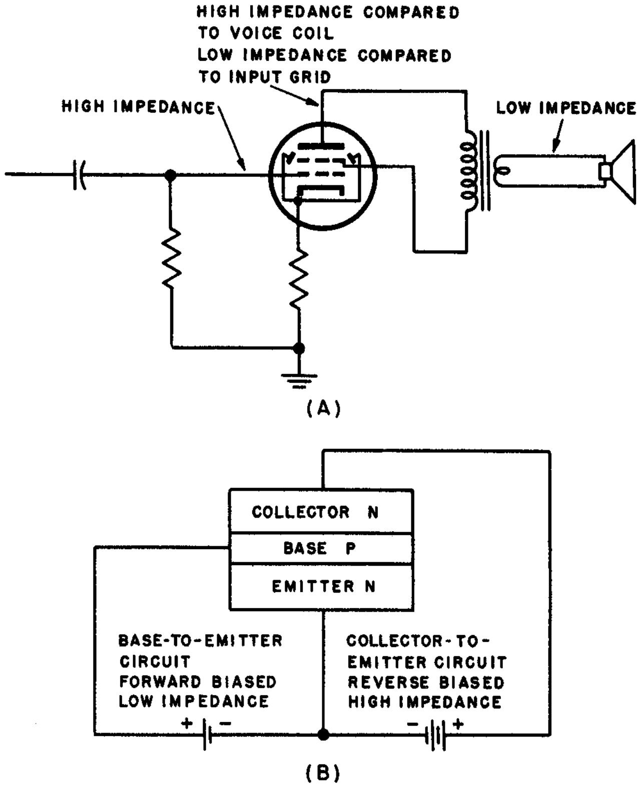


Fig. 208. *Input and output impedances in vacuum-tube and transistor circuits.*

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

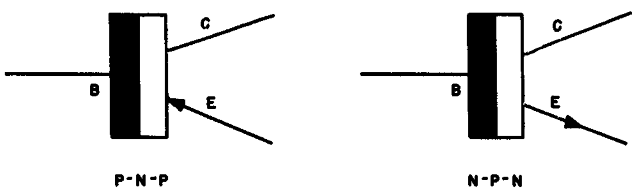


Fig. 209. *Electronic symbols for p-n-p and n-p-n transistors.*

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

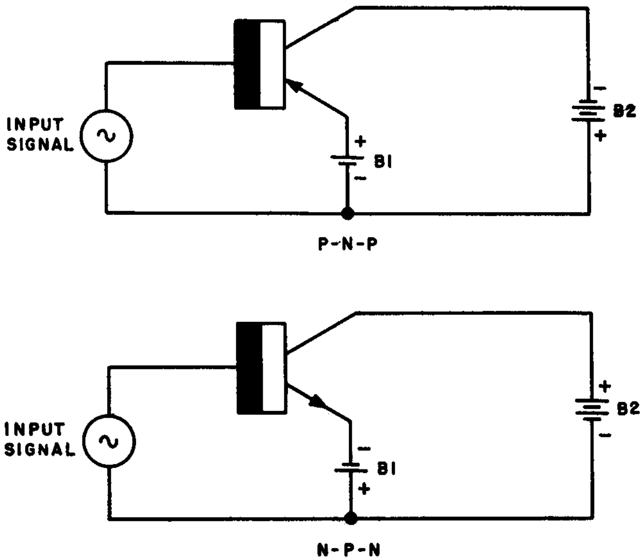


Fig. 210. *The input can be a radio signal or the output of a generator.*

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.

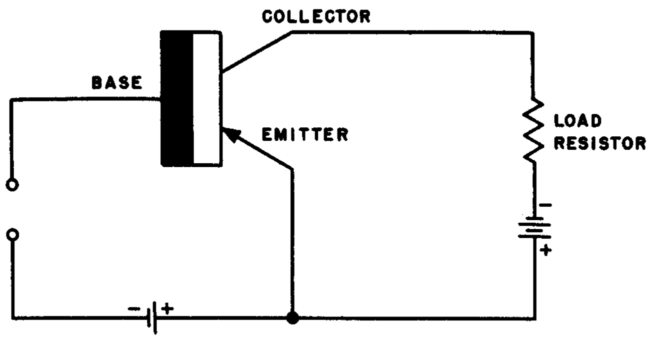


Fig. 211. *Technique for connecting the load resistor to the transistor.*

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

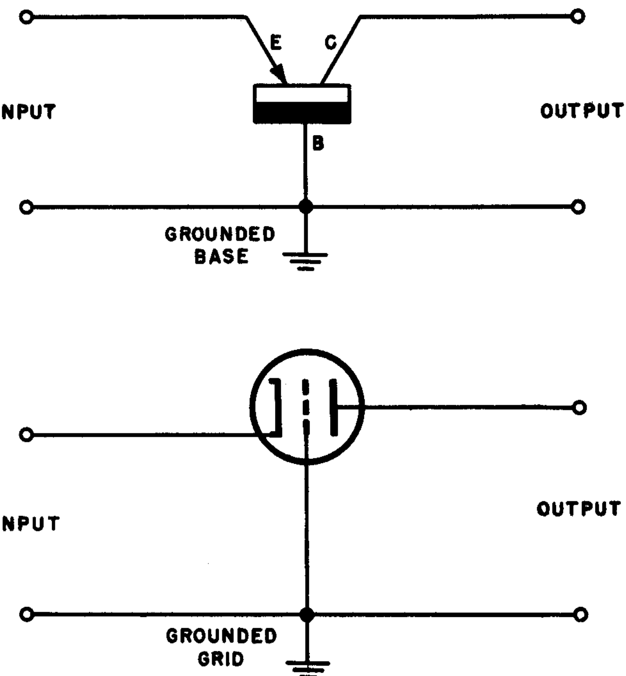


Fig. 212. *Circuit of the grounded-base transistor and its counterpart, the grounded-grid vacuum-tube amplifier.*

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,

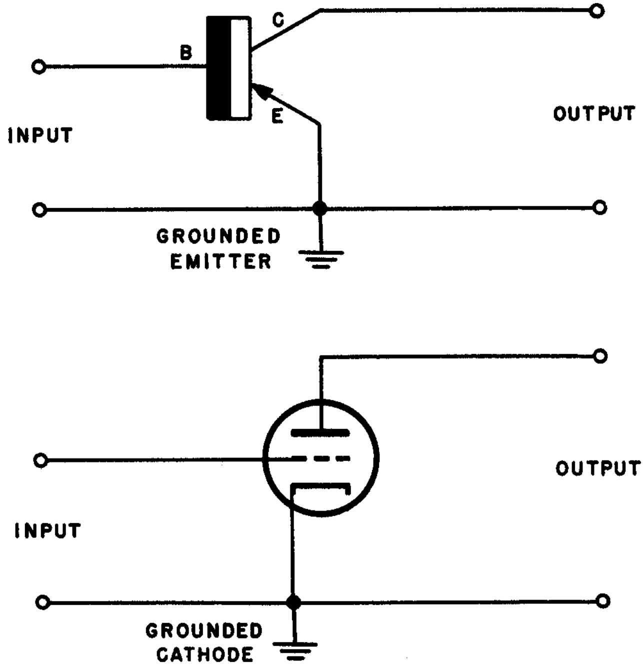


Fig. 213. *The grounded-emitter transistor amplifier is similar to the grounded-cathode vacuum-tube circuit.*

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.

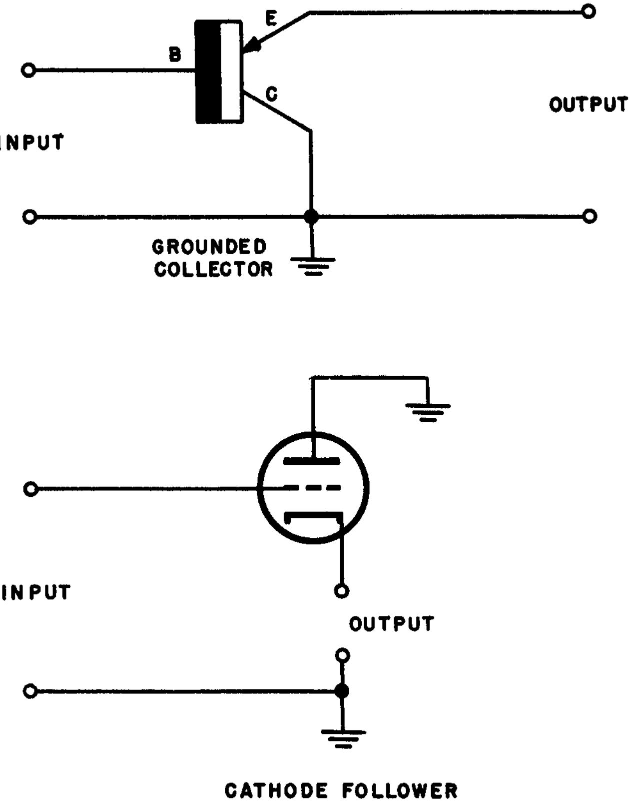


Fig. 214. *The grounded-collector has characteristics similar to those of the cathode follower.*

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

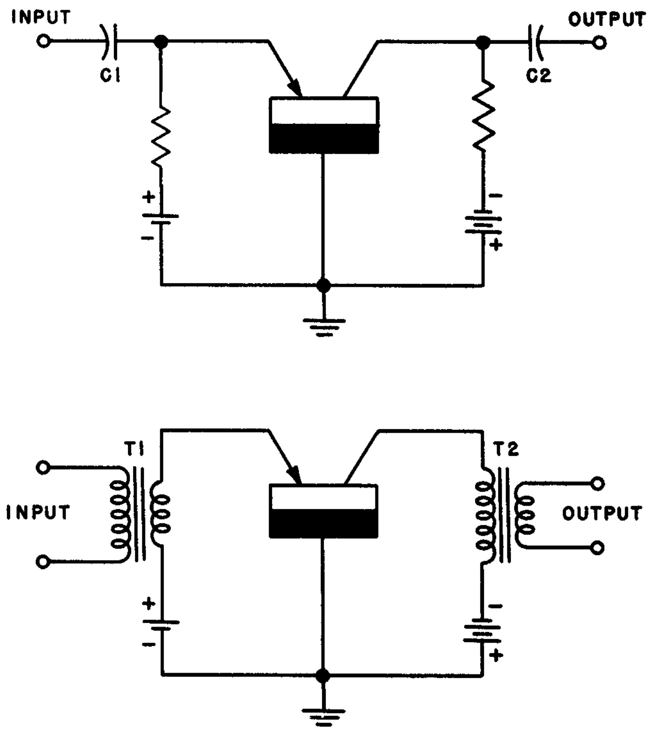


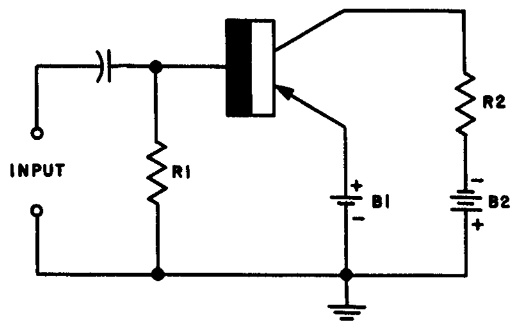
Fig. 215. *Resistance- and transformer-coupled grounded-base amplifiers.*

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



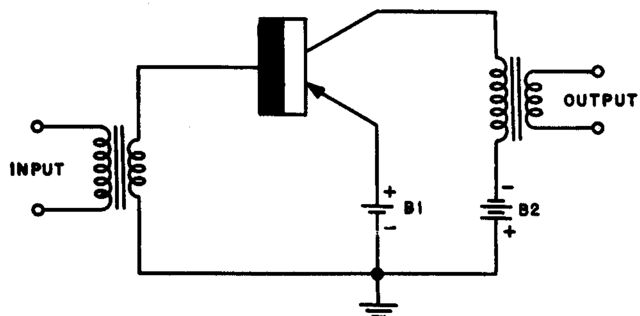


Fig. 216. *Resistance- and transformer-coupled grounded-emitter amplifiers.*

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.

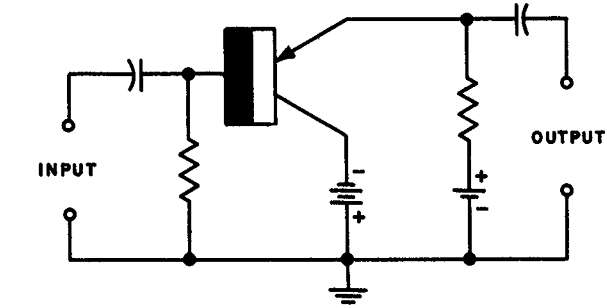
Transistor components

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.



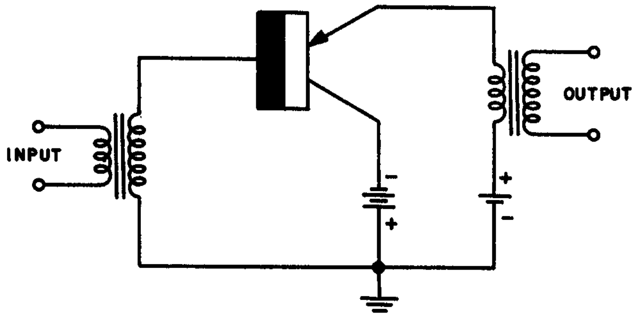


Fig. 217. *Resistance- and transformer-coupled grounded-collector amplifiers.*

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.

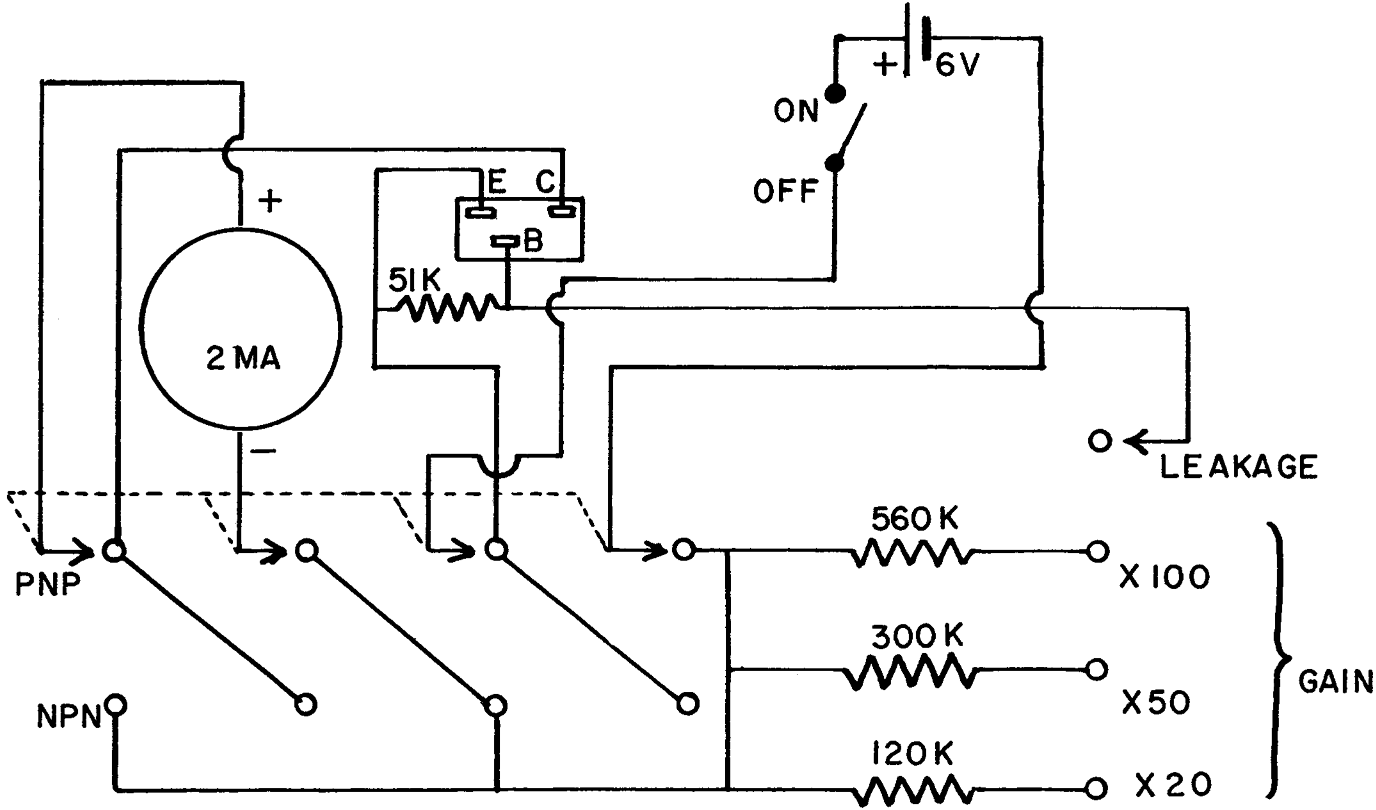


Fig. 218. *Circuit used in a transistor tester kit. A meter, three switches, four resistors, a battery and a socket are all housed in a neat prefinished cabinet.* (Electronic Measurements Corp.)

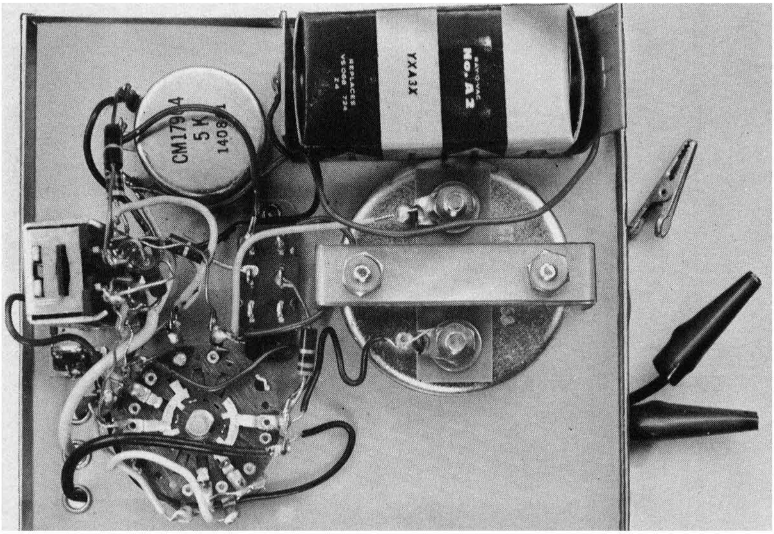


Fig. 219. *Factory-wired transistor tester uses a calibrated potentiometer. Clip leads supplement transistor socket.*

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-

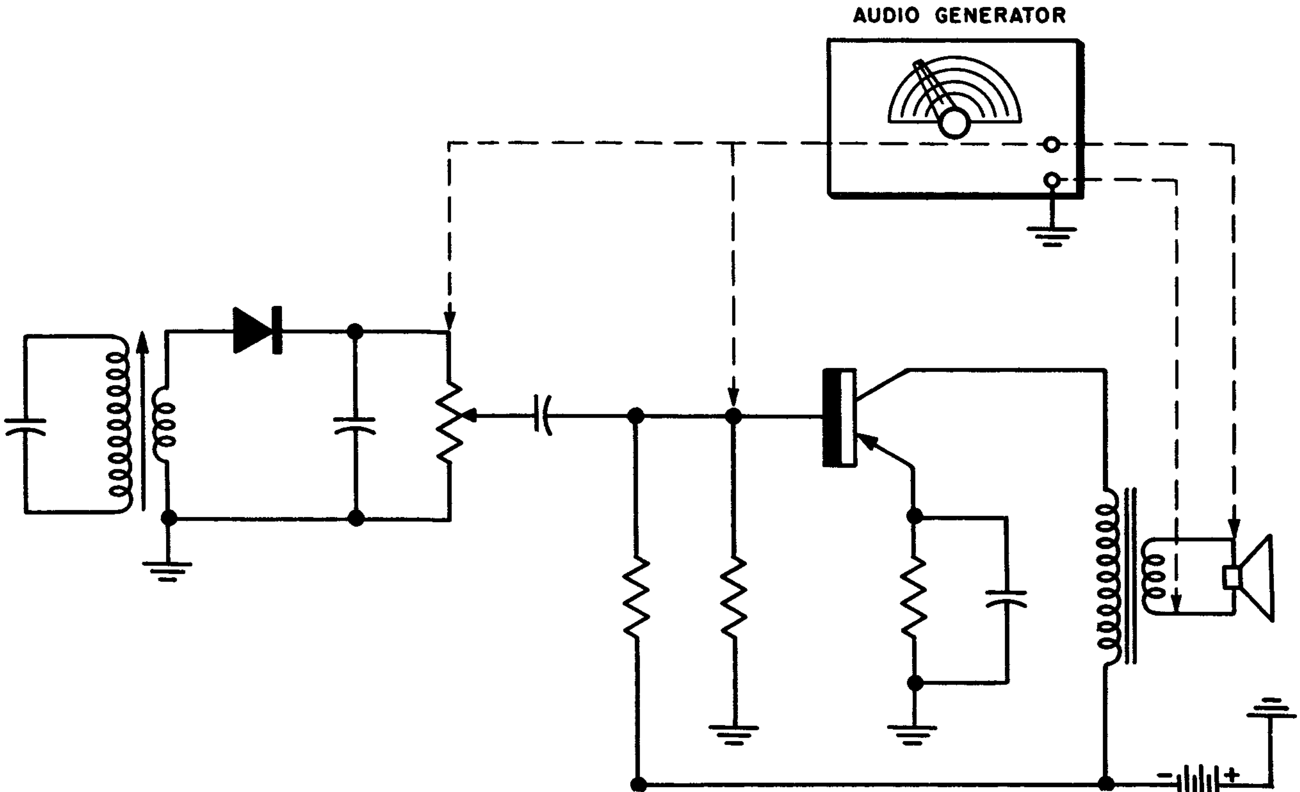


Fig. 220. *There are a variety of connections that can be used for the audio generator signal-injection technique in finding a defective audio transistor. The practical applications of this system will be explained more fully in Chapters 7 and 8 in Vol. II.*

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

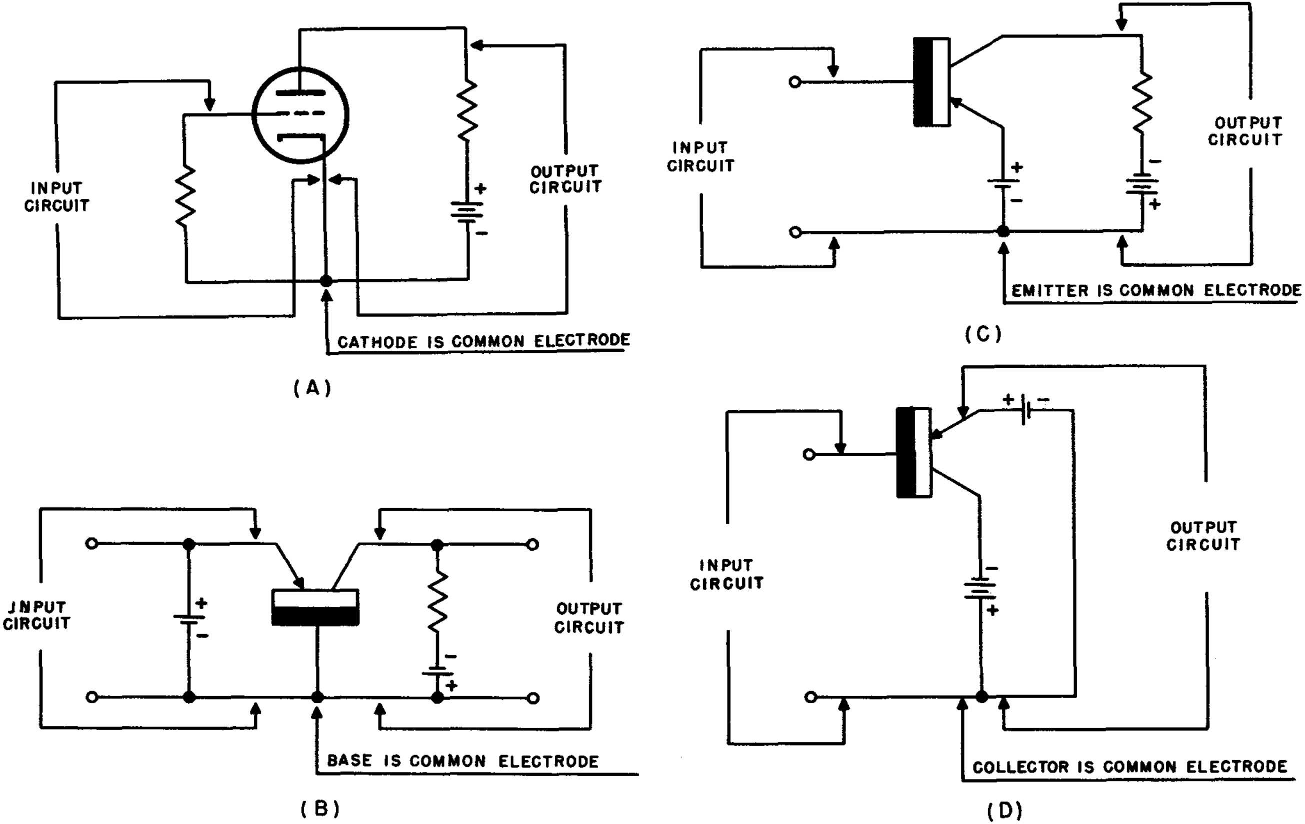


Fig. 301. *Like the vacuum tube, the transistor uses one electrode common to input and output circuits.*

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

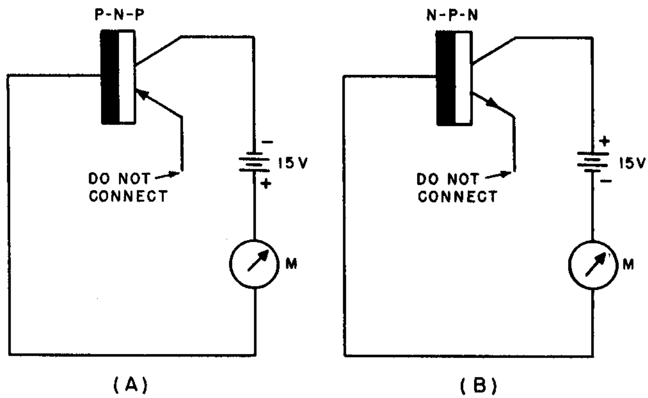


Fig. 302. *Method for checking collector-to-base leakage in p-n-p and n-p-n transistors.*

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-

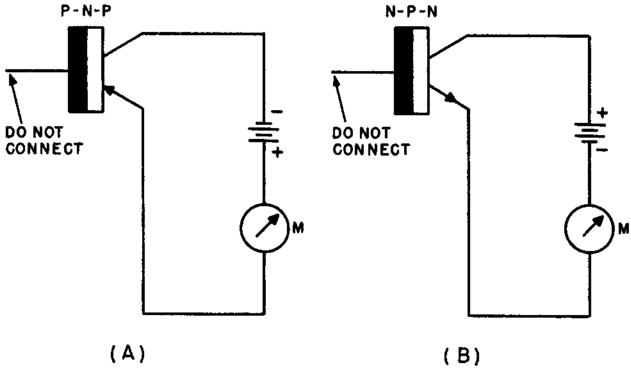


Fig. 303. *Technique for measuring collector-to-emitter leakage in p-n-p and n-p-n transistors.*

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

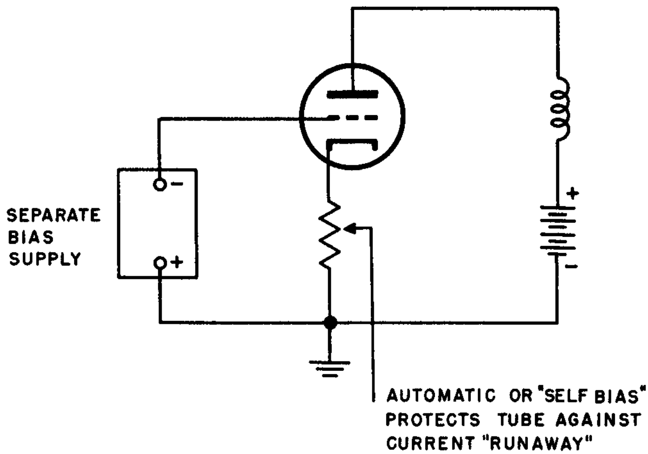


Fig. 304. *The cathode resistor helps keep the plate current within reasonable limits.*

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-

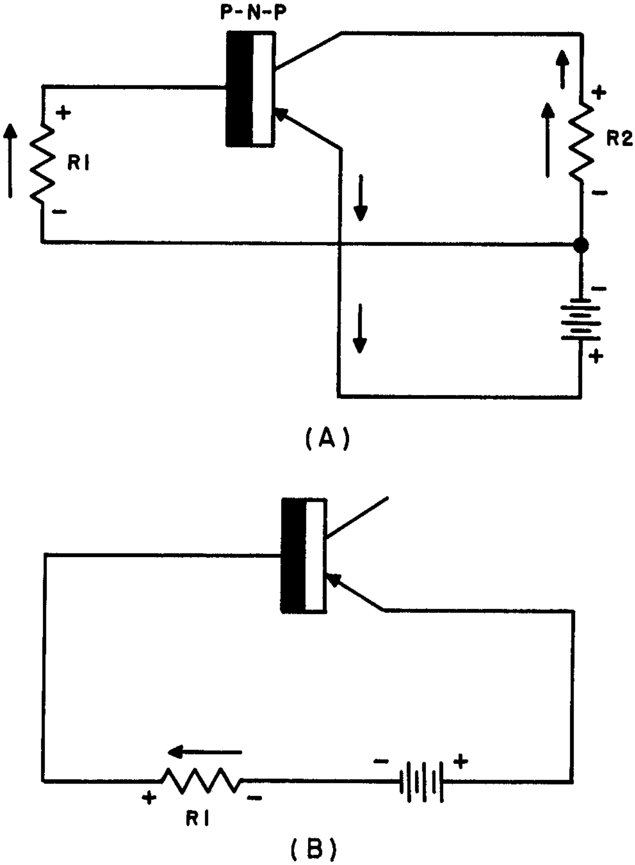


Fig. 305. *Electrons move into the transistor through the collector, return via the base and emitter in the p-n-p transistor.*

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

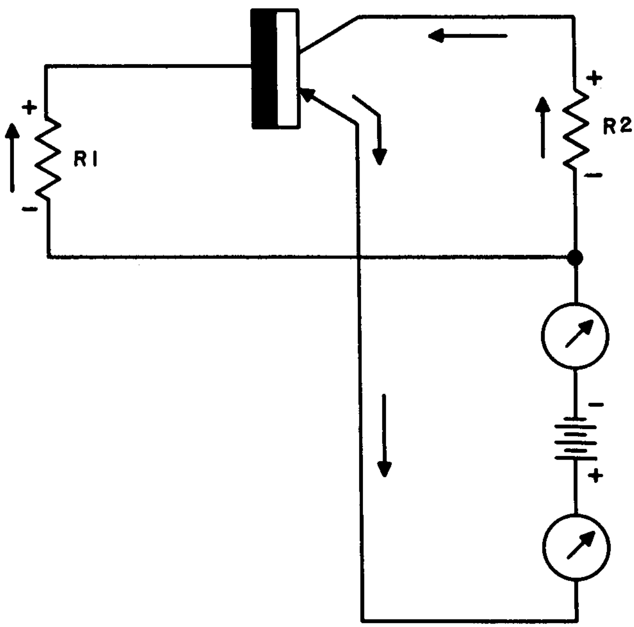


Fig. 306. *The electron flow out of the battery is identical to the electron flow into the battery.*

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.

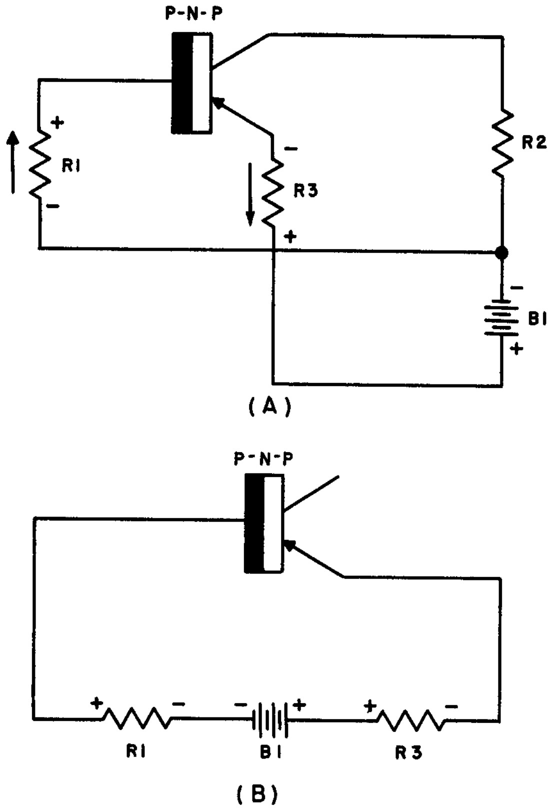


Fig. 307. *The voltage across R1 supplies fixed bias. This bias remains fairly constant. The voltage across R3 supplies self-bias. The value of self-bias depends primarily upon the amount of collector current.*

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.

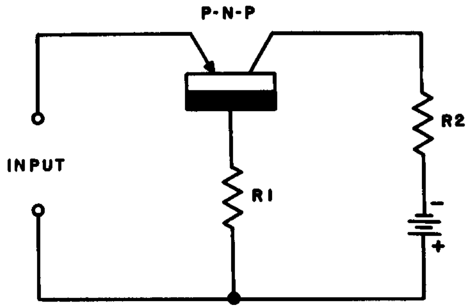


Fig. 308. *Common-base p-n-p arrangement using self-bias.*

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.

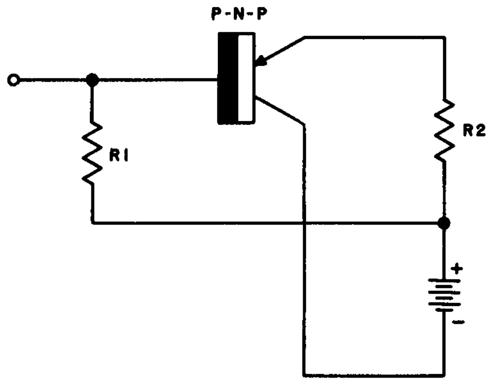


Fig. 309. *Common-collector circuit using fixed bias supplied by the voltage drop across R1.*

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.

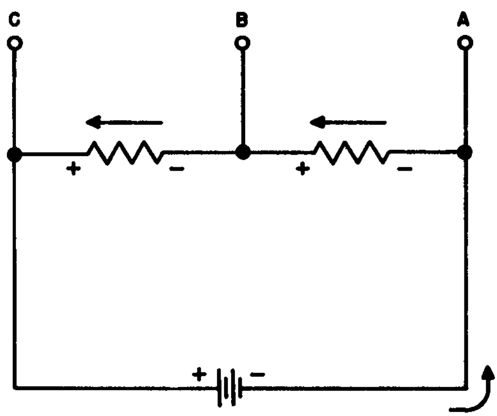


Fig. 310. *Simple voltage-divider action.*

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.

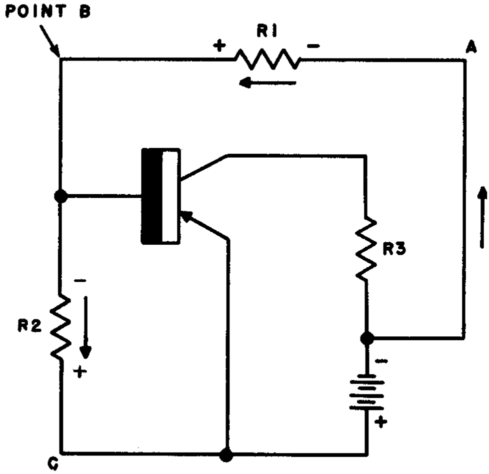


Fig. 311. *R1 and R2 act as a voltage divider across the battery.*

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.

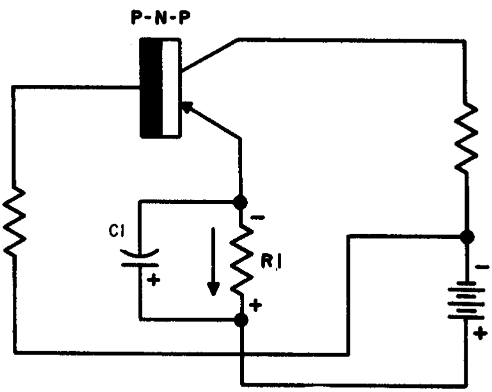


Fig. 312. *The emitter resistor, R1, is bypassed by capacitor C1. If C1 is an electrolytic, its polarity must be the same as that of the emitter resistor.*

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.

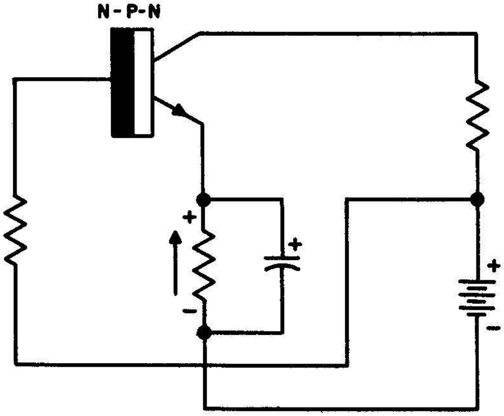


Fig. 313. *When using an n-p-n unit in place of p-n-p, not only must the battery leads be transposed, but the emitter bypass (if an electrolytic) must also have its leads changed.*

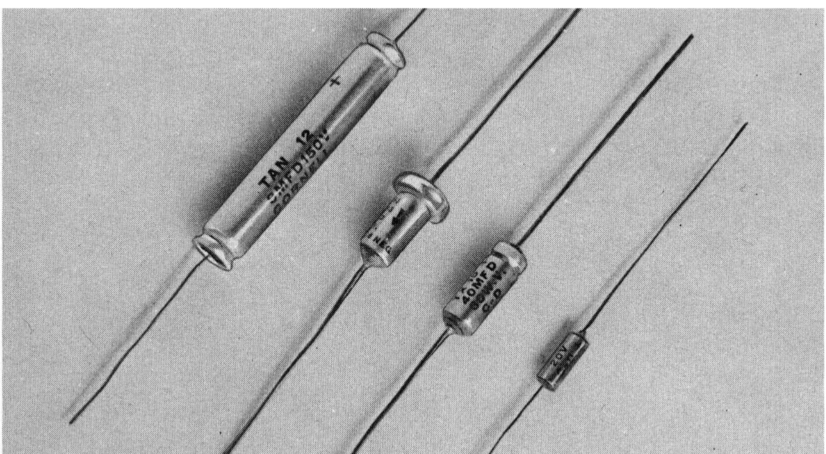


Fig. 314. *The photo shows typical electrolytics used in transistor receivers. These are very small compared to the units you will find in vacuum-tube receivers.*

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.

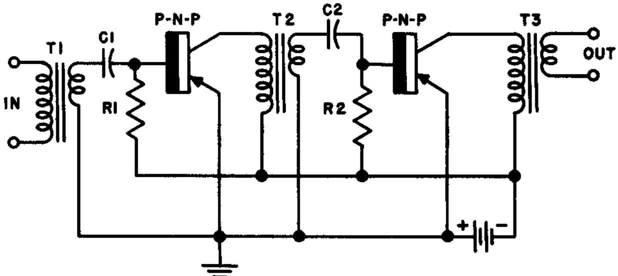


Fig. 315. *Two-stage transformer-coupled amplifier using p-n-p units. A single battery supplies collector bias. Resistors R1 and R2 furnish fixed bias for the base-to-emitter input circuits.*

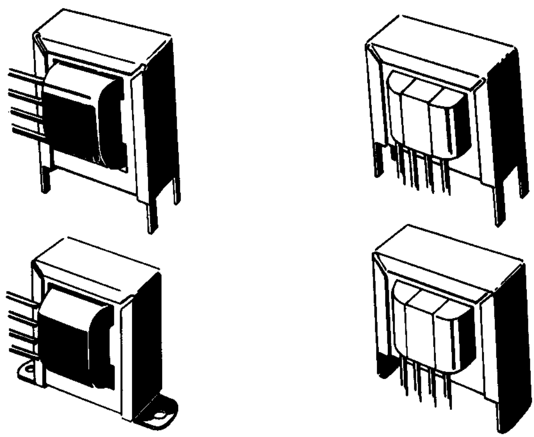


Fig. 316. *Transistor transformers are small compared to those used in vacuum-tube receivers.*

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

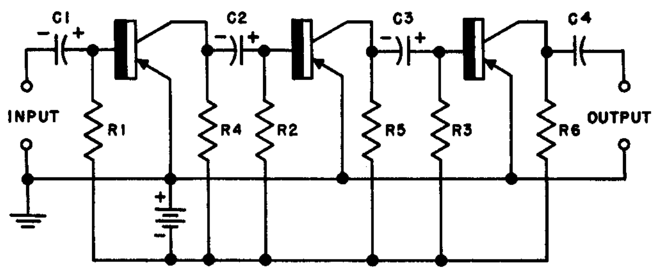


Fig. 318. *R-C-coupled transistor amplifier using p-n-p units. Fixed bias is used throughout. The coupling capacitors can be 2-μf tantalum electrolytics.*

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

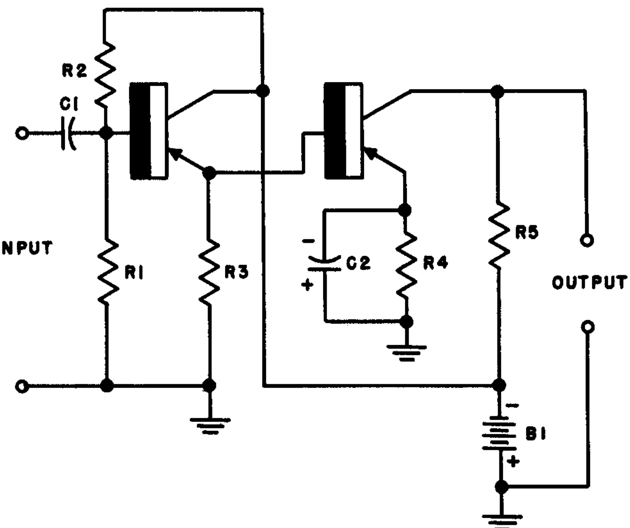


Fig. 319. *Direct-coupled transistor amplifier.*

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.

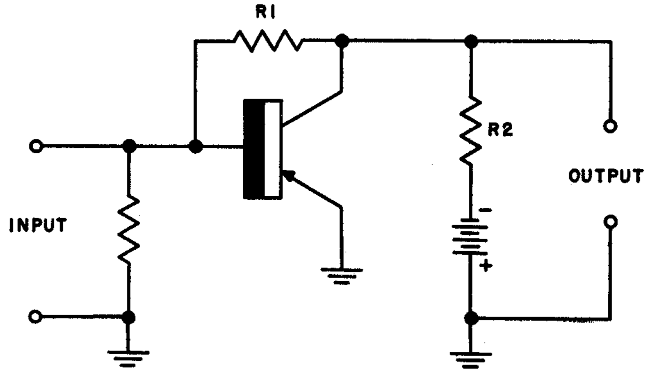


Fig. 320. *R1 has two jobs. It supplies fixed bias and negative feedback.*

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

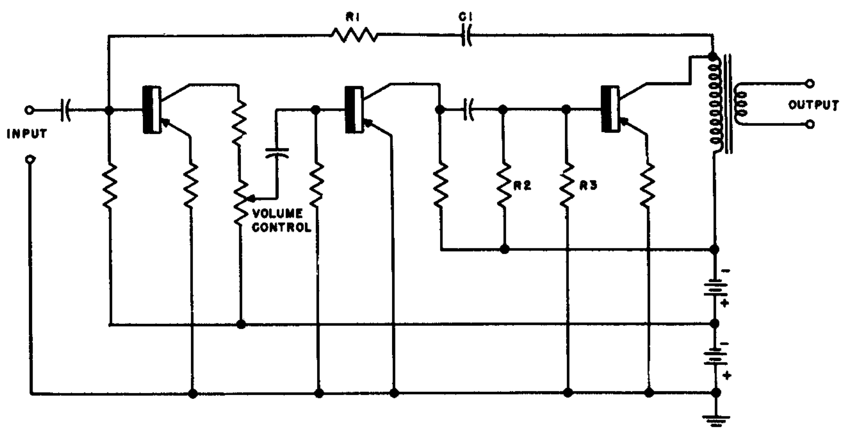


Fig. 321. *R1 and C1 represent the negative feedback circuit. The amount of voltage fed back depends upon the values of R1 and C1 and also upon the output signal voltage. R2 and R3 form a voltage divider across the battery supply and place the correct amount of bias voltage on the input circuit of the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

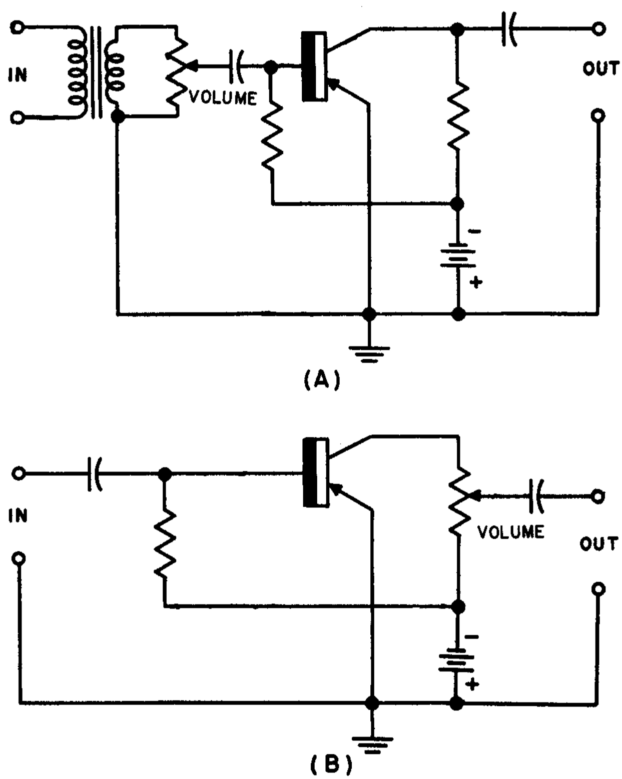


Fig. 322. *Typical placement of the volume control in transistor receivers.*

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

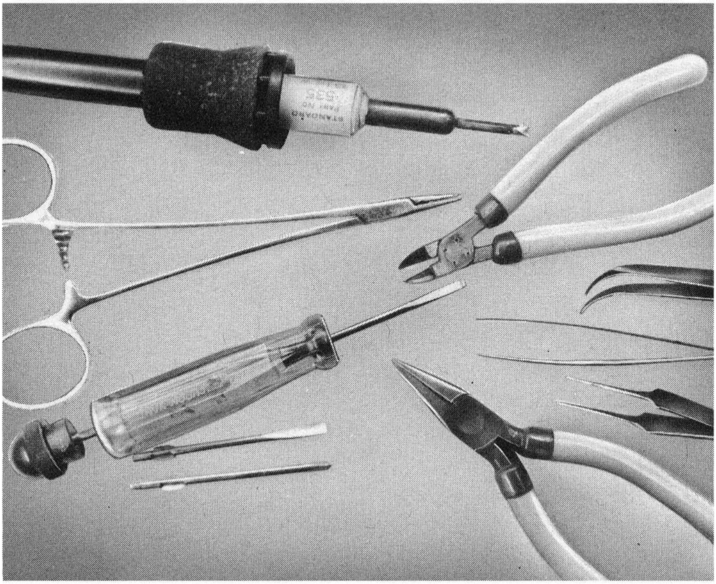


Fig. 401. *Typical tools used in servicing transistor receivers.*

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.

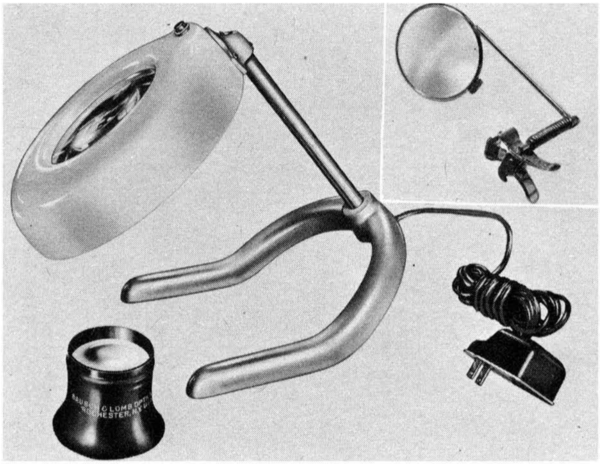


Fig. 402. *Magnifying lenses are useful in working with transistors.*

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

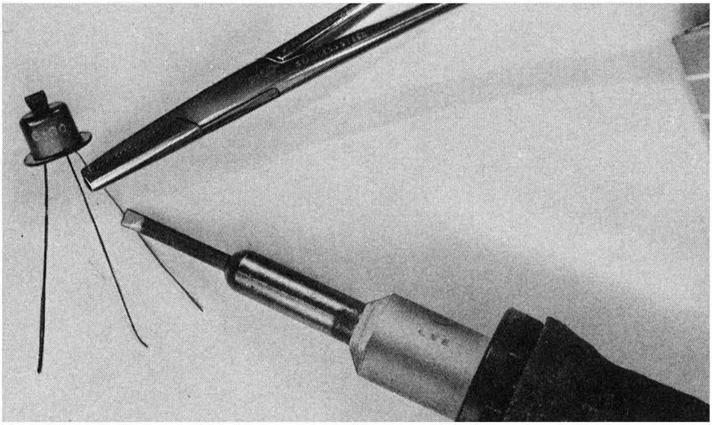


Fig. 403. *Pliers used as heat sink when soldering transistor leads.*

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.

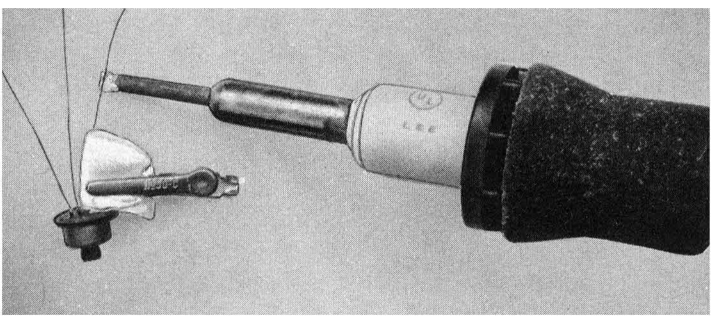


Fig. 404. *A bit of damp cloth held in place with an alligator clip can serve as a heat sink.*

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.

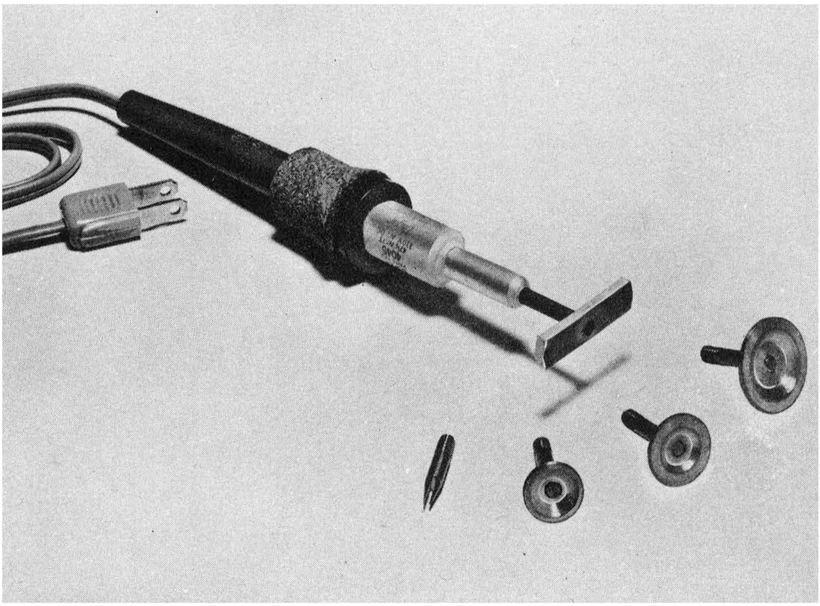


Fig. 405. *Interchangeable tips are designed for unsoldering components from printed-circuit boards.* (Ungar Electric Tools)

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

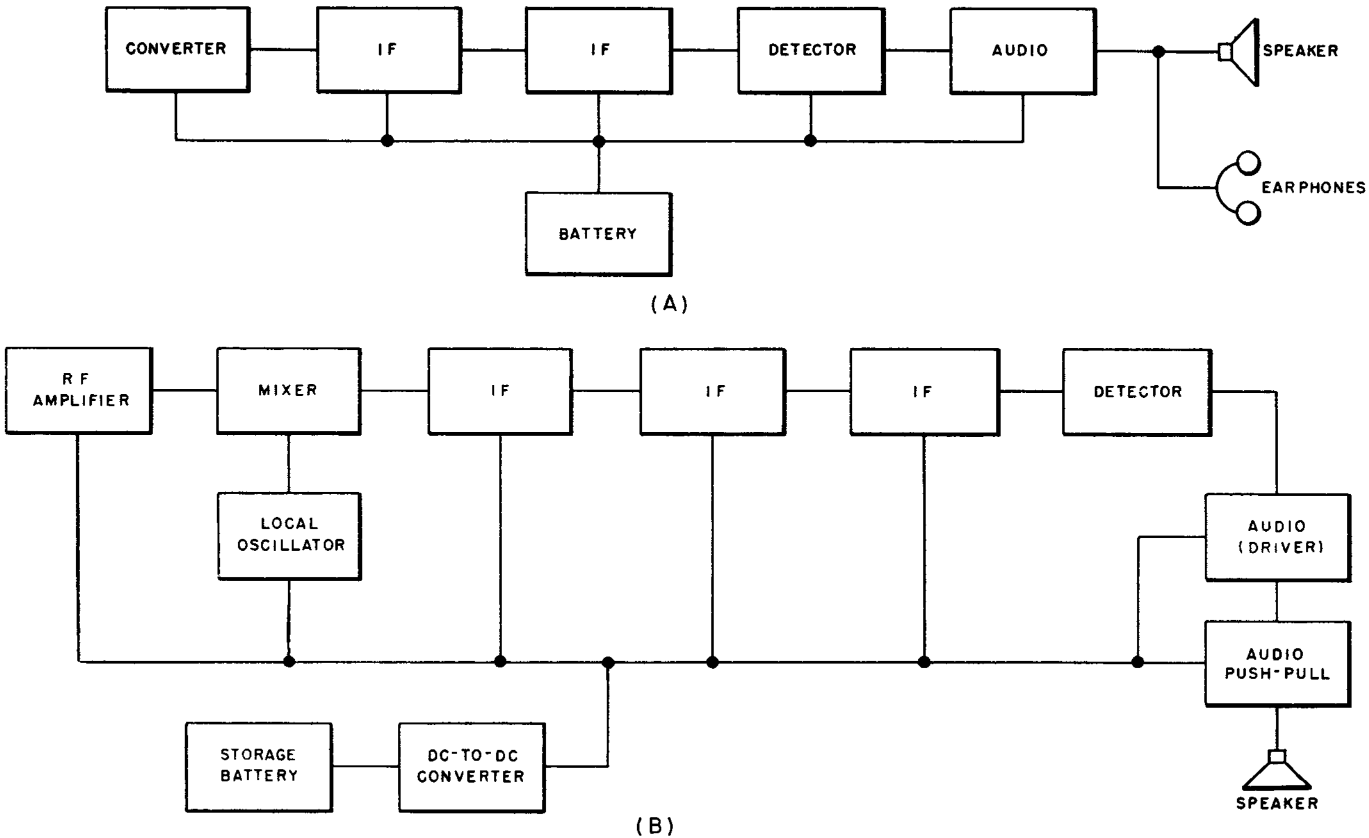


Fig. 406. *Block diagram of a portable or home receiver (A) and a diagram of an auto radio (B). The automobile receiver is more complicated.*

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-

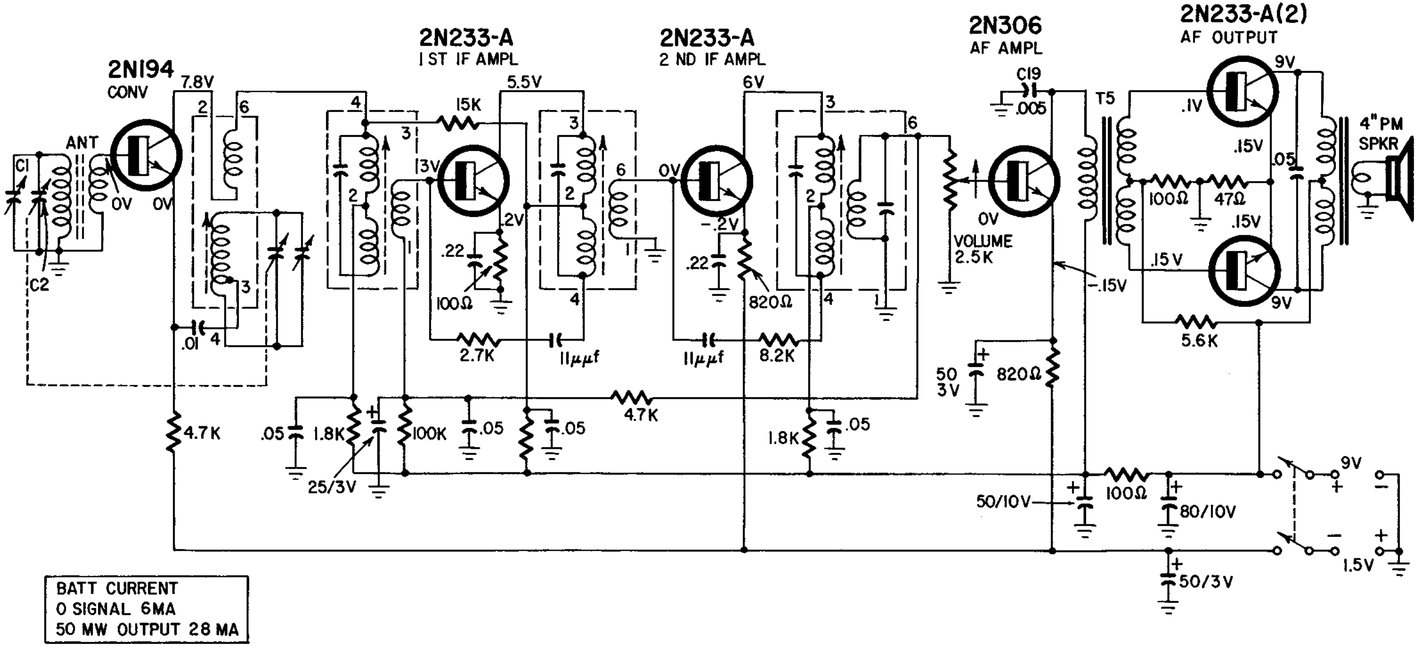


Fig. 407. *Complete schematic of a portable transistor receiver.*

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

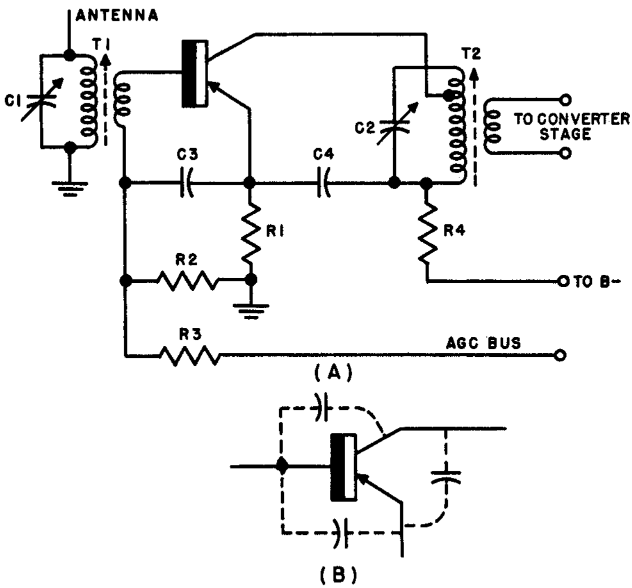


Fig. 408. *Typical rf amplifier stage found in the more expensive portables and in auto radios. The illustration (B) shows the capacitances that may exist around a transistor.*

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

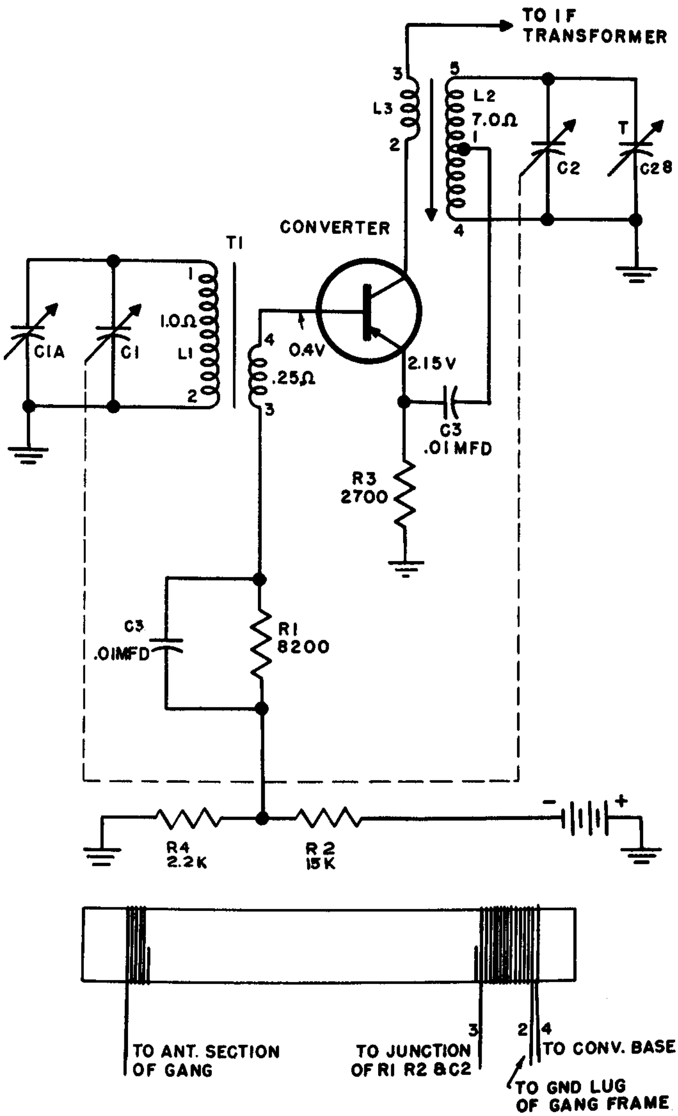


Fig. 409. *Typical converter circuit. A Hartley oscillator is used. L3 is a feedback coil and is in series with the if transformer.*

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).

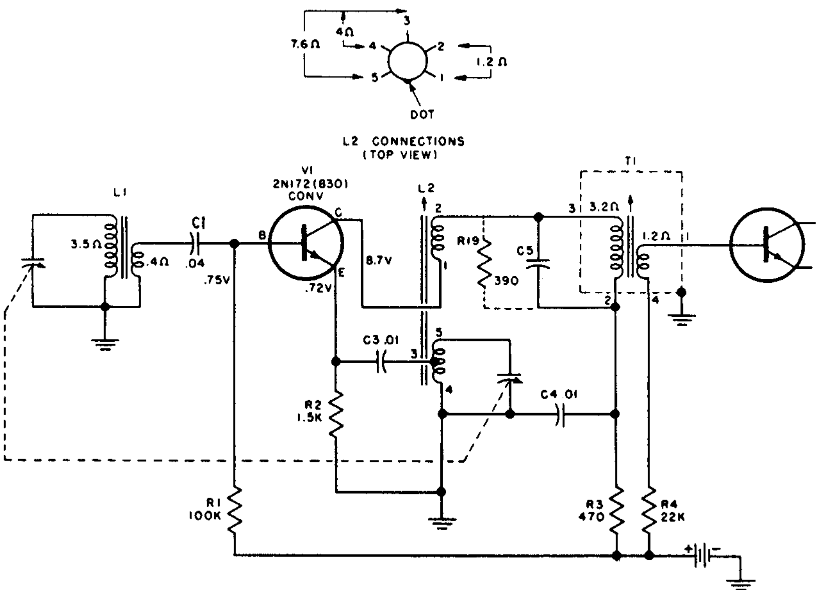


Fig. 410. *Converter circuit using an n-p-n transistor. The input rf transformer is connected to the base through a capacitor.*

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.

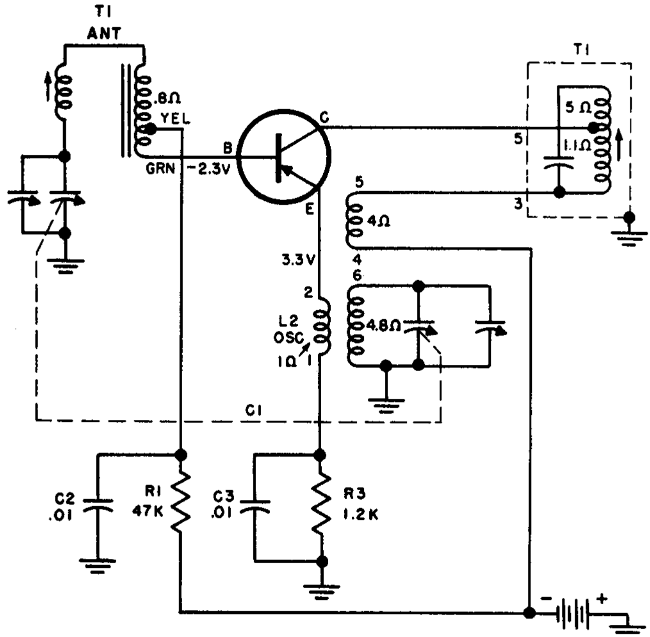


Fig. 411. *Converter circuit using an autotransformer type of antenna transformer. The collector is tapped down on the primary of the if transformer.*

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.

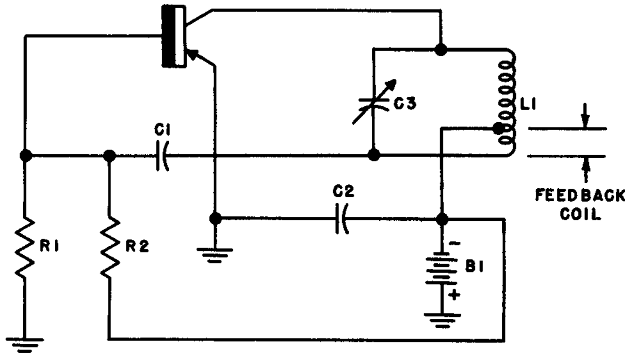


Fig. 412. *Hartley oscillator. Oscillator action is the same as in a vacuum-tube type.*

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.

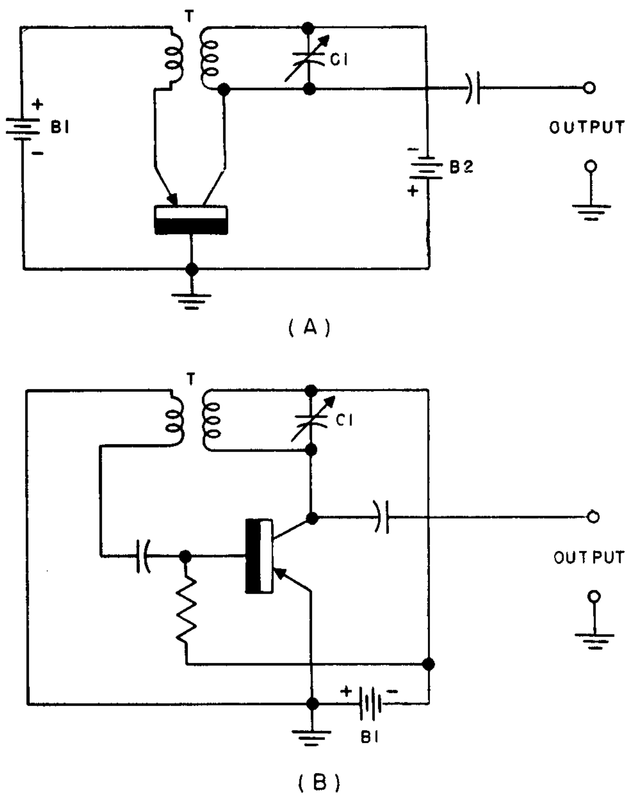


Fig. 413. *Grounded-base and grounded-emitter oscillators using a transformer for feedback.*

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.

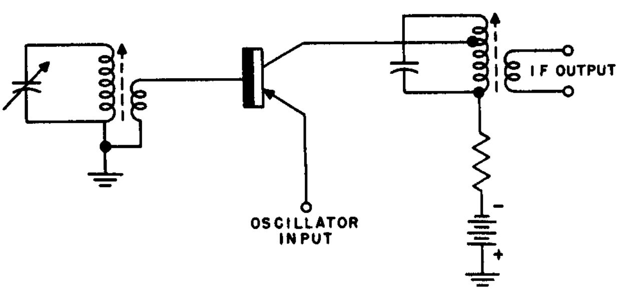


Fig. 414. *The oscillator circuit can be connected to the emitter of the mixer or converter.*

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

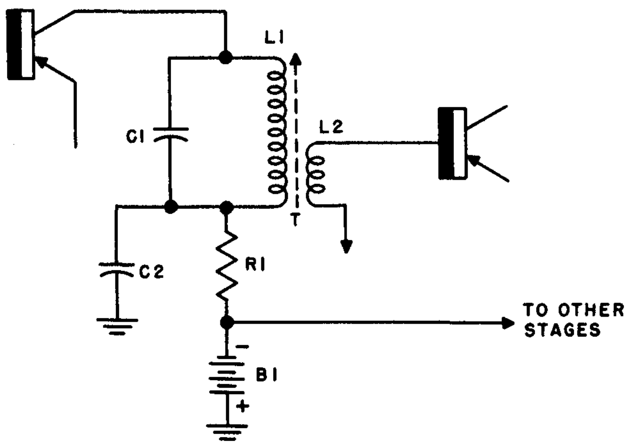


Fig. 415. *The if transformer is a stepdown type. The collector circuit has a higher impedance than the base circuit of the following stage.*

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

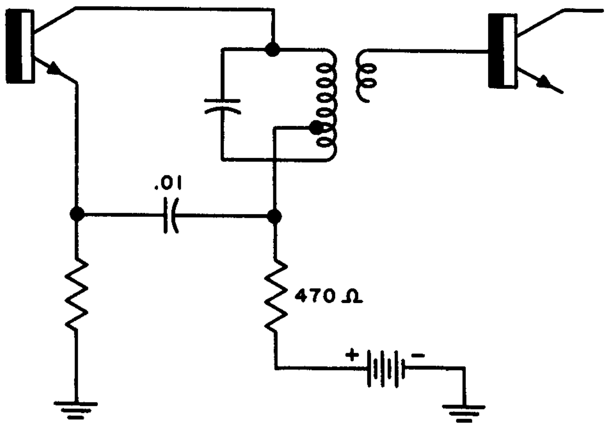


Fig. 416. *Because of the presence of the .01 μf capacitor, the tap on the primary of the if transformer is at signal ground potential. Tapping down is a widely used method of obtaining a suitable impedance match.*

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

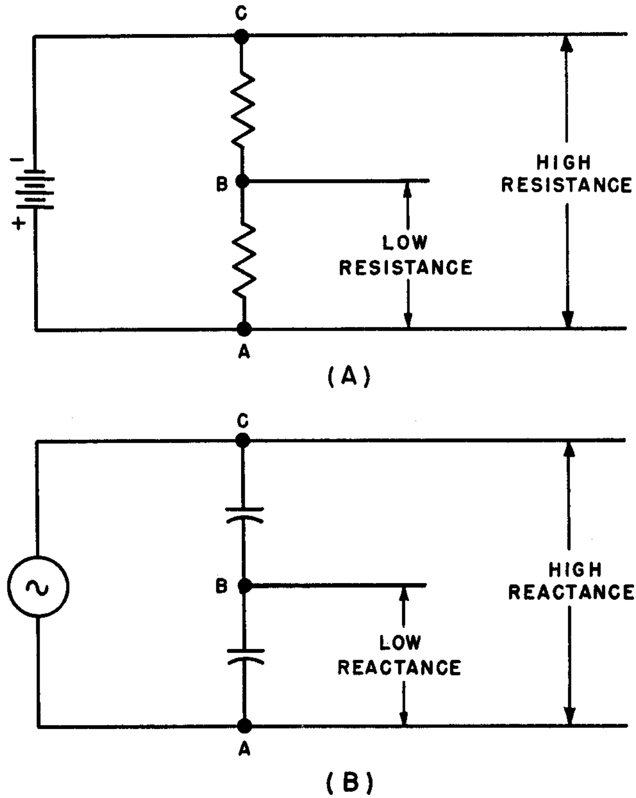


Fig. 417. *Resistors and capacitors can be used as voltage dividers.*

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

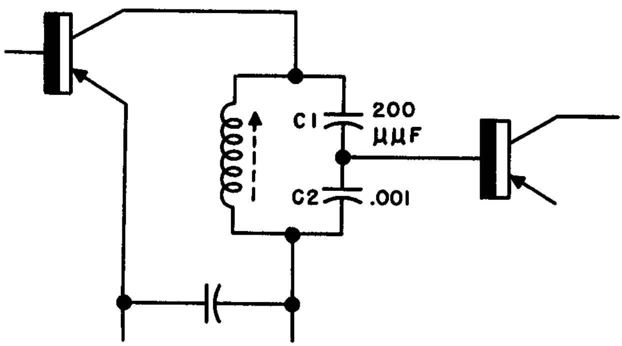


Fig. 418. *Method of coupling if stages through the use of series capacitors.*

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

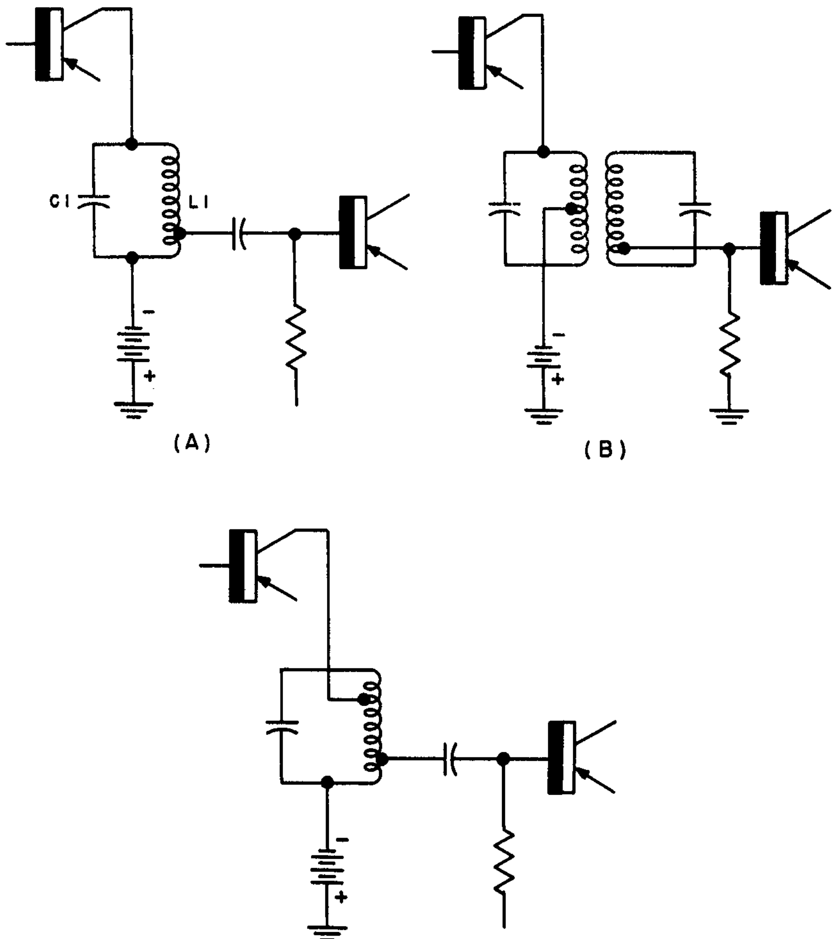


Fig. 419. *Other methods used in coupling if stages.*

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.

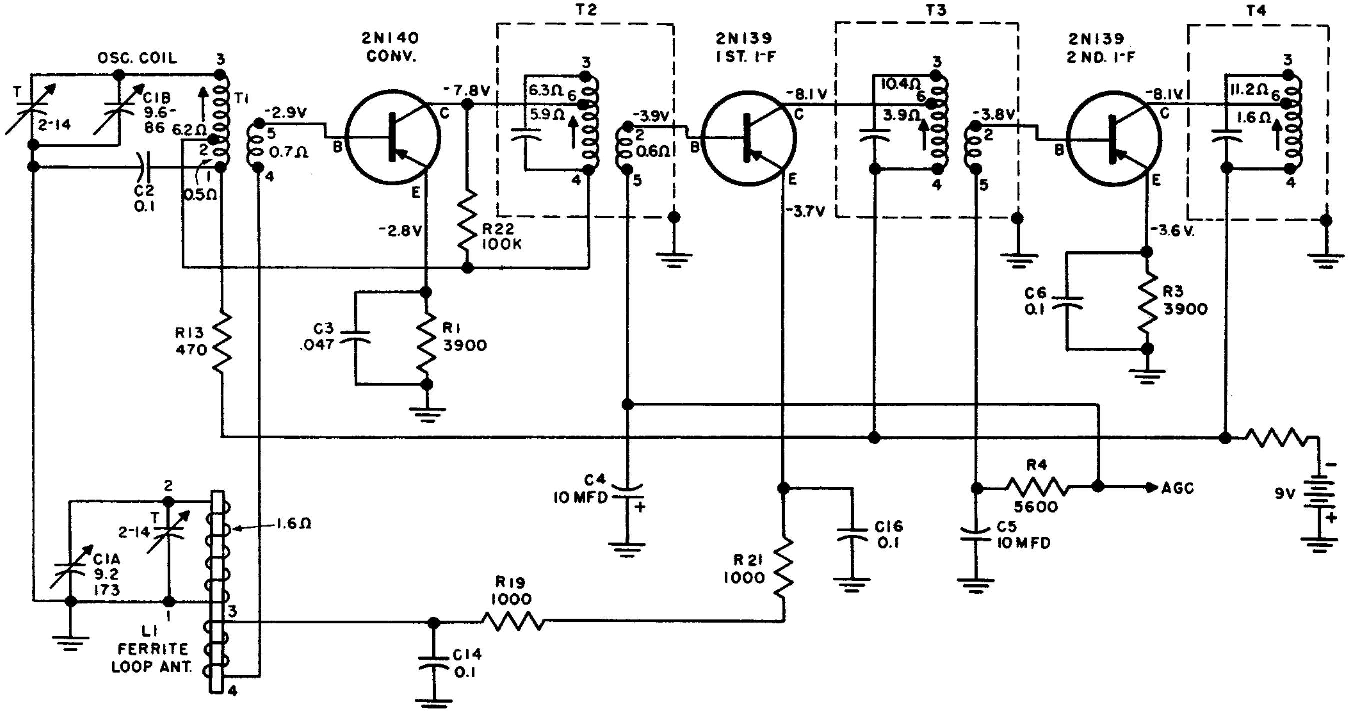


Fig. 420. *A complete if amplifier circuit.*

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

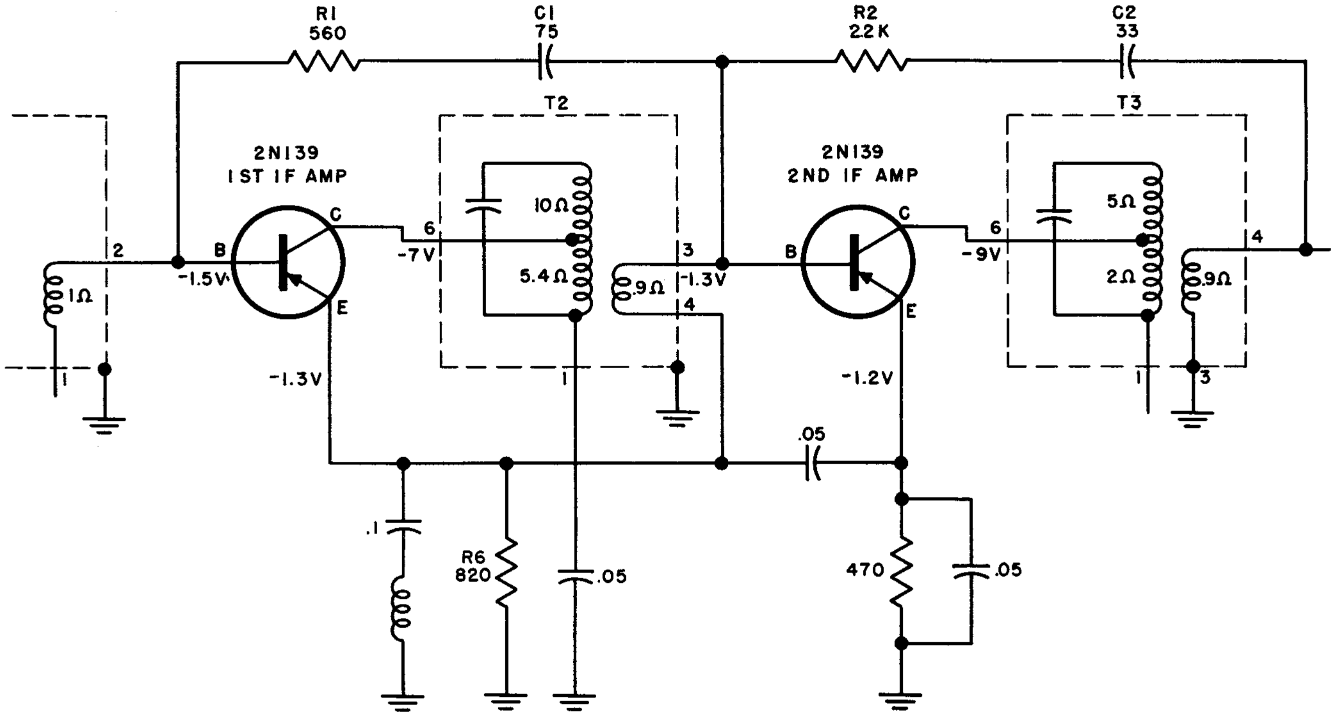


Fig. 421. *Neutralization of transistor if stages.*

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

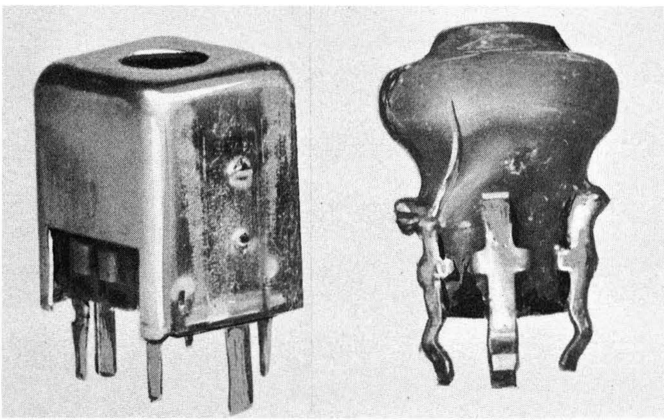
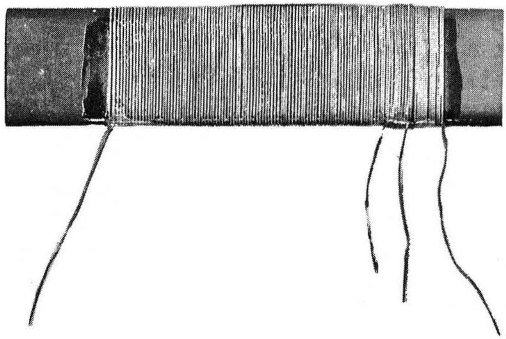


Fig. 422. *Oscillator coil (left) and if transformer are attached to the printed-circuit boards by terminal lugs that are designed for easy insertion.* (Thordarson-Meissner.)

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

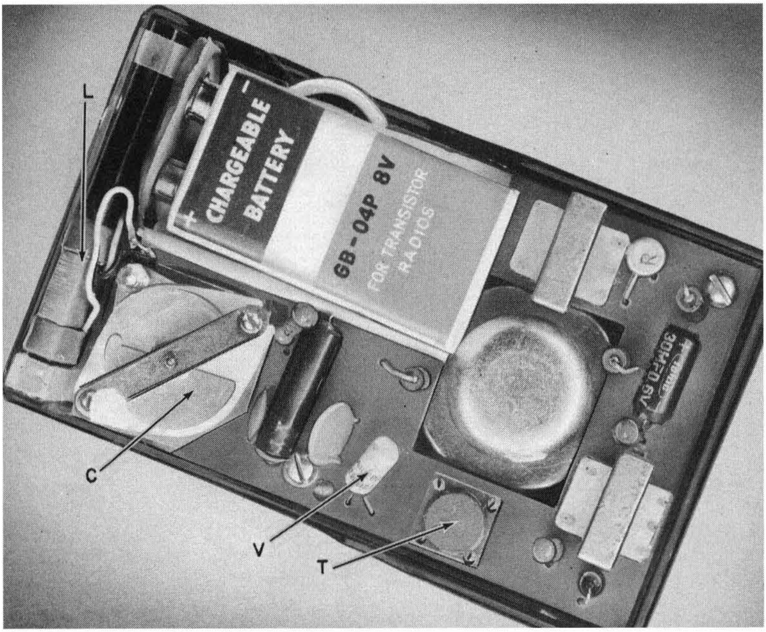


Fig. 424. *The printed-circuit board of a two transistor reflex receiver is not very crowded.*

(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

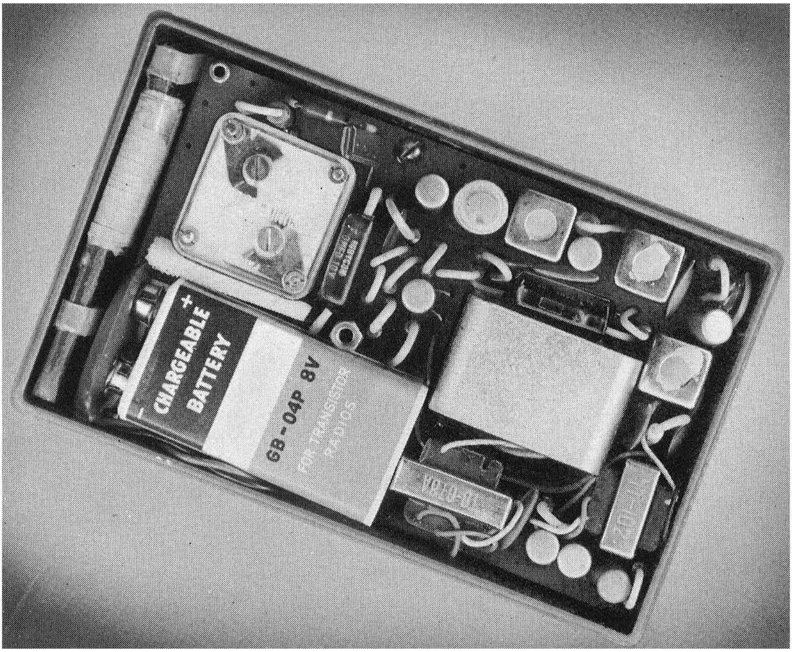


Fig. 425. *Circuitry for six transistors fits compactly in the same space used by the receiver in Fig. 424.*

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 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

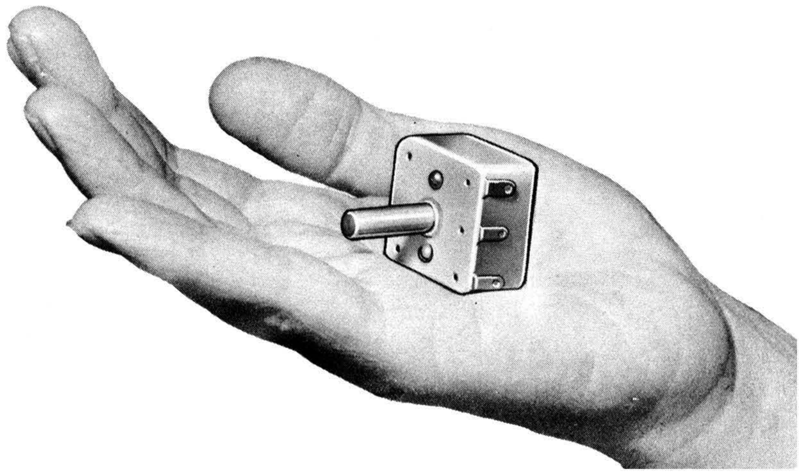


Fig. 426. *Tuning capacitor is completely boxed in plastic.* (Argonne Electronics Mfg. Corp.)

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.

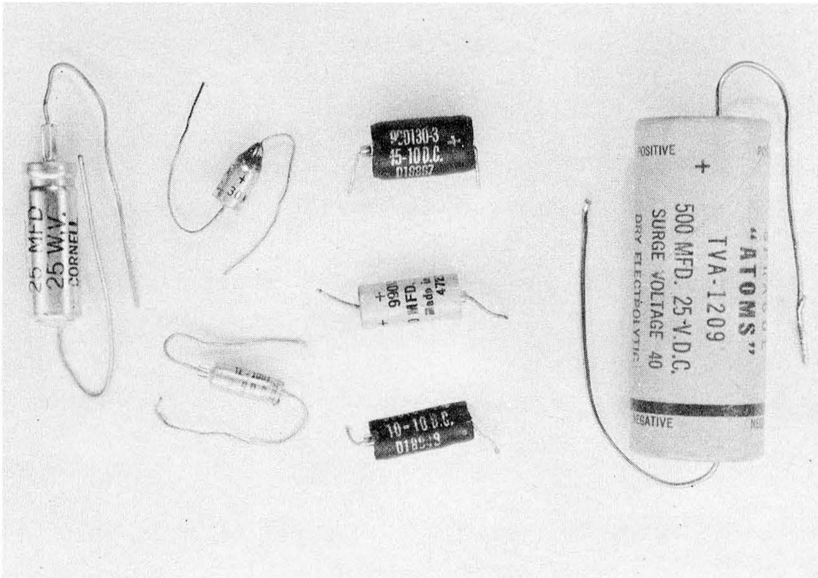


Fig. 427. *These electrolytic capacitors are approximately one-half actual size.*

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.

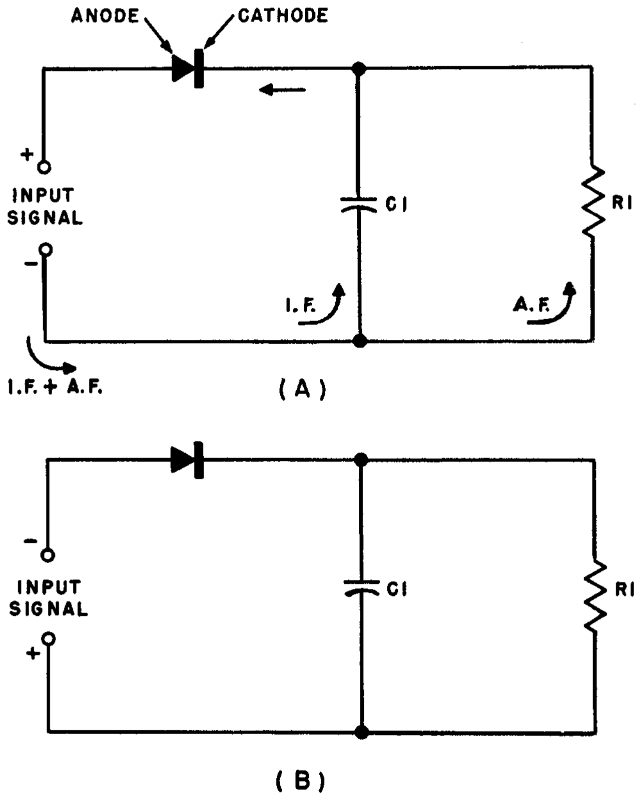


Fig. 501. *When the input signal is of the proper polarity, current will flow through the diode, as indicated in A. When the input signal is reversed, practically no current will flow B.*

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

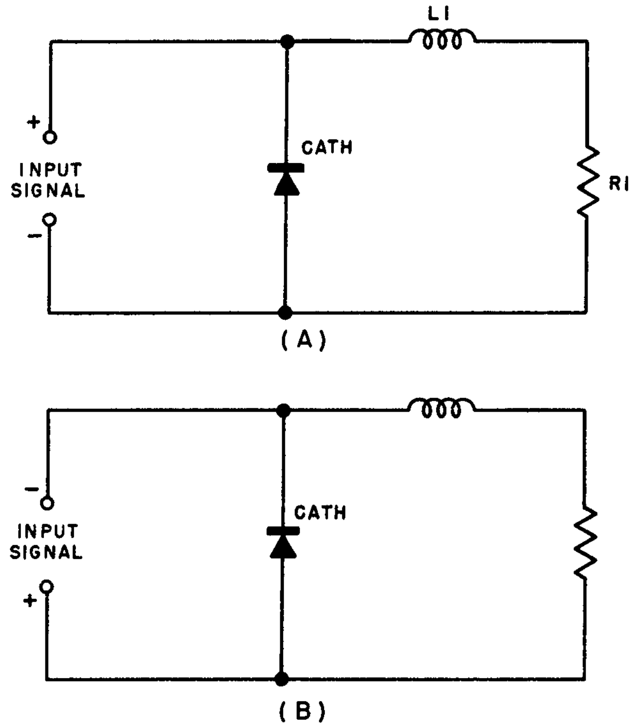


Fig. 502. *Alternate arrangement of the diode in a crystal detector circuit.*

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-

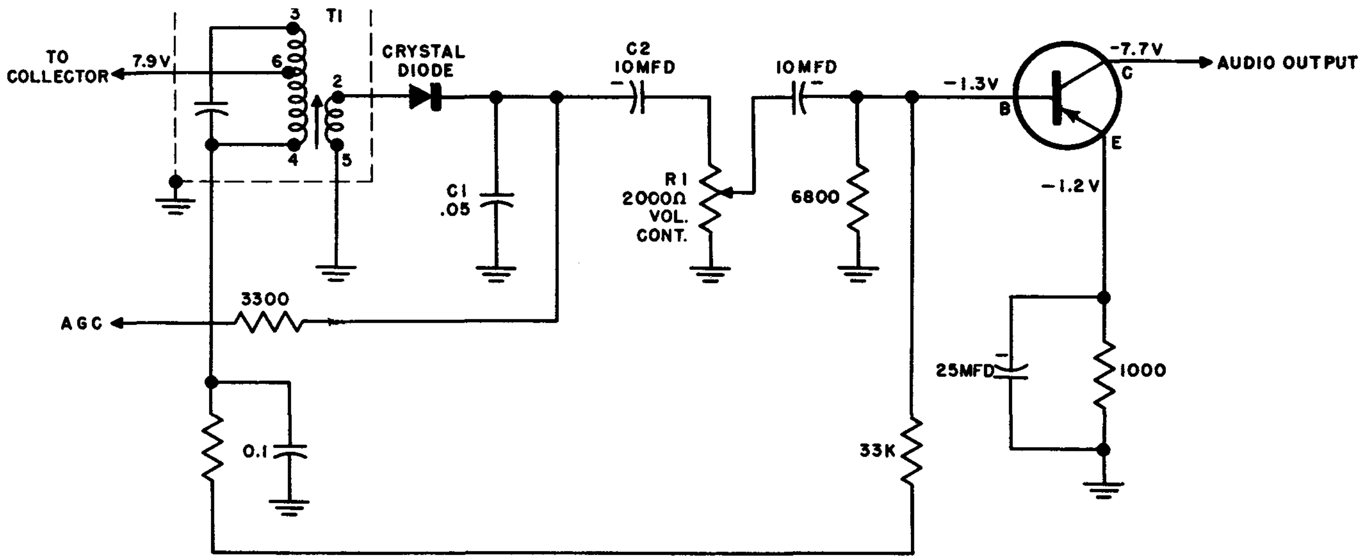


Fig. 503. *Typical crystal detector circuit. The agc bus is taken from the output of the detector.*

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

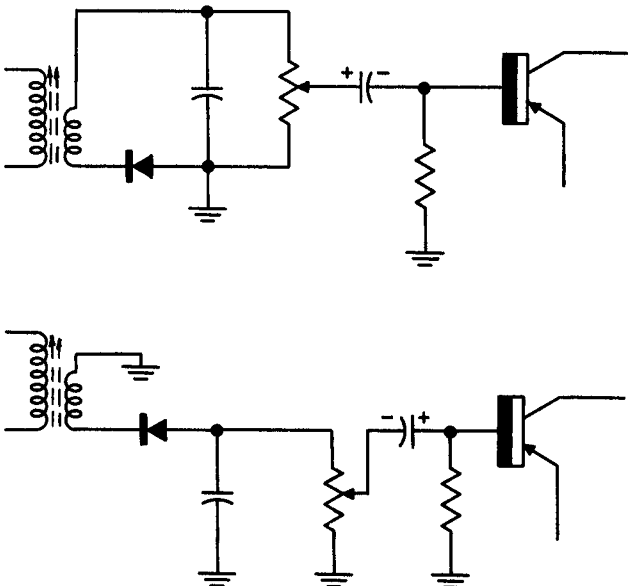


Fig. 504. *Circuit arrangements using crystal diodes.*

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

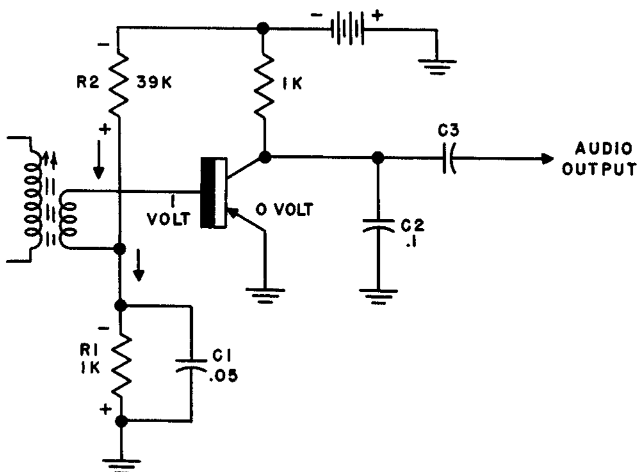


Fig. 505. *Schematic showing a transistor used as a detector. The transistor has an advantage over the crystal diode in that it supplies gain.*

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.

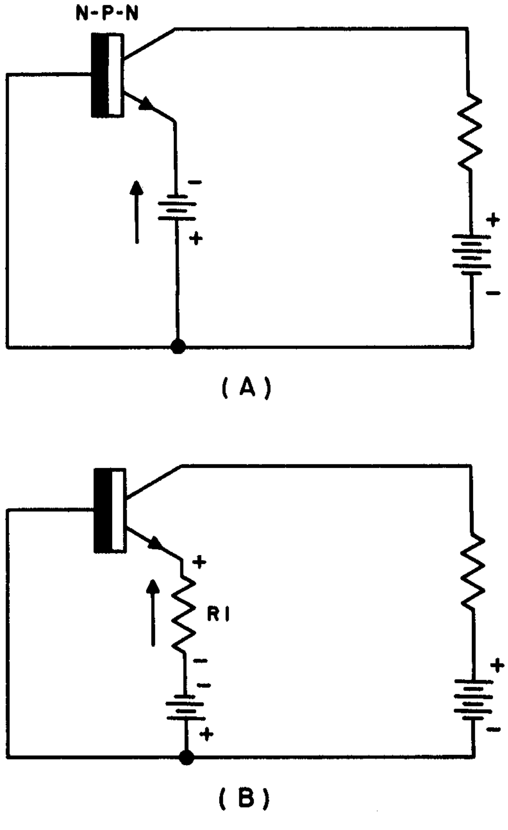


Fig. 506. *Fundamental operation of an agc circuit.*

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.

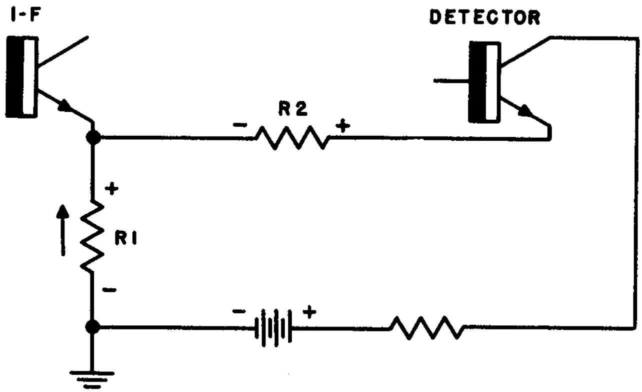


Fig. 507. *Basic arrangement of an agc circuit.*

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

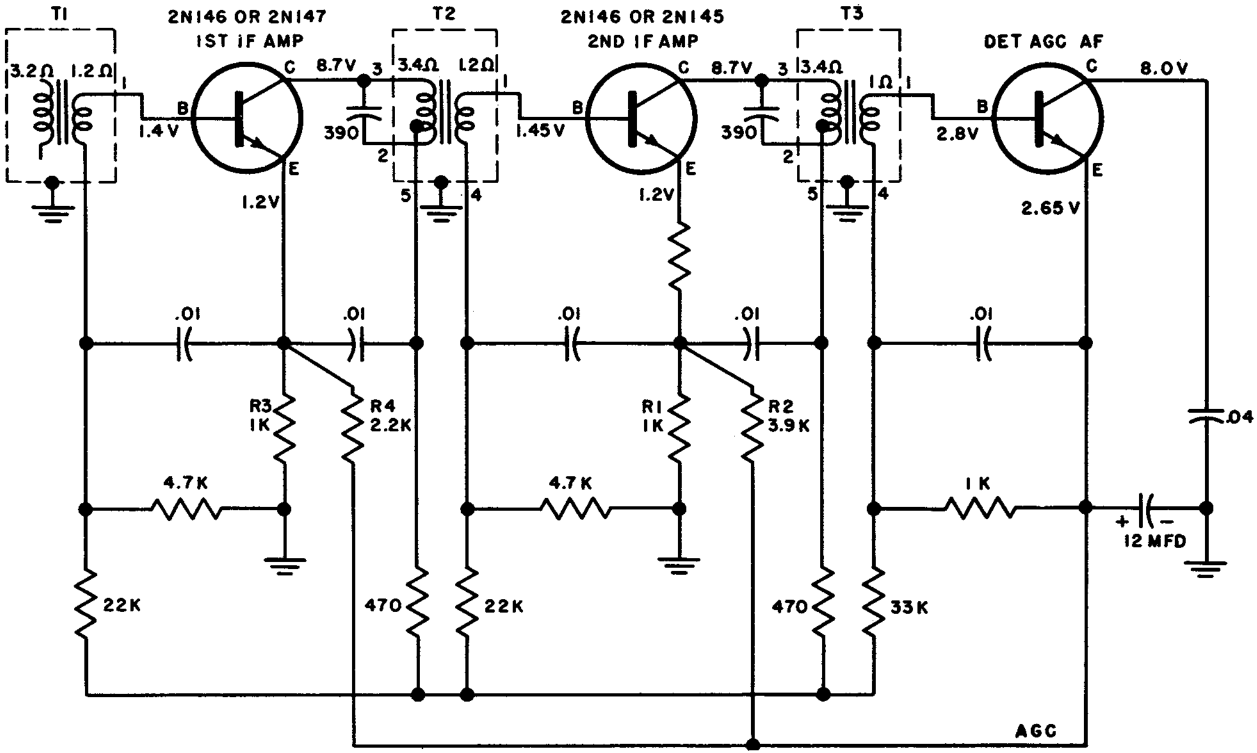


Fig. 508. *Automatic-gain-control circuit. The transistor at the output of the if stage acts to supply agc and audio voltages in addition to working as a detector. While in this circuit the agc controls the if stages, in some sets (especially automobile receivers) the agc is fed back to the rf amplifier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

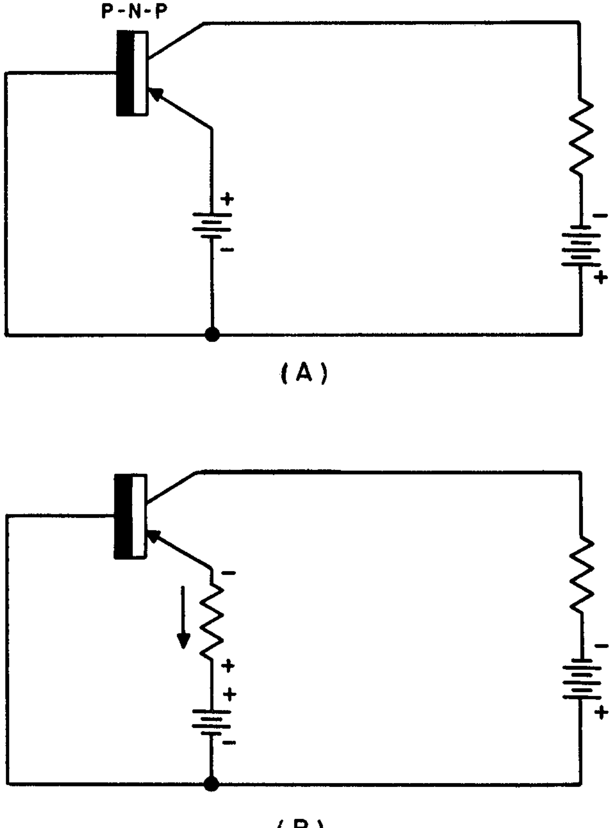


Fig. 509. *The gain of the transistor is reduced by putting a resistor in series with the emitter.*

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

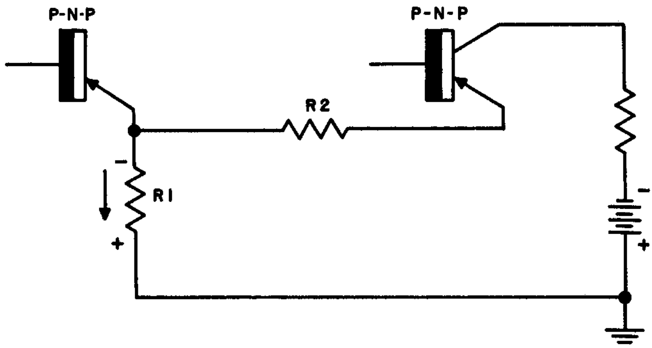


Fig. 510. *Agc bias network for p-n-p transistors. Note that the voltage across bias resistor R1 is in opposition to the emitter bias voltage. Current flowing from the emitter through R1 reduces the forward bias, thereby lowering the gain of the transistor stage.*

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.

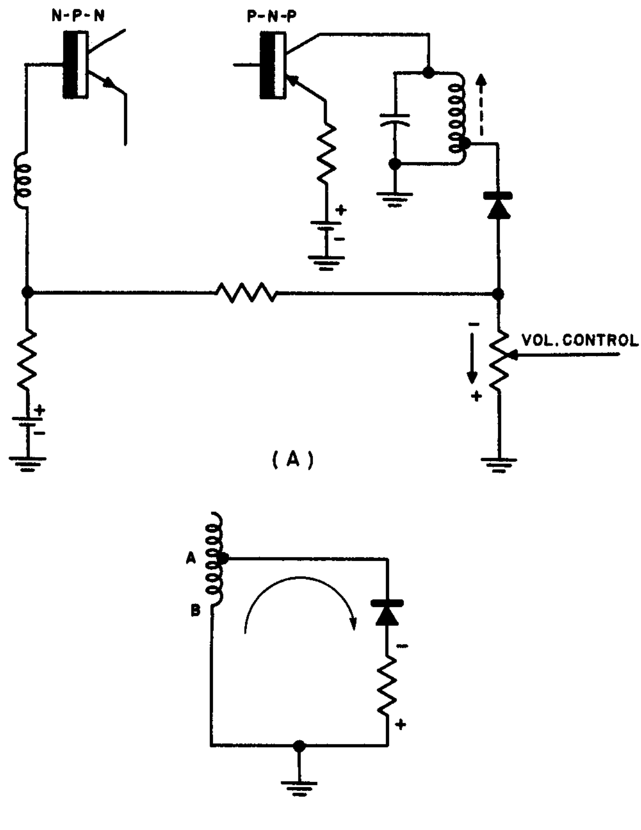


Fig. 511. *Agc bias circuit for receivers using both n-p-n and p-n-p transistors. The agc voltage is used only by the n-p-n transistor.*

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.

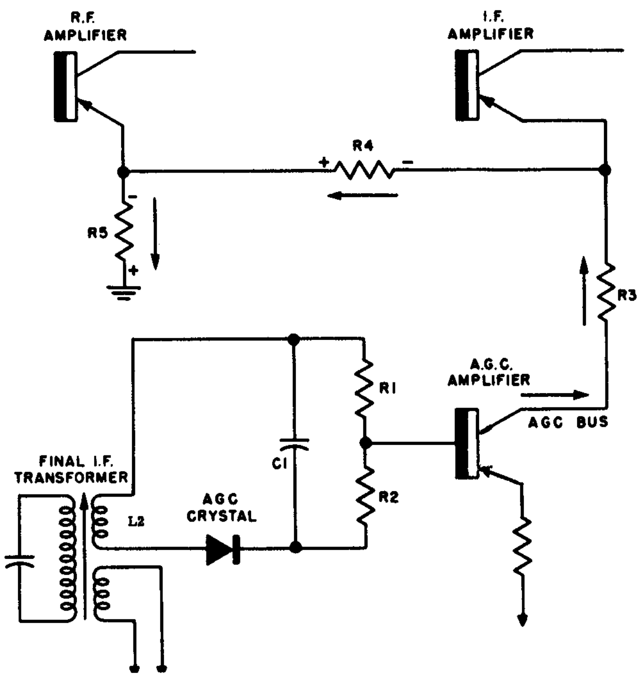


Fig. 512. *Some transistor receivers use a crystal diode as an agc detector and a transistor as an agc amplifier.*

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

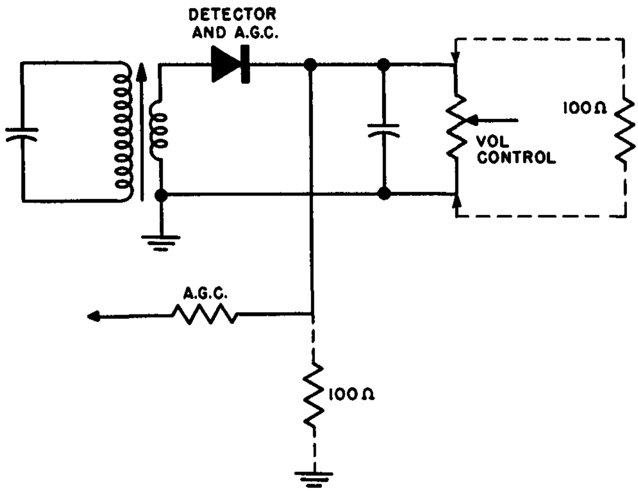


Fig. 513. *To disable the agc, connect a 100-ohm resistor from the agc bus to ground.*

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.

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

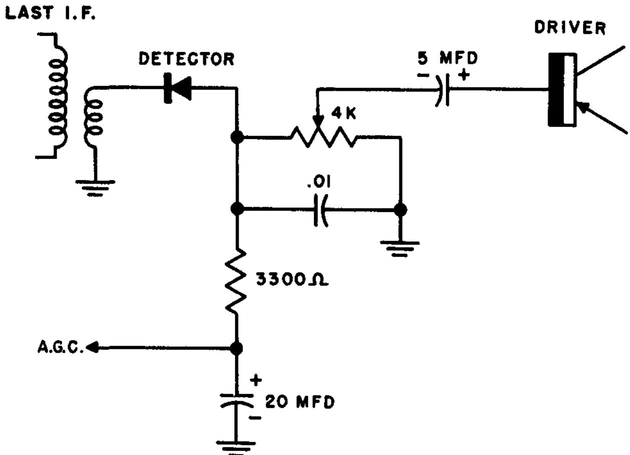


Fig. 601. *Volume control circuit. Note the large-value coupling capacitor between the volume control and the base input circuit of the driver stage.*

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

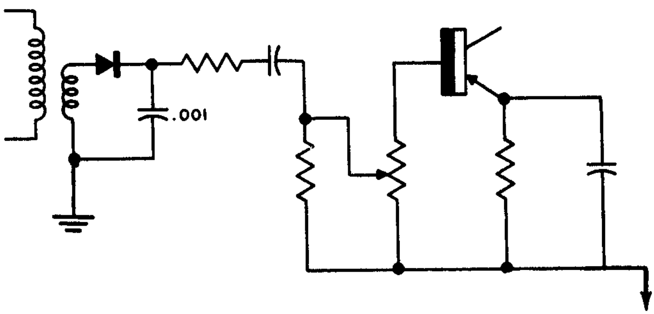


Fig. 602. *In this circuit the volume control is part of the input circuit of the first audio amplifier.*

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

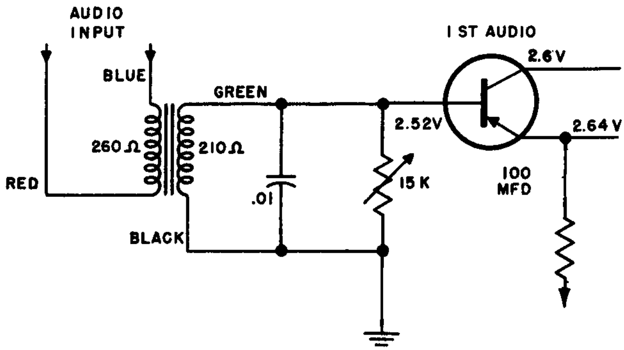


Fig. 603. *In this circuit the volume control is placed across the secondary of the audio driver transformer.*

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

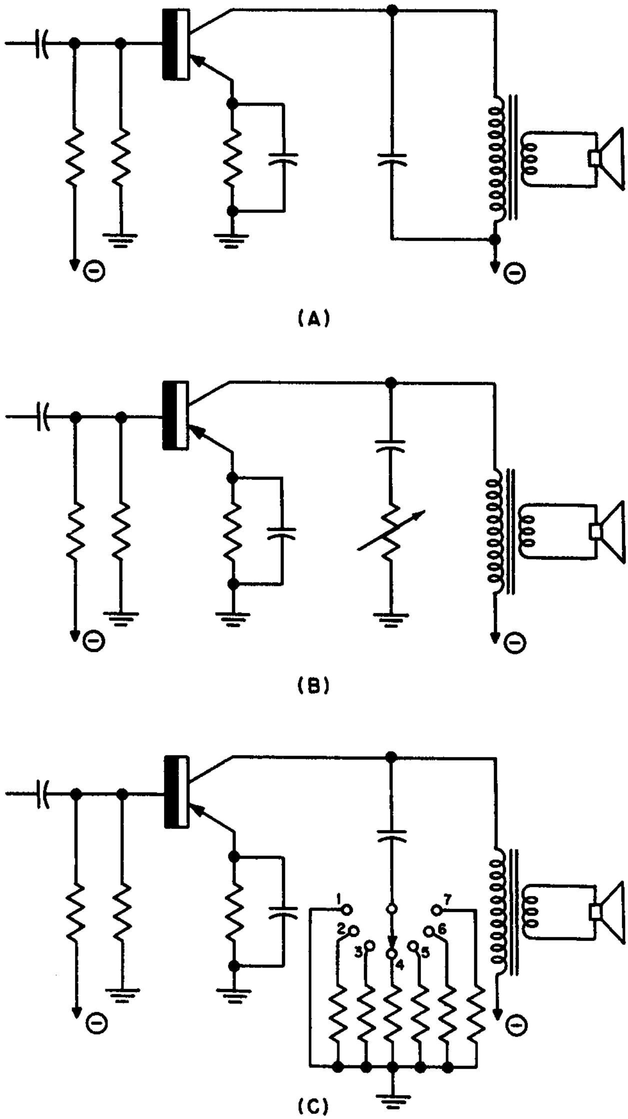


Fig. 604. *Typical control circuits. The resistor can be a potentiometer or a number of resistors which can be switched in and out of the circuit. The tone control can be part of the driver stage or can be located in the audio output.*

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-

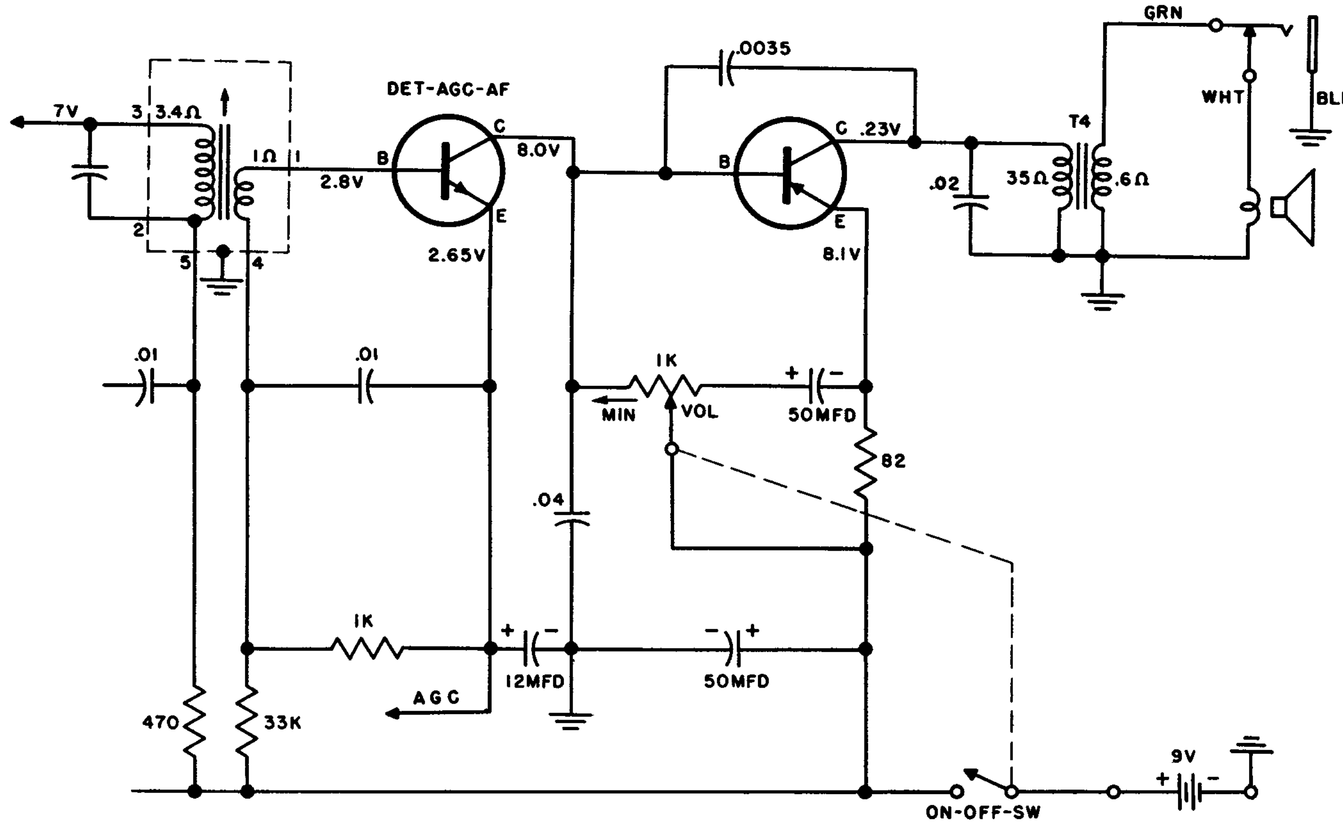


Fig. 605. *Simple audio amplifier using two transistors. The detector transistor also supplies some audio gain.*

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 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.

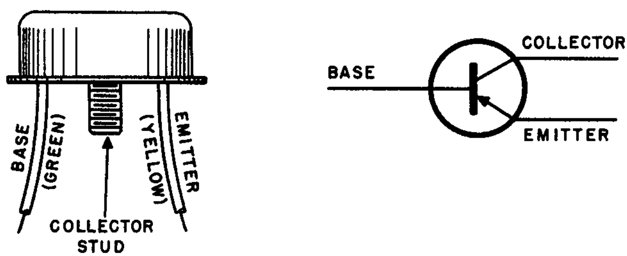


Fig. 606. *Power transistors come in various shapes. The electronic symbol for all three-element transistors is the same.*

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

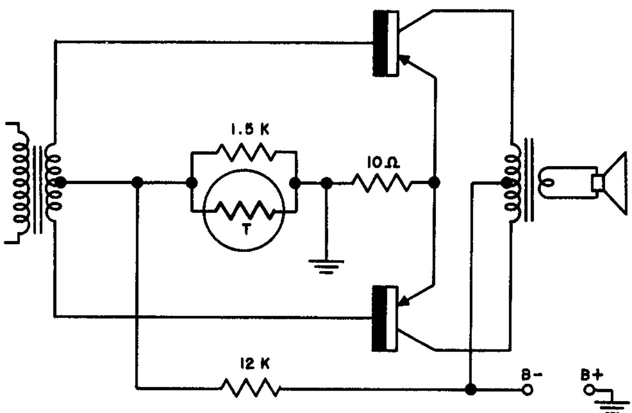


Fig. 607. *The thermistor is placed in shunt with the common-base resistor of the two transistors.*

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

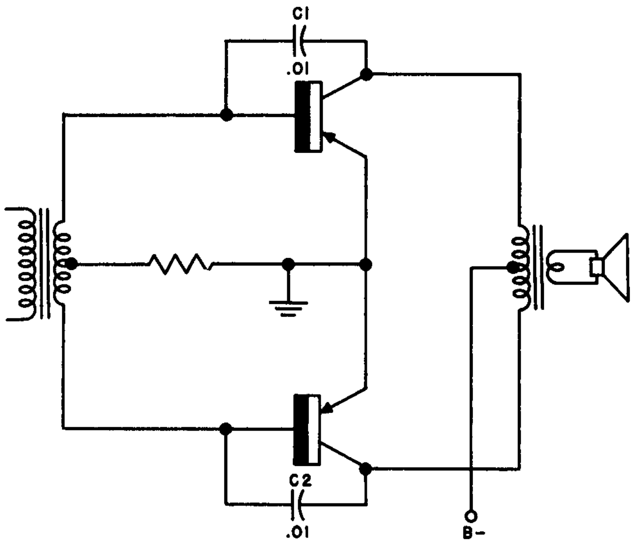


Fig. 608. *Feedback capacitors are used to improve the stability of the output stage.*

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.

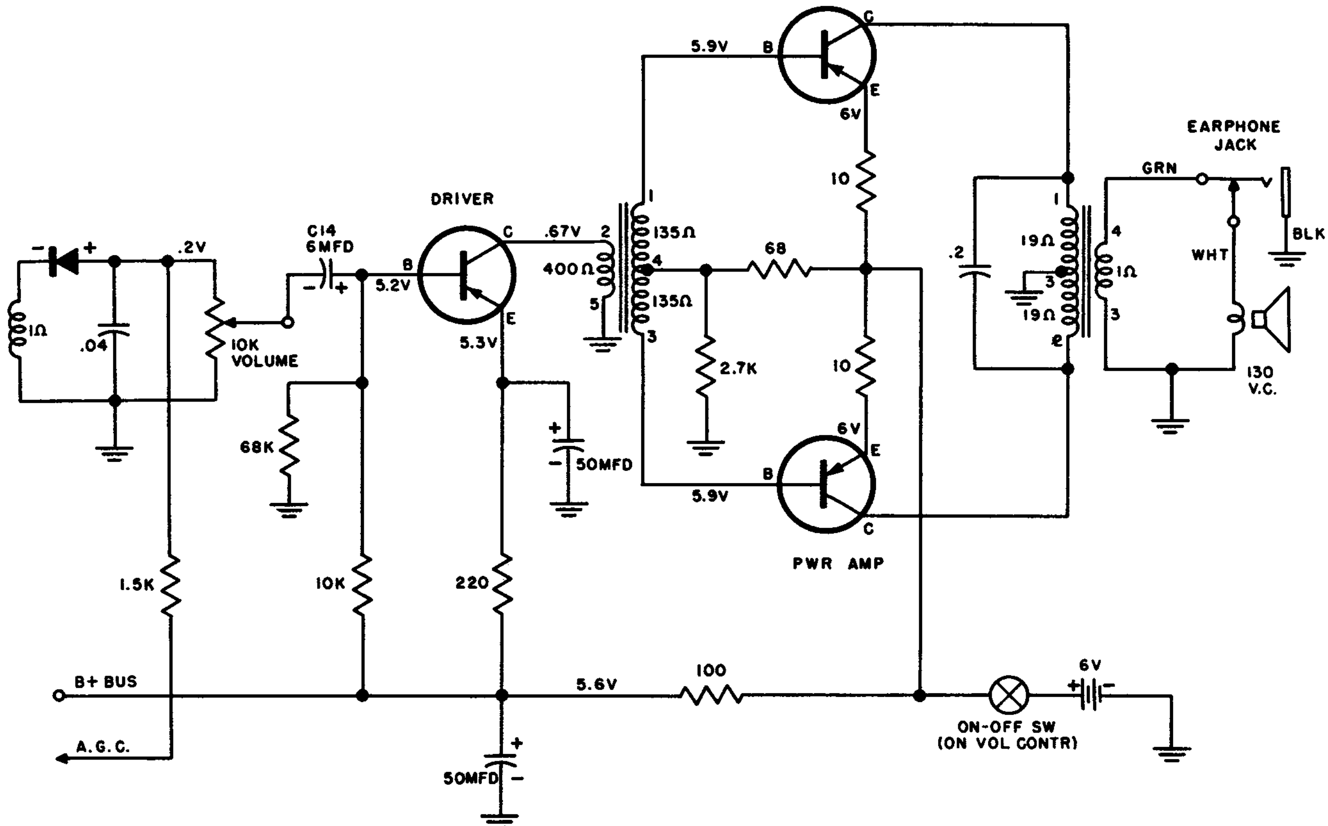


Fig. 609. *Transistor audio amplifier using push-pull output.*

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,

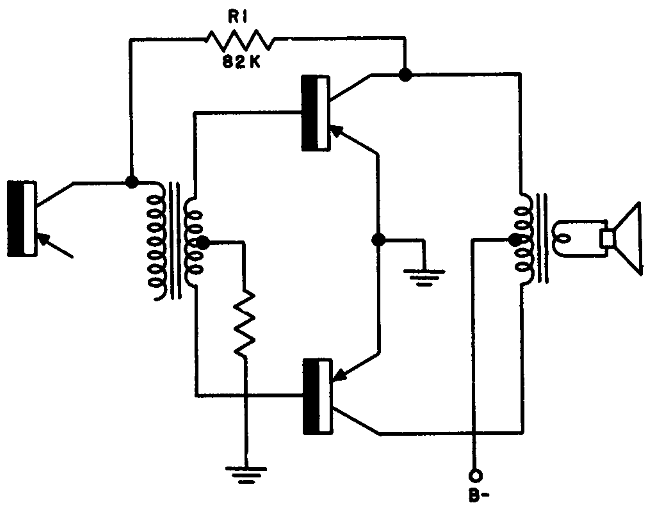


Fig. 610. *Resistor R1 in this circuit supplies negative feedback.*

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

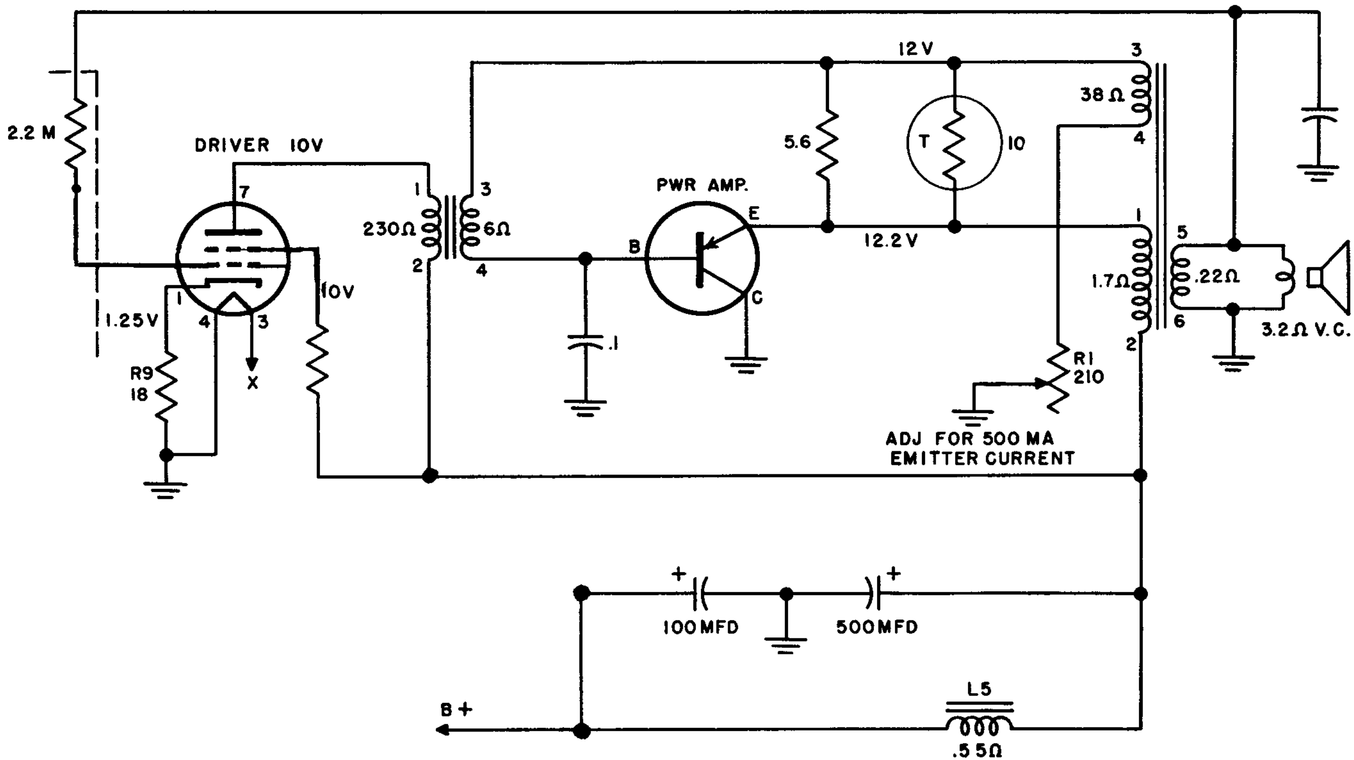


Fig. 611. *Hybrid circuit using a vacuum-tube driver and power transistor for the output.*

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

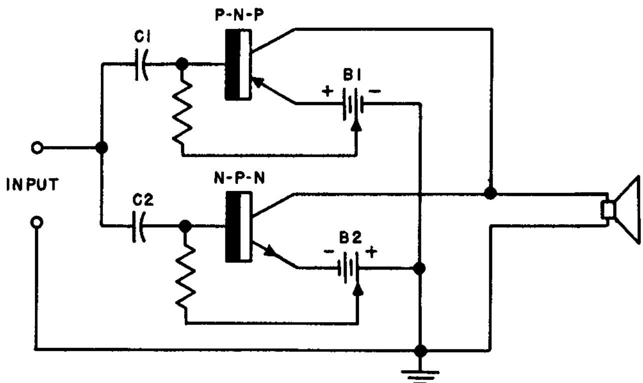


Fig. 612. *Push-pull circuit does not use input or output transformers.*

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

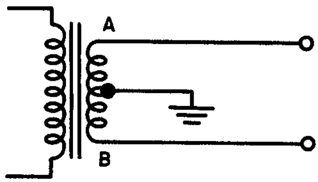


Fig. 613. *An easy way to get out-of-phase voltages is to use a tapped transformer.*

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

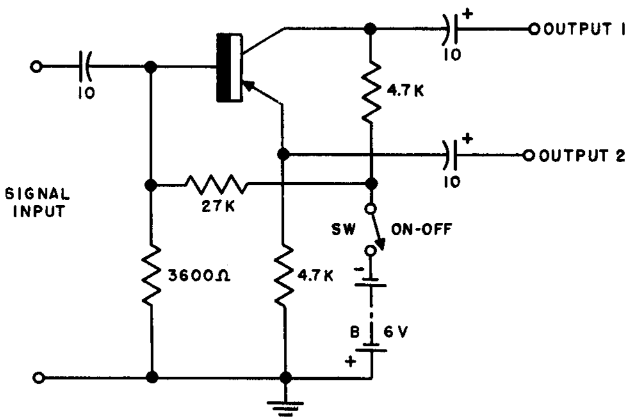


Fig. 614. *A single transistor can be used to supply two outputs.*

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

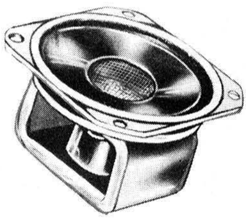


Fig. 615. *PM speakers have magnets of many shapes. Many styles are quite shallow.* (Argonne Electronic Mfg. Corp.)

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.

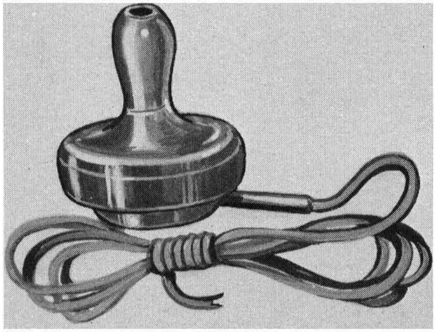


Fig. 616. *The earphone plugs into the ear cavity. It excludes almost all outside noise.* (Argonne Electronic Mfg. Corp.)

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

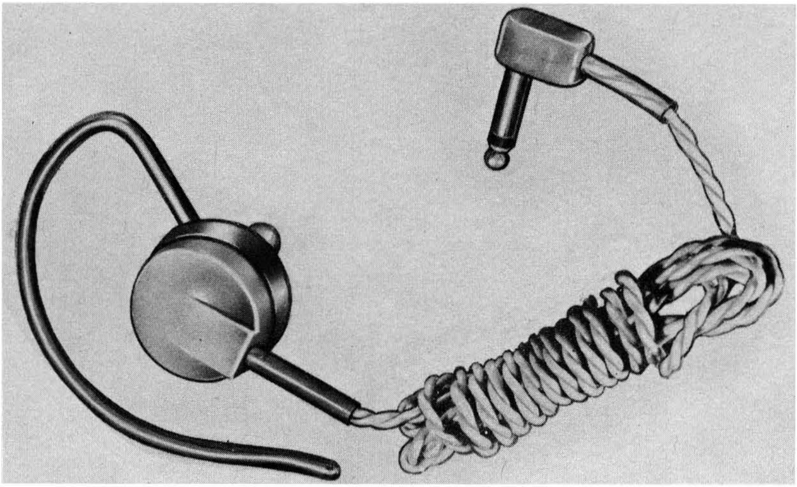


Fig. 617. *Band attached to this earphone hooks over the ear like a pair of spectacles.* (Argonne Electronic Mfg. Corp.)

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.

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HOW TO FIX TRANSISTOR RADIOS & PRINTED CIRCUITS

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To Arlene, Stewart

and Clifford

Volume 2

contents

introduction

IN the second book of this two-volume set, the emphasis is on the practical applications of the semiconductor fundamentals presented in Volume 1.

General servicing methods are stressed. For example, the special techniques required to test batteries and how to determine the circuit defects that cause seemingly short battery life are described. We will show why, although percentage-wise the tolerances of semiconductor circuits are equal to vacuum-tube parameters, small voltage changes are just as troublesome in these low-impedance circuits as the more apparent changes caused by defective vacuum-tube components.

Special consideration is given the unique problems of hybrid and all-transistor auto radios. Here some types of interference are treated as part of *radio* servicing although it is actually a characteristic fault of the internal combustion engine used to propel the radio and its listener through the most difficult conditions possible for reception of radio waves.

Circuit alignment and measurements are spotlighted. Ways of using the commonly available test equipment for in-circuit component and transistor evaluation is covered and common vacuum-tube servicing techniques adapted to the low-impedance and low-voltage characteristics of transistor circuitry.

Printed-circuit boards are evaluated, and their advantages and disadvantages analyzed from a servicing viewpoint. Some simple practical repairs are described.

This volume also covers the many types of transistors created by different manufacturing processes. Some basic circuits are used to illustrate the applications for which these specialized semiconductors were designed.

The engine of the horseless carriage of yesteryear bears as little resemblance to the power-plant of modern-day earthmovers as the transistor of today and the marvels it makes possible will resemble the as yet undreamed-of possibilities of future semiconductor devices.

Just as Fleming's valve generated a multi-billion dollar industry, semiconductor operated devices are sparking a new spiral of development whose future wonders we can only guess at. But one thing is certain: ever-increasing numbers of knowledgeable technicians will be needed. And don't forget that all big circuits are made up of little circuits, that the sophisticated circuitry of complex machinery utilizes the same basic theories that we are studying.

May these volumes be a stepping stone to a better and more prosperous future for everyone!

LEONARD LANE

chapter

7

servicing methods—part I

THE problems of servicing transistor radio receivers can be solved using the same test equipment you now have available. No two service technicians are ever in complete agreement as to the amount of test equipment that should be on the bench, but you should at least have an rf signal generator capable of covering the complete AM broadcast band. This generator should also have a spot frequency, generally at 455 kc, for alignment of the if stages. (Many auto radios have an if of 262.5 kc, so we cannot assume that the same if is used by all manufacturers.)

You should also have an audio generator so you can trace through stages starting with the detector diode load and proceeding to the speaker. As an alternative, you can use the audio output terminal of your rf signal generator. Unfortunately, many of the less expensive signal generators have no means for controlling the strength of the audio signal. If such is the case, you can attenuate the audio by bringing it into a potentiometer and then taking the audio output from the pot itself, as shown in Fig. 701.

You should have a multimeter, but a vtvm is certainly preferable. Since transistor receivers are characterized by very low voltages, a low-voltage scale on the vtvm is extremely important. Of course, the vtvm can also be used for measurement of resistance.

In an earlier chapter we mentioned the need for special tools for use in servicing miniaturized components so widely used in transistor receivers. Equally important is a bench lamp which can be moved into any desired position and which will permit you to focus a strong light on any part of the receiver chassis. A desirable feature on some of these lamps is a magnifying glass which is hinged to the lamp and which forms a part of it. This is ideal for examining tiny connections in close quarters.

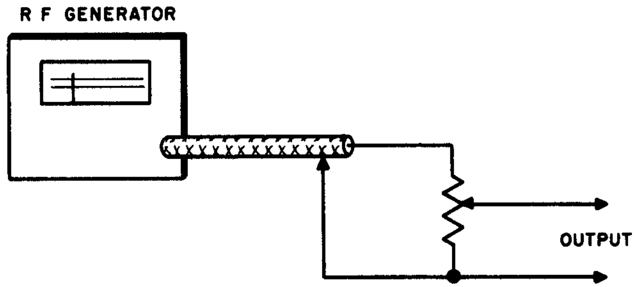

Fig. 701. *Some signal generators have an audio output connection but no provision is made for controlling the audio level. You can make a simple control unit with a 500,000-ohm potentiometer as shown.*

Some manufacturers claim that their transistor radios are built like a fine watch – and if we consider size as the determining factor, they are certainly right. Don't insist on using man-size tools for these midgets.

Dc voltage measurements

When making voltage measurements in a transistor receiver, keep in mind that working with low voltages may require a revision of your thinking. As an example, consider a vacuum-tube receiver in which the plate voltage is supposed to be 250. If for any reason, you get a 10% decrease in plate voltage, you will measure 225 volts. 10% of 250 is 25, and subtracting this from 250, gives us 225 (Fig. 702).

Now let us assume a transistor receiver in which you are supposed to measure a potential of 6 volts and let us further assume that there has been a 10% decrease. But 10% of 6 is only 0.6. Subtracting this amount from our original 6 volts, leaves us with 5.4. Note that the percentage difference in both cases is identical and yet for the vacuum-tube receiver it would be very easy to recognize a 25-volt difference. However, a difference of 0.6 volt on a vtvm scale might not be so easy to detect (Fig. 703).

When working with low voltages, it is always preferable to adjust the range switch on the vtvm so that the meter needle will have to swing full scale or almost full scale. This will make any slight deviation much more recognizable. If you have any doubt about the accuracy of your vtvm on the low-voltage scale, you can easily check it by using one or more fresh penlight batteries as a calibrating voltage, as shown in Fig. 704. Four such batteries, when fresh, should give you 6 volts. With mercury type cells, four of these in series will give you a total voltage of 5.36.

Before we go into a detailed analysis of transistor receiver troubles, let us consider the symptoms that you will find in a majority of cases. The complaints, all caused by a common trouble, will consist of the following: (1) Dead receiver; (2) weak receiver; (3) receiver able to pick up strong stations only; (4) distortion; (5) receiver plays on earphones but sound is too weak for loudspeaker reception. All of these difficulties could be caused by a weak battery (in series with good batteries) or by several batteries whose terminal voltage has decreased. Just as in a vacuum-tube receiver, the first thing to suspect are the tubes so, in a transistor receiver, you should first make a check of the battery voltage (under load) before proceeding with any other servicing.

As a general rule, a transistor receiver will continue to operate even if the battery voltage takes a 30% drop. Suppose, for example, that the transistor receiver you are servicing uses three 1.5-volt cells. This gives us a total of 4.5 volts. Using our figure

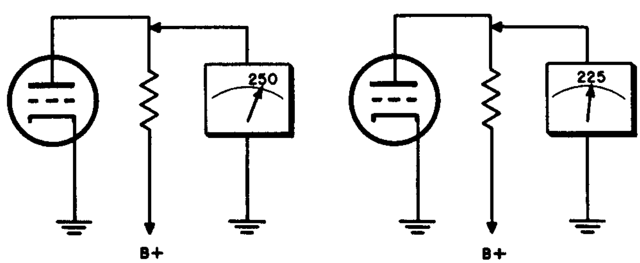

Fig. 702. *If the voltage at the plate of a tube is supposed to be 250, but your meter measures only 225 volts, you have a 10% difference between the actual voltage and the voltage as specified. For most tube circuits, this small difference is of no importance.*

of 30%, this means that the battery voltage had dropped to about 3.15 before any of the symptoms which we have mentioned became noticeable or annoying. Similarly if the transistor receiver uses a 9-volt supply, you will find as a general rule that the voltage can drop to about 6 volts before one or more of the symptoms we have mentioned begin to appear. However, if the symptoms show themselves and the battery voltage has dropped, say, only 5% to 10% of fresh battery voltage, then the trouble is not in the battery supply but elsewhere in the receiver.

In making a battery voltage check in the receiver, remember

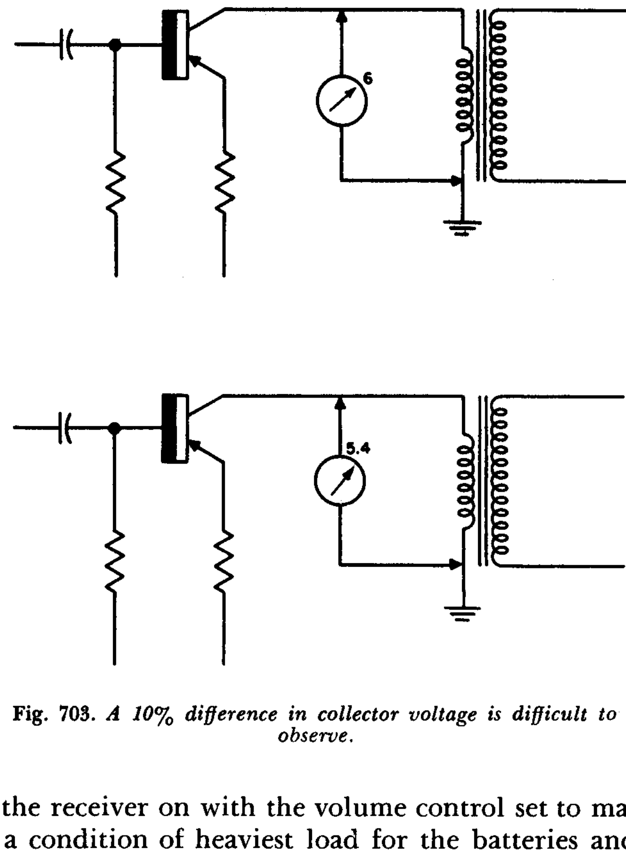

Fig. 703. *A 10% difference in collector voltage is difficult to observe.*

to turn the receiver on with the volume control set to maximum. This is a condition of heaviest load for the batteries and, if the batteries are weak or defective, the voltage will drop. If you do not wish to make a voltage check, you can always make this test by battery substitution. The voltage check is faster, however, and does not require you to have replacement batteries on hand (Fig. 705).

In practically all vacuum-tube radio and television receivers, the chassis is common ground or B-minus. Because of this it has been quite easy for service technicians to get into the habit of considering the chassis as the B-minus reference point. In a transistor receiver, however, the chassis can be B-minus or B-plus (Fig. 706). Offhand, you might think that you should be able to determine the polarity by considering whether a receiver uses p-n-p or n-p-n transistors, but this is of no help. You can determine the polarity by (1) just looking at the battery connections or (2) setting the voltmeter on a high scale (such as the 100-volt scale), connecting one lead to the chassis and momentarily touching the other lead to the battery connection. If the needle moves

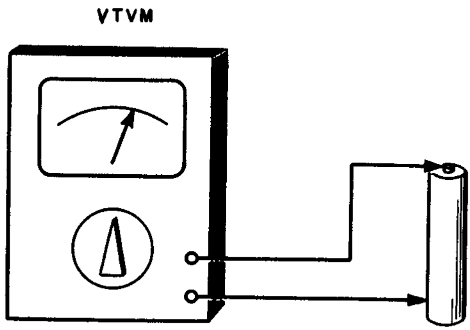

Fig. 704. *To check the low-voltage scales of your vtvm, set the range switch to read low volts dc and then use a fresh penlight cell (or other type of dry cell) as a calibrating voltage. Low-voltage measurements in transistor receivers are very important.*

backward, transpose the connections. Some instruments have a minus—plus switch so all you will have to do is to turn this control.

The two circuits shown in Fig. 706 are almost identical yet the battery connections are different for each. However, in both cases the emitter is made positive with respect to the base. In the circuit Fig. 706-A the collector is marked zero volts, but observe that the collector is grounded through the primary of the output transformer. The collector is negative with respect to the base and the emitter. In Fig. 706-B the collector also has its return through the center tap of the output transformer primary and from that point to the negative terminal of the battery. Although in one instance the minus terminal of the battery is grounded and in the other the plus terminal, in each circuit, the collector is connected to the negative end of the battery supply. Note that p-n-p transistors are used in both circuits.

Batteries consume themselves whether they are used or not, and the batteries in transistor receivers are no exception. Your customers who operate their transistor receivers sparingly, with the idea of battery economy in mind, are fooling themselves. You

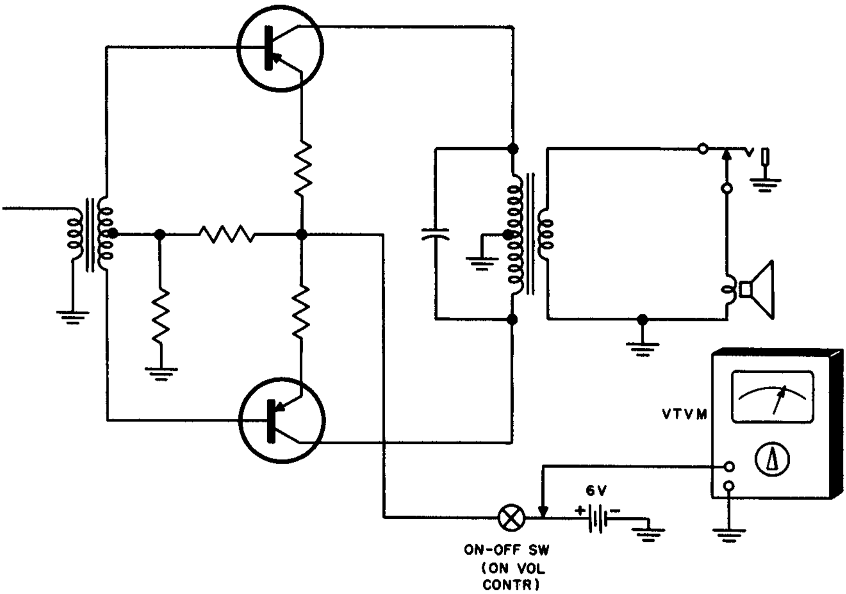

Fig. 705. *To check the condition of the battery, connect the vtvm as shown. The set must be turned on since the battery must be tested under actual load conditions. Tune in a station and then detune, noting if this has any effect on the battery.*

should educate them to the fact that it is false economy to try to conserve battery life by rationing receiver operation. At the same time, however, it is entirely possible for short battery life to be a legitimate complaint. If battery life is much less than can be reasonably expected, you can run a quick check by inserting a milliammeter in series with either the positive or negative lead of the battery supply in the receiver and measuring the total current drain as shown in Fig. 707. Check this figure against manufacturer's service notes. If the drain is excessive, a leaky condition in the receiver is indicated. If the current drain is normal, examine the battery holder and all wires coming to the batteries themselves.

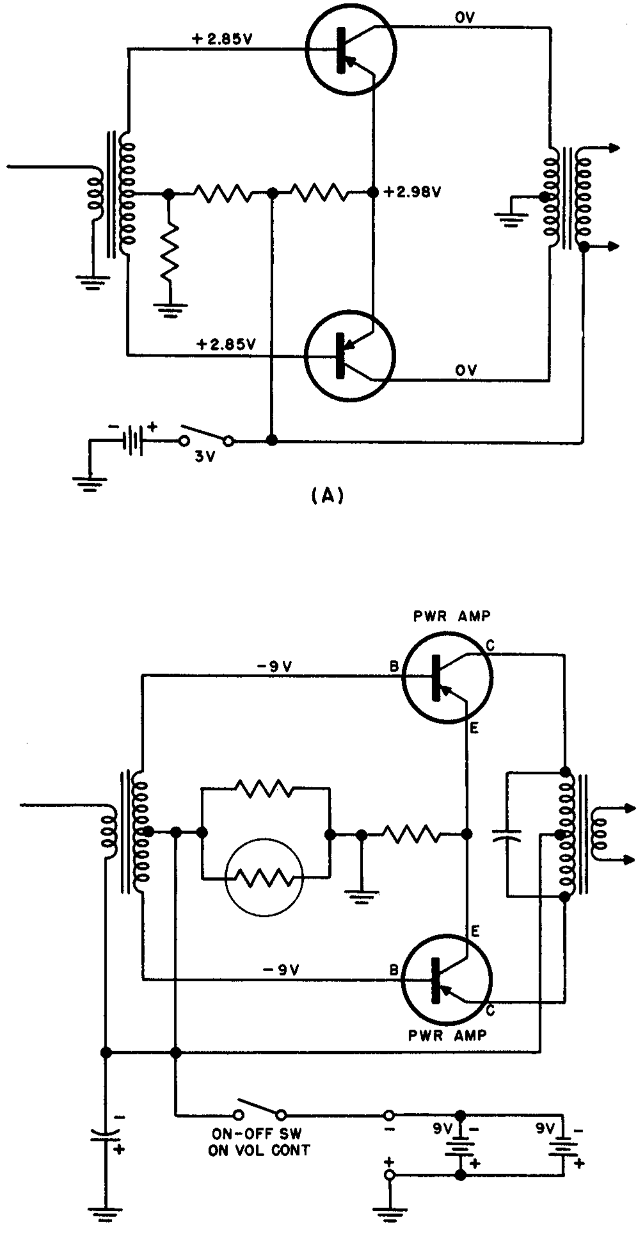

Fig. 706. *The chassis can be a plus or a minus point, depending entirely upon the circuit arrangement.*

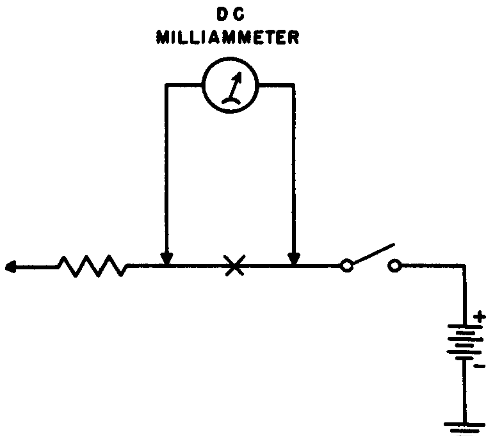

Fig. 707. To check receiver current drain, unsolder the wire connected to the switch on the volume control and insert a dc milliammeter as shown. The disconnect point is shown by the letter X in the diagram. After the meter is connected, close the switch. Sometimes you can avoid unsoldering leads by lifting the battery connector and inserting the meter between the battery connector and the battery. This method isn't always possible since some transistor radios use battery holders.

It is difficult to estimate amounts of current. In some receivers the current drain will be as little as 4 or 5 ma. In other sets it will be 15 ma or more. The current drain of auto radios is quite another story and is covered in a separate chapter.

Current consumption will vary with signal. That is, it will depend upon whether or not you have a station tuned in. Manufacturers usually specify current ratings with no signal.

It is in this instance also that your volt-ohm-milliammeter (vom) will come in handy. Most multitesters have some provision for measuring current and if you have such an instrument you can put it to good use. Vacuum-tube voltmeters aren't designed for measuring current. If you do not have a vom, a 0-1-ma dc milliammeter provided with suitable shunts will do the job.

Short battery life

Where the customer complaint is short battery life, open the lead to the switch on the volume control and insert a milliammeter. You should then proceed to take three current readings. The first of these is with the set turned off, then with the volume control turned on (but at its minimum setting) and finally with the volume control at maximum and with the receiver tuned in to a strong station. The meter needle of your milliammeter should read zero with the receiver switch in the off position.

If you get an appreciable current reading, check the switch or look for some short-circuit condition. If you get an unusually high current reading with the volume control turned down, look

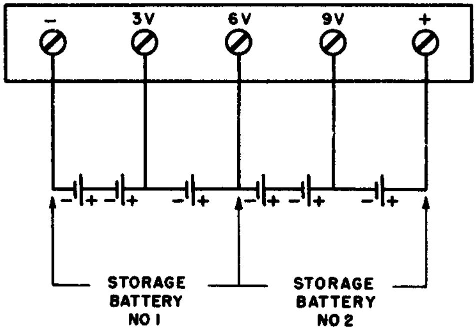

Fig. 708. *A pair of 6-volt storage batteries or a single 12-volt battery will supply all the voltage and current needed for testing transistor receivers.*

for leaky electrolytic capacitors. And, finally, if current drain is excessive with the volume control turned up, then the bias of one or more transistors, especially in the output stages, is not correct.

While we are on the subject of voltage and current measurements, keep in mind that the low-voltage supply of a transistor receiver has its advantages but also its disadvantages. In servicing a vacuum-tube receiver, a defect can sometimes be spotted very readily because the component will shown burn marks or will be hot to the touch. This rarely happens in transistor receivers, since the voltages involved are so small. At the same time, you can work with the voltages in a transistor receiver with a little more assurance since the voltages are not high enough to give you a shock. However, you will find that in circuits using heavy currents (such as in power output transistors in auto radios), you will have to exercise a certain amount of care.

Working with low voltages has other disadvantages. You will recall from earlier chapters that the proper operation of a transistor depends upon its biasing voltage. While bias voltages may be small, they must be correct. It doesn't take much of a change in bias voltage to ruin a transistor. For this reason, poking around with a screwdriver or careless use of test leads, where wires can be shorted, can easily result in a burned-out transistor.

Expected battery life

It is very difficult to give accurate figures on how long batteries should last. As a general rule, penlight cells used in a receiver might work up to 100 hours. The more expensive mercury batteries can reasonably be expected to have a battery life in excess of 400 hours. Keep in mind, however, that, when batteries are

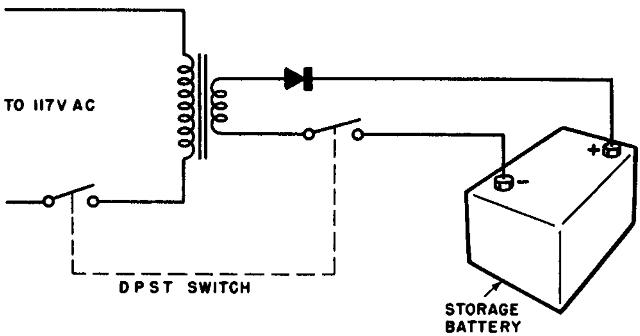

Fig. 709. *A dry rectifier type charger can be used to keep the the test storage batteries in ready operating condition. The double-pole single-throw (dpst) switch should be in the off position when the battery is in use.*

used in series (as they are in transistor receivers), the battery supply can be no better than that of the weakest cell in the group. If you find that the receiver you are servicing is restored by battery substitution, it is always safest to replace all of the batteries rather than just one.

When substituting batteries, remember that failure to observe proper polarity can result in damage to transistors. In many receivers, it will be impossible to transpose the batteries since the receiver may have some polarizing device. However, not all receivers are so equipped.

Voltage substitution

It is entirely possible in servicing a transistor receiver that you will find the cause to be defective batteries and it is also possible that you may not have a suitable replacement on hand. Under these conditions it is inadvisable to use a vacuum-tube-operated power pack or a selenium-rectifier type supply. An excellent power source would be 1½ volt cells of the type commonly associated with door buzzers.

These cells are rather large but have a long useful life. Another substitute supply that you could use would be a storage battery. This need not be a new unit, but can be one which has seen service and is about ready to be discarded. The battery may not be able to supply the heavy current required to start a car, but might still be useful for servicing work, provided, of course, that the battery is not too far gone. Two such batteries can be used

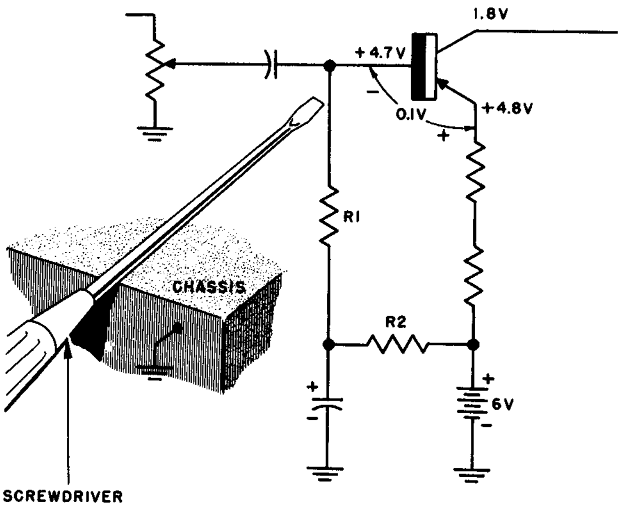

Fig. 710. *Sparking the base to the chassis removes the bias between emitter and base and can ruin the transistor.*

to supply a total up to 12 volts or a single 12-volt battery can be used (Fig. 708). You should be able to tap off at 3, 6 and 9 volts if required.

The batteries can be stored under the service bench and test leads brought up to suitable connectors in a test panel on the bench. The batteries can be kept charged by a small disk rectifier charger. These are readily available and are inexpensive. However, the charger must not remain connected when the storage battery is being used (Fig. 709).

Sparking test

A common servicing procedure in the case of vacuum-tube receivers is to "spark" either the grid or plate leads of a vacuum tube in an effort to locate a defective stage. This is a form of quick testing, but should not be done in transistor receivers. If, for example, you accidentally short the base lead to ground, you will be removing transistor bias, and this loss of bias can result in permanent damage to the transistor.

The effect of sparking the base to the chassis is shown in Fig. 710. The voltage between the emitter and the base is very small — actually in this case, only 0.1 volt. A "disturbance" test will put the base at ground and will put R1 and R2 across the battery. The bias will no longer be the proper value for the transistor.

Battery replacements

Some receivers use individual cells, others use a battery pack. In the case of a battery pack, the cells are contained within one package and the entire battery is replaced as a unit. Exact replacements are not always required since the battery packs of one manufacturer are often interchangeable with those of another. The type of pack to be used is described in the manufacturer's service notes or you can get this information from your jobber or from radio parts catalogs. The fact that one battery pack has the same voltage as another does not always mean that it can be used. There are physical considerations as well. Not only must the voltage be correct but the battery must be able to fit into the receiver and must be held properly by the holder designed for it.

Checking transistors

In a transistor receiver, the first item to suspect is the battery or batteries. The last item to concern you should be the transistors. But, having discussed batteries and now entering our discussion of transistors, we are swinging from one extreme to the other:

You can make a rough check of the transistors using a vtvm. If the transistors are in sockets (and easily removable), they can then be checked out in the open. If, however, the transistors are soldered into place, do not remove them but check them in position. Make sure the receiver is turned off and the battery disconnected.

In an earlier chapter, you will recall, we mentioned that a transistor resembles a pair of crystal diodes placed back to back. We can take advantage of this bit of information in making a transistor check. The check consists simply of measuring the forward and reverse resistances of the transistor. Fig. 711 shows how to do this.

Set the range selector of your vacuum-tube voltmeter on the R $\times$ 10 scale. This scale is to be used for making all forward resistance measurements. In the R $\times$ 10 position, the range se-

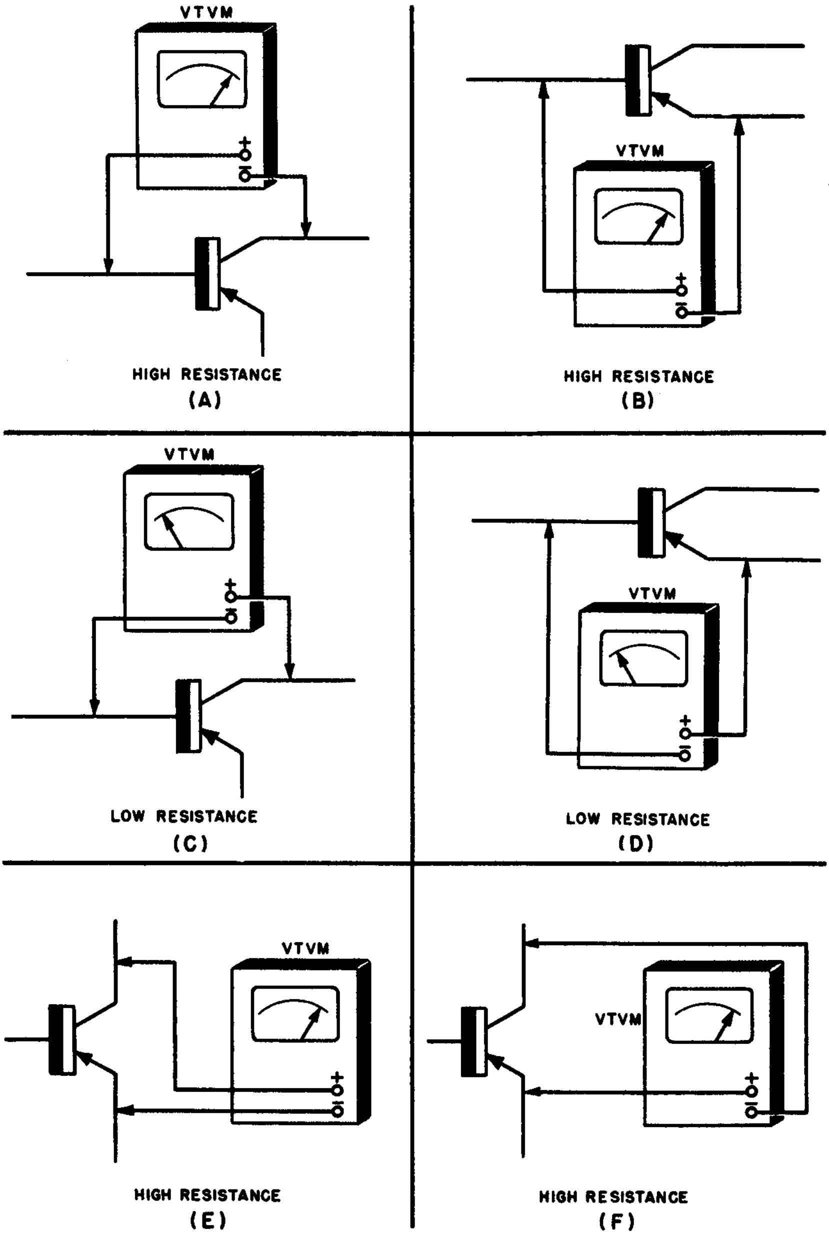

Fig. 711. *Techniques for measuring the reverse and forward resistances of a p-n-p transistor.*

lector on your vtvm automatically inserts a resistor between the transistor and the test instrument.

First, consider measurements of p-n-p types. Connect the positive terminal of the vtvm to the base lead. Now connect the negative lead of the vtvm to the collector lead (Fig. 711-A). You should measure high reverse resistance. The resistance should have a value of 50,000 ohms or more. With the positive lead of the vtvm still connected to the base lead, connect the negative test lead to the emitter. Once again you should measure a high reverse resistance, generally in the order of 50,000 ohms or more (Fig. 711-B).

Before checking transistors in this manner however, become acquainted with the circuit diagram of your meter. You will not obtain correct results unless the negative lead of your meter is connected to the negative side of the battery in the instrument.

Most meters used in these instruments have some identification to indicate the positive and negative terminals. Very often the plus symbol appears on one of the screws coming out of the meter itself. In some circuits this might be a help.

With your vtvm still set on the R $\times$ 10 scale, connect the negative lead of the instrument to the base terminal of the p-n-p transistor. Touch the positive lead of the instrument to the collector lead as shown in Fig. 711-C. Since you are now measuring forward resistance, your instrument should give a reading of 500 ohms or less. With the negative terminal still connected to the base lead of the transistor, touch the positive test lead to the emitter wire, as in Fig. 711-D. Once again you should measure a low resistance, 500 ohms or less.

Finally, check between base and collector, as in Figs. 711-E,-F. For these two measurements the resistance should be high.

You can measure n-p-n transistors in the manner just described except that the test leads must be transposed.

Precautions in using meters

We have stressed the use of a vtvm because it is getting to be quite common among service technicians. However, an ohmmeter can be used just as well. Normally, with an ohmmeter or a vtvm, you are supplied with a red lead and a black lead. The black lead is known as the common, ground or negative lead. The red lead is called the "hot" or plus or positive lead.

However, batteries are color blind — a condition that sometimes applies to service technicians. It does not necessarily follow that the red lead is connected to the positive side of the cell inside the test instrument. Sometimes the red test lead has a negative voltage — that is, it is connected to the negative terminal of the cell inside the test unit. This is not a fault. It is simply the way in which the instrument is constructed.

A similar situation exists in an automobile with the chassis of the car connected to the plus terminal of the battery and not to the negative terminal of the battery, as you might readily assume. If you have any doubts as to the polarity of your test leads, you

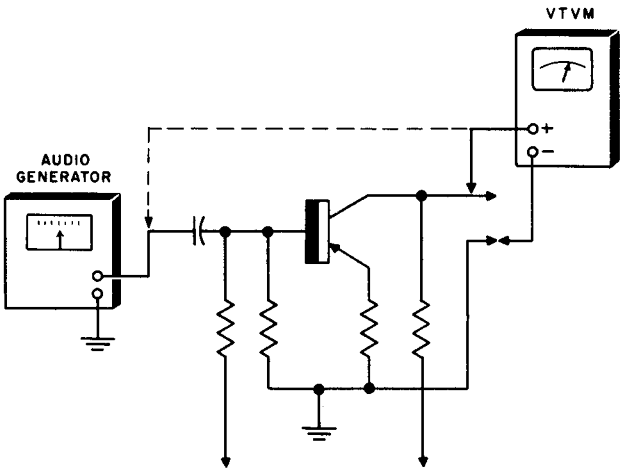

Fig. 712. *Checking the gain of a suspected transistor stage. The vtvm is alternately connected across the input and output of the audio amplifier circuit.*

can settle your suspicions quite readily. All you have to do is to connect a voltmeter across your ohmmeter test leads. Set your range selector on the highest range, and reduce or rotate the range switch until a reading is indicated. If the meter needle reads backward, transpose the test leads. You must, of course, use a voltmeter that has at least one terminal marked with its polarity. A voltmeter having a full scale range of 5 to 10 volts is satisfactory.

Not only is it important that you know the polarity of the test leads of your ohmmeter or vtvm for checking transistors, but you should remember that other components such as electrolytic capacitors are also polarized. Electrolytics are used in transistor receivers both as coupling capacitors or as emitter bypass units. In checking an electrolytic, connect the positive lead on the test instrument to the positive terminal of the capacitor.

Transistor types

Whether a receiver uses n-p-n or p-n-p transistors depends entirely on the manufacturer. You will sometimes find both n-p-n and p-n-p types used in the same set. This means you must be somewhat alert in making the forward and back resistance checks we have just described. Remember that p-n-p transistors operate with the emitter positive with respect to the base (the first letter of the abbreviation p-n-p represents positive). In the case of n-p-n transistors, the emitter is negative with respect to the base. The voltage difference between base and emitter and the transistor type are usually clearly specified on the schematic of the receiver.

Switching transistors

You can sometimes improve performance by switching transistors from one position in the receiver to another, provided that the transistors are identical types and can easily be moved from one position to the other (that is, the transistors are socket-mounted types). Performance can sometimes be improved in this way since a transistor may work better in one circuit than in another.

Further checks on transistors

The general tendency in modern transistor manufacture is to solder the transistor in place. This makes sense since a transistor is such a durable device. The method for testing transistors is exactly the same technique you would use in running a check on vacuum tubes. This is shown in Fig. 712.

For testing audio transistors, connect an audio generator to the coupling capacitor leading to the input side of the transistor. Connect a vacuum-tube voltmeter across the output side of the transistor. In checking an audio stage, for example, you could use the 400-cycle audio output of your signal generator or an audio generator itself. Since we are feeding in an ac signal and not rectifying it at all, the output will be that same ac signal, amplified, and of course must be measured with a vacuum-tube voltmeter set to read ac volts. To determine the gain of the stage, connect the vtvm across the signal generator (or input to the transistor) and then switch the hot test lead to the output side of the transistor.

Since the input will be a fraction of a volt, and the output 1 volt or less, you will have to set the range selector on your vtvm for full-scale deflection on the lowest voltage range. The gain of the stage should be approximately equal to the beta of the transistor. Thus, if the beta of the transistor is 10, the voltage measured on the output side of the transistor should be 10 times that measured on the input side.

To check all of the transistors in the receiver, you can continue to have the vtvm (or scope) connected as shown in Fig. 713 while working your way back toward the front end of the set, using your signal generator. Once you reach the rf or if side of the

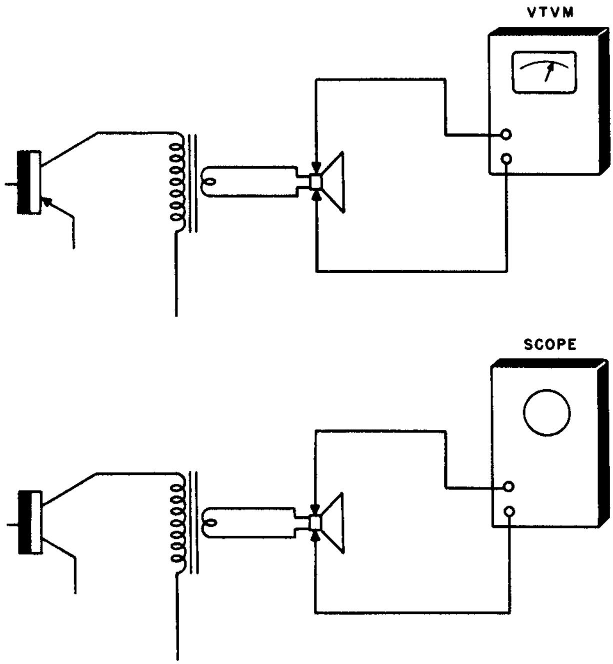

Fig. 713. *When signal-tracing through a receiver, connect a scope or vtvm across the voice coil as a signal indicator. The speaker can also be used but it is not as sensitive an indicator as these test instruments.*

crystal detector, however, you will need to switch the frequency of the signal generator. Obviously, when signal-tracing through the if stages, use a modulated if signal and, when the signal generator reaches the antenna, use a modulated rf signal.

Since we are, at the present time, merely interested in getting a general indication of operating or non-operating condition by working our way through the receiver, there will be no necessity for disabling the agc line.

In Fig. 714, we have a circuit diagram of a representative transistor radio. On this diagram we have marked a number of test points, starting with the letter A on the voice coil of the speaker and proceeding (using letters of the alphabet) until we reach the antenna. There is no law that says you must start at the speaker and go toward the front end. You can start at the antenna and work your way to the speaker or start at the detector and proceed to the front end or speaker if you so desire.

When using a signal-injection technique, you will find that your vtvm makes a much more sensitive indicator than the speaker. Many technicians prefer to use a speaker as an output indicator but it takes quite a change in sound level energy before it is really noticeable. A good technique is to disconnect one lead going to the voice coil of the speaker and to place a 5-ohm 2-watt resistor across the output transformer secondary leads. The leads to the vtvm can then be placed across this resistor. As you work your way from the output stage to the front end of the set, the ac voltage reading as shown by the vtvm should increase.

However, be suspicious of any stage that gives an increase in excess of what is considered normal. Sometimes signal injection produces a condition of oscillation and what you will really be measuring will be the injected signal voltage plus the voltage generated by the stage that is so triggered. Any stage that produces a decrease in gain, or any stage that does not produce sufficient gain, requires further checking.

Component replacement

Removing defective components can sometimes be a problem in small receivers, and that is exactly what many transistor receivers are. Even if the component is readily available, there is always the possibility that you might damage an adjacent part (especially a transistor) by excessive heat or pulling on component leads. If you are sure that the component to be replaced is definitely defective, cut away the part but permit the leads to remain. If the defective part is a capacitor, cut the leads as close to the body of the capacitor as possible and then use the old leads as soldering terminals for the new unit. If the part is a resistor, you can crush it with a pair of pliers (if you feel that the leads just aren't long enough).

When replacing batteries, remember that with carbon batteries, such as the penlight type, the button at the top of the battery is positive and the metal portion of the case is negative. The reverse is true of mercury cells.

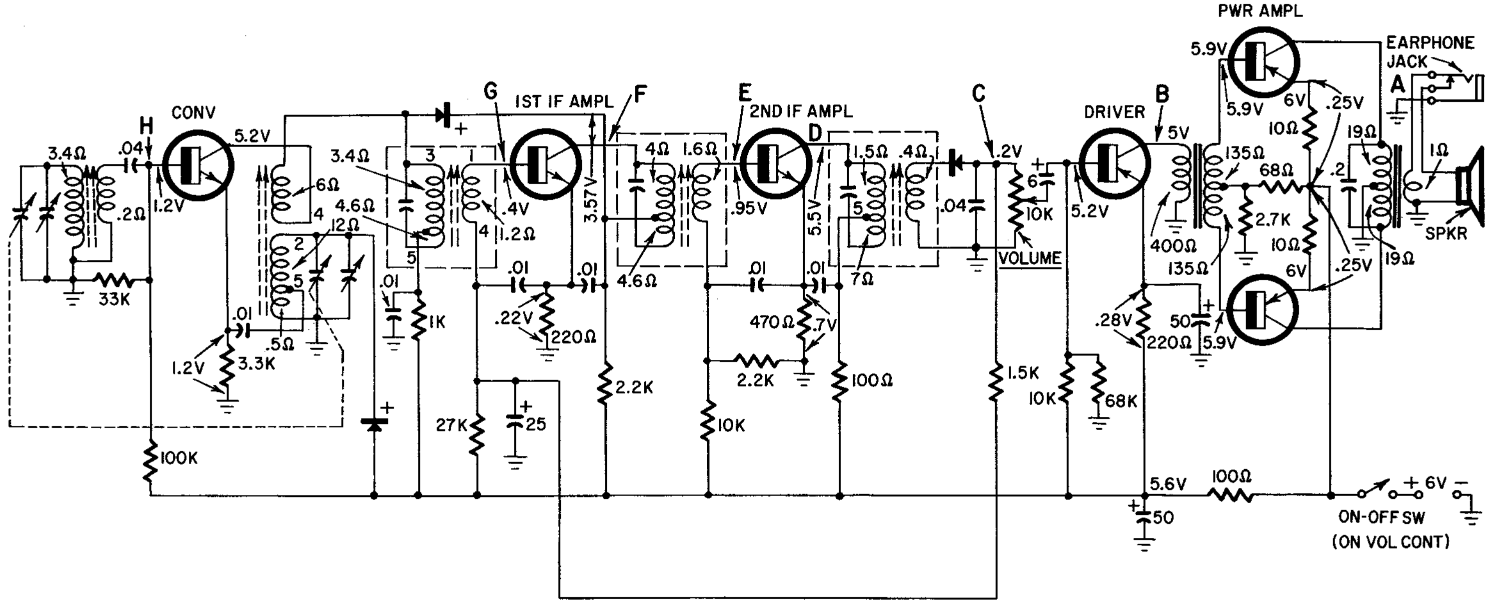

Fig. 714. *Voltages are measured from the points indicated to ground with a vtvm. Resistances are measured with the transistors out of associated circuits.*

Watching the voltage

In servicing vacuum-tube receivers, we often connect the test-equipment leads directly to the control grid. The grid return is usually to ground through a high value of resistance. In a transistor receiver, however, the input (base) is generally tied to the battery through a voltage divider connected directly across the battery itself. This voltage point is important since it establishes the working point of the transistor.

The output of your generator may be a low resistance. It can be the low-resistance winding of a transformer or a resistor. In any event, when you connect the generator leads between base and chassis, you will probably upset the bias on the transistor. To prevent this, use a blocking capacitor. A low-voltage unit rated at about 1 μf will do.

chapter 8

servicing methods—part II

WHEN conditions in a transistor receiver are right, the receiver will work and will work well. But when we stop to think of the job the receiver has to do, the amazing thing is, not that these sets ever become defective, but that many of them work for such long periods of time.

Troubles in the audio section

The words "audio instability" cover a number of problems that are often listed under other names. As an example of audio instability, the complaint would be that the receiver squeals, especially when the volume control is turned up. Sometimes this squealing will be intermittent – a symptom which you will promptly recognize as "motorboating."

This trouble can be produced by a variety of causes. Your first suspicion should be directed at the battery. As a battery gets older, its internal resistance increases. As the internal resistance of the battery gets larger, most of the voltage drop takes place inside the battery itself. The result is a reduction in the voltage available for the different circuits of the transistor receiver. As a consequence, the volume control must be advanced to increase the driving signal voltage to the various stages. This results in a condition of instability and the receiver tends to squeal or motorboat.

Audio instability can also be caused by poor connections. In one instance, squealing was produced by the battery itself. The battery holder was riveted into place and the rivet had become loose. The problem was solved by soldering the rivet into place.

If battery connections are made by means of snap-fasteners, examine these to make sure that the fastener hasn't "spread" and that good contact is being made. Check by removing the fastener and then trying to snap it back into place again. The action

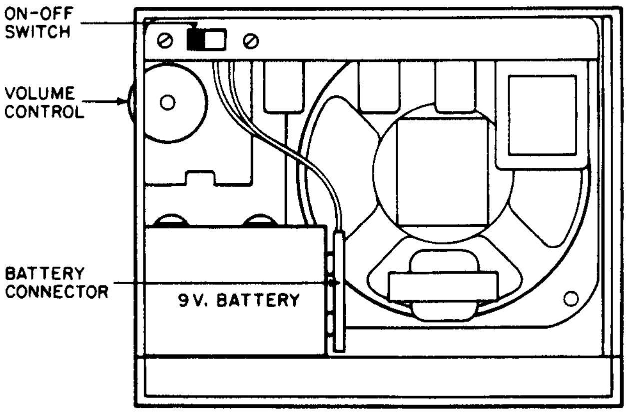

Fig. 801. *A loose battery fastener can cause audio instability.*

should be a positive one and you should hear a definite click as the snap fastener is pushed into position (Fig. 801).

Rotate the variable capacitor and observe any instability produced as you turn the tuning dial. If you do have this trouble, examine any and all screws used to fasten the tuning capacitor to its chassis.

Another cause of audio instability is leaky or otherwise defective electrolytic filters placed across the battery power supply. You will find one or more of these with capacitances ranging from 10 to 50 µf (Fig. 802). To check, turn the receiver on and produce the condition of squeal or motorboating. Take a known good capacitor and shunt it across the suspected defective electrolytic. If the squeal disappears or is reduced, replace the filter.

Sometimes, inadequate filtering is used in receivers sold for a low price. Squealing or motorboating in such sets is not due to any defect, but is simply caused by an insufficient amount of filter capacitance. In such instances, parallel the existing capacitor with a unit having an equal or greater amount of capacitance.

Motorboating or squealing can also be caused by an open collector decoupling capacitor (Fig. 803). To check if this is the trouble, shunt the existing capacitor with a similar unit. When shunting a test capacitor across a suspected defective unit, make sure that the positive terminal of the test unit is connected to the positive terminal of the defective electrolytic in the receiver.

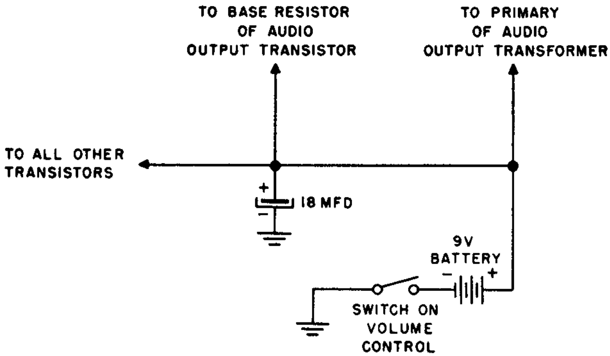

Fig. 802. *Electrolytic capacitors are often shunted across the power supply (battery).*

Similarly, the negative terminals of the two capacitors should also be connected. Do not transpose connections.

Many transistor receivers use decoupling networks from the battery power supply to the various transistor receiver stages. The decoupling network consists of one or more resistors and capacitors. If the capacitors have seriously decreased in value or have become excessively leaky, there is always the possibility of motorboating or squealing. Here again a test capacitor should be shunted across the suspected unit.

Finally, the remaining suspect in our search for the cause of motorboating or squealing could be the feedback resistor. The feedback resistor improves the stability of the set. If the resistor should become open or disconnected or if, for any reason, its resistance value is excessive, the benefits of feedback will be removed. An ohmmeter check (with one end of the resistor disconnected) will soon reveal whether the resistor meets the values specified in the manufacturer's circuit diagram (Fig. 804).

Weak audio signal

The first thing to do is to turn on the receiver and, with the volume control set in its maximum position, check the battery voltage. If the battery voltage is normal, the trouble could be due to defective electrolytics. Remember that a transistor radio receiver's electrolytics are often used as coupling capacitors and in this position can seriously affect the gain of the receiver. Check all electrolytics, whether used for coupling or bypass functions.

Run a resistance check on the audio transformers used in the

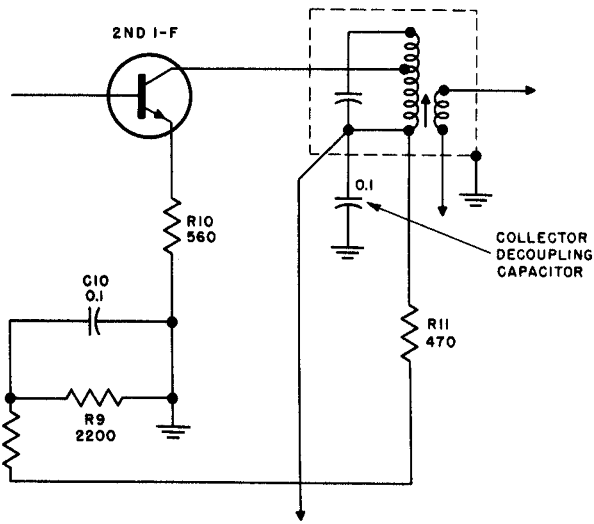

Fig. 803. *Squealing can be caused by open collector decoupling capacitor.*

receiver. This test should be supplemented by signal tracing. The reason for this is fairly easy to see. If a transformer has a shorted turn, volume will be greatly reduced. However, a shorted turn or a few shorted turns will not materially reduce the resistance of the winding. As a consequence, a resistance check is not always conclusive. However, signal tracing will reveal the defective transformer.

Cases have been reported where a weak output signal was due to rubbing of the voice coil in the loudspeaker. Push the speaker cone gently with your fingers. The cone should move back and forth easily and with no rubbing sounds. A good check is to use a substitute test speaker. This condition is often accompanied by distortion.

No output signal

Make sure that the battery leads have not become disconnected. Turn on the receiver and, with the volume control in its maxi-

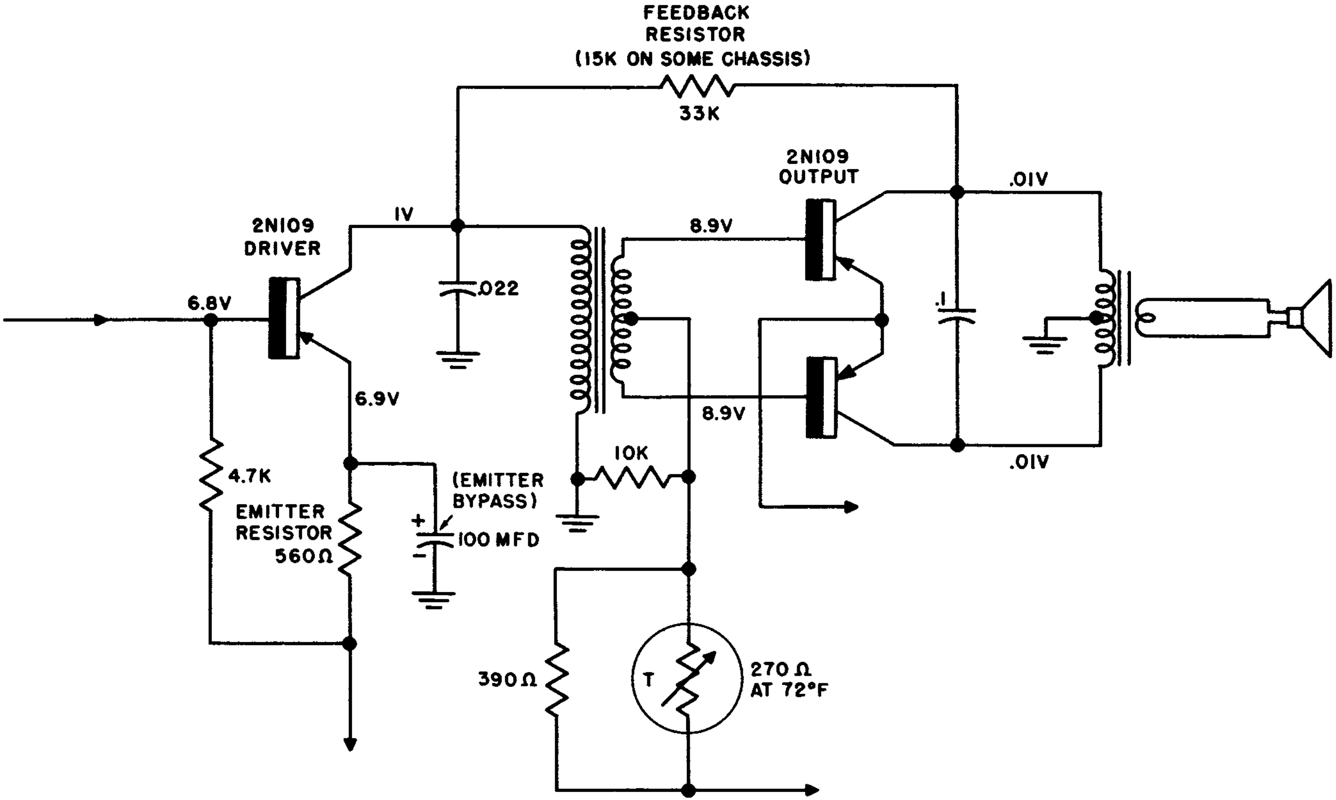

Fig. 804. *An open or changed-value feedback resistor can cause squealing. Check the value of resistor against the receiver schematic.*

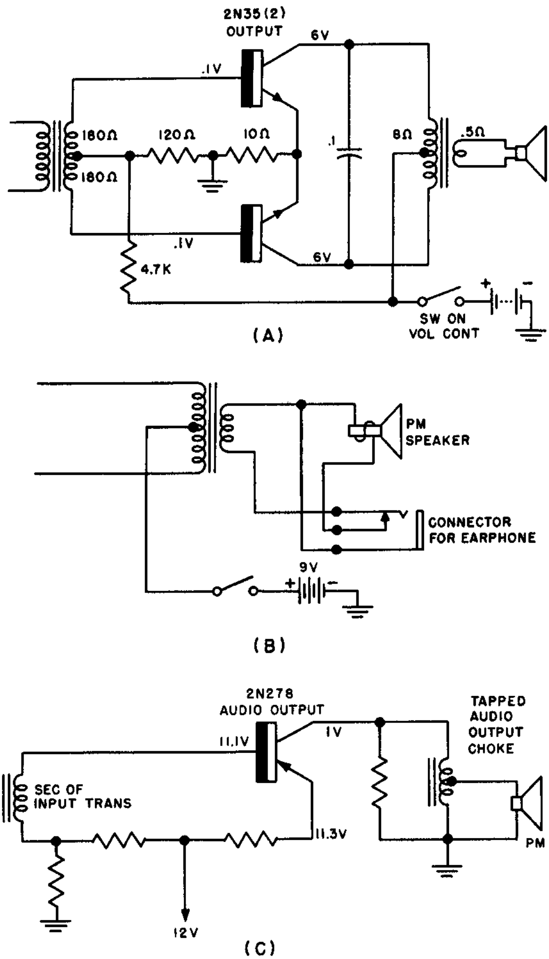

Fig. 805. *Some transistors have loudspeaker output only. Others have one or more jacks for earphones. Impedance coupling is used in Fig. 805-C. The choke is tapped down to match the impedance of the voice coil. In some radios, the phone jack is placed at the output of the driver stage instead of the push-pull stage.*

mum position, make a check of battery voltage. If the battery voltage is normal, connect the audio generator across the diode load resistor and use signal-tracing techniques to find the defective component.

If the batteries are in good condition, a complete loss of signal could be caused by an open voice-coil winding in the speaker, an open output transformer (either the primary or the secondary winding could be defective), or there is an open component in any circuit between output of the detector and the output stage.

Sometimes the trouble is due to the on-off switch mounted on the volume control. This should make a definite click as it is rotated from the off to the on position. Short the switch terminals with a screwdriver and note if the receiver comes on. If it does, then the switch is defective.

Some receivers use a jack so that earphones can be used in place of the speaker. In some sets, inserting the earphone jack automatically disconnects the speaker, putting a load resistor across the voice coil in place of the speaker. In other sets, no load resistor is used. If the earphone jack is defective, it is possible that that speaker is not reconnected into the circuit when the earphone jack is removed (Fig. 805).

Complete lack of audio could be caused by a leaky or shorted component placing an excessive drain on the battery. Connect a milliammeter in series with either battery lead. Turn on the receiver and note the current reading. If the current reading is greatly in excess of normal receiver requirements, then you have a leaky or shorted component.

Distortion

In transistor receivers as in vacuum-tube sets, distortion often arises in audio amplifier stages. A common cause is incorrect bias, although other components such as bypass capacitors can also produce distortion.

Since distortion (in the audio section) can come from a defect anywhere from the output of the detector diode to the speaker, one of the easiest techniques for localizing the difficulty is to signal-trace the entire amplifier system. Before you do so, however, become familiar with the sound of your own generator. Connect a speaker or earphones to your audio generator (or audio output terminal of your signal generator) and listen to the tone at low volume. Use any frequency between 400 and 1,000 cycles.

Now connect the audio generator directly across the voice coil leads. It isn't necessary to turn the receiver on. Listen to the tone. If there is any roughness, examine the speaker for a sticking or rubbing voice coil, rips or tears in the cone. Sometimes one side of the voice coil is grounded. Make sure the connection isn't open since it may be part of a feedback network.

If the sound is good, connect the generator leads across the primary of the output transformer. (The receiver is still turned off.) Distortion can be caused by corrosion in the transformer or by shorted turns. If the transformer is a push-pull type, test each half (from tap to outer lead) separately. Since the tone-control capacitor is connected to the output collector, unsolder one end (end connected to the battery or chassis) and note if the disortion disappears. If it does, then the capacitor is defective. If the tone control has a switch, try putting the switch into its different positions. If distortion occurs at one postion only, then the capacitor connected to that position is defective. If the receiver sounds shrill or tinny, the tone capacitor may be open.

If the check across the primary of the output transformer does not reveal the trouble, connect the audio generator to the base input of the last stage (here we are assuming single-ended output). Make the connection through an audio coupling capacitor inserted in series between the generator lead and the base of the transistor. Turn on the receiver and listen to the tone. The signal should come through much louder than in the previous tests (assuming that you have not touched the gain control of the generator).

If it does not, then examine the base resistor, emitter resistor and emitter bypass capacitor, if any. Remove the transistor from its socket and resistance-check all components in the base and emitter circuits. If you cannot remove the transistor conveniently, check emitter and collector current by making a voltage check across the emitter resistor using a vtvm set to read low volts dc. Measure the base-to-emitter voltage to make sure the bias for the transistor is good.

If the transistor is a push-pull stage, make the check by connecting the generator across the primary of the input transformer.

By now you undoubtedly have the idea of how we proceed. If the audio output stage tests do not reveal the trouble, move your generator lead back to the base input of the audio driver or to the hot end of the volume control.

Distortion often stems from the audio stages. If, however, distortion appears only when the signals are strong, then look for trouble in the agc network, starting at the detector or separate agc rectifier if one is used.

In push-pull stages, distortion can be produced if transistors do not match or if one transistor has become defective. Substitution of a matched pair will quickly reveal if this is the cause of the trouble. Push-pull transistors are often sold as matched pairs and should be replaced as such.

When replacing transistors, be very careful to keep from shorting any one of the transistor leads to the chassis. This is especially the case for power output transistors. For example, it is entirely possible to short the bias resistor. The resulting large increase in collector current will probably ruin the transistor immediately.

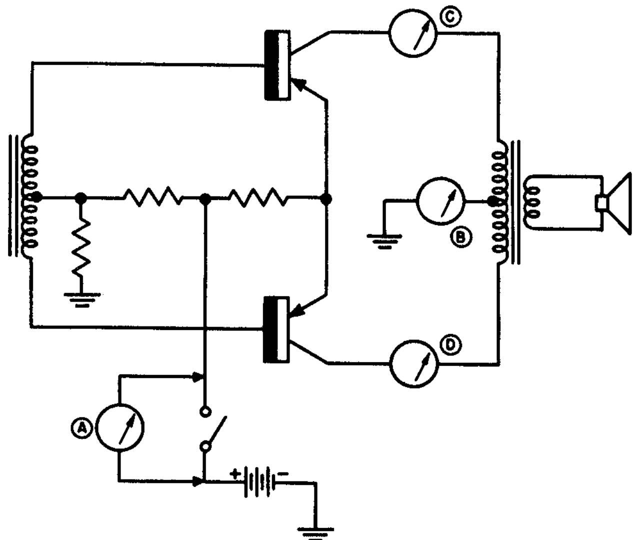

Fig. 806. *Methods for making current checks. With the meter shunted across the on-off switch, you will read total current (A). At B, you will read collector current of both output transistors. When making the test at A, keep the switch open. Note: The test shown at A does not permit adjustment of the volume control.*

Most push-pull output stages of transistor receivers are operated in class B. In this circuit arrangement, the current required by the transistor increases considerably as signal voltage is applied to the output stage. In a typical receiver, the current required by the push-pull output transistors in the absence of driving signal is less than 10 ma. For maximum audio output, the current demand grows to 35 ma. This gives us a clue for checking push-pull stages without the necessity of removing the transistors. Set a milliammeter in series with the lead going to the center tap of the output transformer. Adjust the tuning dial so that it is between stations, that is, so that no signals are received. Note the current reading. Now tune in the signal and turn the volume to maximum.

The current reading as indicated by the milliammeter should be about three times that obtained with the first check. If you get but a slight increase, or if the increase in current reading does not agree with the amount of current specified in the manufacturer's literature, then one of the transistors can be presumed to be defective. To find which is the defective transistor (assuming that you do not wish to replace both), put the milliammeter in series with the collector lead, that is, the lead between the collector of the output transistor and the primary of the output transformer (Fig. 806). In this way you will be able to measure the individual transistor current. By running a test on both transistors in this manner, you will be able to determine how closely the two transistors are matched.

The troubles we have described are those which will most commonly appear in the driver and power output stages of a transistor receiver. Remember, many of the troubles which you will encounter in vacuum-tube sets will not crop up in transistor receivers. For example, breakdowns due to unusually high voltage or burned-out resistors and similar troubles will not be part of the routine in servicing such sets. However, from what we have described thus far, you can easily see that servicing transistor receivers is no more difficult (and in many cases is easier) than servicing vacuum-tube sets. Fig. 807 shows how an audio generator (or the audio output of your signal generator) can be used to check single-ended and push-pull output stages. And now that we have covered the back end of the receiver, let's move forward to the detector stage.

The detector

There is a quick and easy way to determine if the detector is providing any difficulties. Connect your signal generator to the output (collector) of the last if stage preceding the detector (Fig. 808). Set the signal generator to the intermediate frequency of the receiver. The modulation of the generator should be turned on. If the detector and the audio stages are working correctly, you should hear the audio tone in the speaker. If no signal is heard, transfer the test lead of the generator to the diode load resistor. Change the cable connection on the signal generator so that it is connected to the audio output terminal. The frequency dial of the signal generator can be left in any position desired

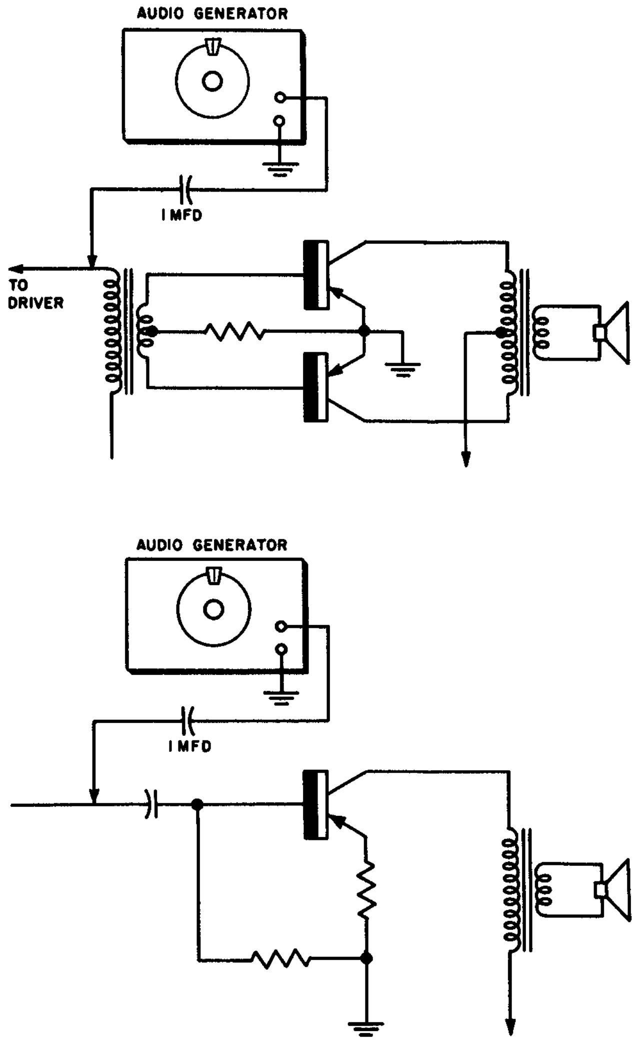

Fig. 807. *Methods for checking single-ended and push-pull audio output stages.*

since (for most rf signal generators) the audio test frequency has a fixed value. If you now hear a signal coming out of the speaker but you did not hear a signal when the generator was connected to the collector of the last if stage, you have a positive indication that the detector circuit is at fault.

Many of the symptoms we have discussed in the preceding paragraphs with respect to the audio amplifier stage or stages also appear in the detector circuit. Thus, defects in the detector can cause a weak signal, complete absence of output signal, distortion, etc. The detector circuit is quite simple and consists of the detector unit, the volume control and a coupling capacitor, usually connected to the base of the first amplifier transistor. The agc network is generally made part of the detector circuit.

To determine if the volume control and the coupling capacitor

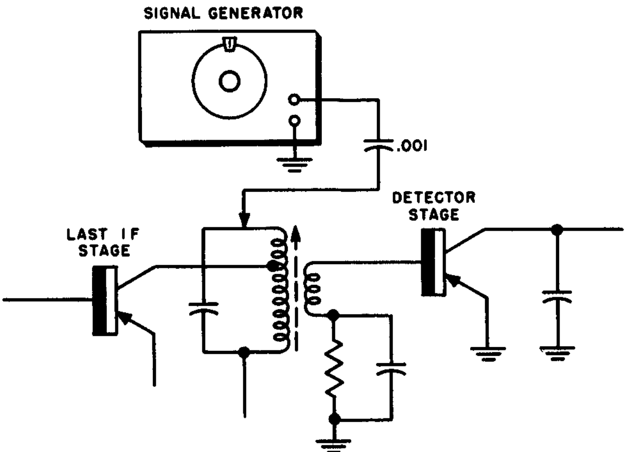

Fig. 808. *Method for checking the transistor detector stage.*

are functioning properly, connect an audio signal across the output terminals of the volume control. With the receiver turned on, vary the volume control and note if you can control the strength of the output signal. If you do get a strong output tone and you can vary this with the volume control, then the trouble lies in the detector itself or in the secondary of the last if transformer. If, however, you get no signal or a very weak signal, under these test conditions, move the generator test lead until it is across the input of the first audio amplifier. A test signal which appears at the speaker when the generator is so connected indicates that either the volume control or the coupling capacitor following it is defective. An ohmmeter check of the volume control will soon reveal whether it is in good working order. Make this test by connecting one lead of the ohmmeter to either outer terminal of the potentiometer and the other ohmmeter lead to the center terminal of the potentiometer. Vary the potentiometer and note whether you can make the ohmmeter needle move smoothly back and forth. In most receivers, the volume control will have a total value ranging between 1,000 and 10,000 ohms, and you should set the range switch on your ohmmeter accordingly. If the potentiometer checks satisfactorily, try shunting the coupling capacitor between the volume control and the base input of the first audio amplifier tube with another capacitor. The coupling capacitor is generally an electrolytic, having a value in the region of 1 to 10 μf. Here is a spot where you must watch polarity and not make any assumptions. Sometimes the negative lead of the coupling capacitor is connected to the base of the first audio amplifier and sometimes the positive terminal of the electrolytic coupling capacitor is so connected. Disconnect one

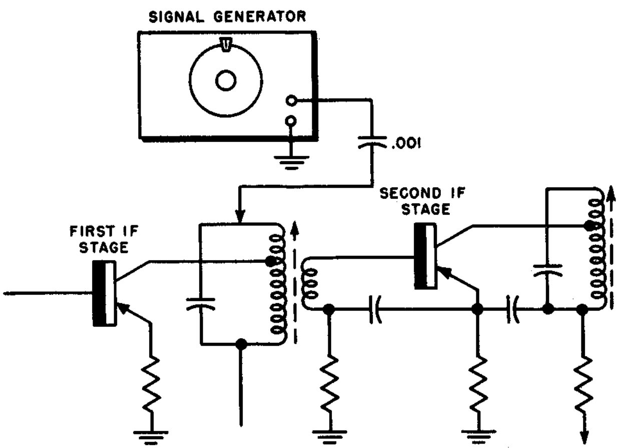

Fig. 809. *Method for checking the if stages.*

lead of the suspected capacitor and then use your test capacitor to see if the sound will come through.

Distortion in the detector circuit

Distortion, whether on strong or on weak signals, could be caused by a defective rf bypass capacitor. The purpose of this capacitor, as you know, is to keep rf out of the following audio stage and to prevent its being overloaded. Of course, if the coupling capacitor between detector and first audio stage is shorted, you will also get distortion. Distortion can also be produced if one or more of the filter capacitors in the agc network connected to the detector have become defective. In some instances, distortion is caused by a misadjusted slug in the secondary side of the last intermediate-frequency transformer. This is considered part of the detector circuit.

The if amplifier stages

The number of intermediate-frequency amplifier stages depends entirely upon the type of receiver you are servicing. However, no matter what number of stages the receiver has, you can check through for trouble by signal tracing, working your way back from the detector to the output of the converter (Fig. 809). As you proceed in this fashion, the signal at the output should become stronger because the output of the signal generator is being multiplied by each transistor stage.

To determine quickly whether all the if stages are functioning, connect your signal generator at the output side (generally the collector) of the converter transistor. The setup for the signal generator should be exactly the same as that used for checking the detector stage. That is, the signal generator should be set to the intermediate frequency of the receiver with modulation turned on. If, with the signal generator connected to the collector output of the converter stage, you get no signal out of the speaker, move forward toward the detector, stage by stage, until the signal reappears. If, for example, you get audio output when at the collector of one of the if stages but no audio signal when you move back toward the input of that same transistor, you have quite obviously located the defective stage.

The troubles which you will encounter in intermediate-frequency amplifier circuits are much the same as those in the audio section. That is to say, many of the symptoms produced by defects in the audio stages are similar to those produced by the if stages. Now, the question may very well arise as to how you will know which section of the receiver is causing the trouble. For example, a weak signal could be caused by trouble anywhere in the if, in the detector or in the audio circuit. Once again, signal tracing will show which part of the receiver requires your attention.

Weak signals in the if

Weak signals are quite often caused by misalignment in one of the if circuits. The if transformers in transistor receivers are quite selective and it doesn't take much turning of the slug to produce either distortion or loss of signal. We are not going to

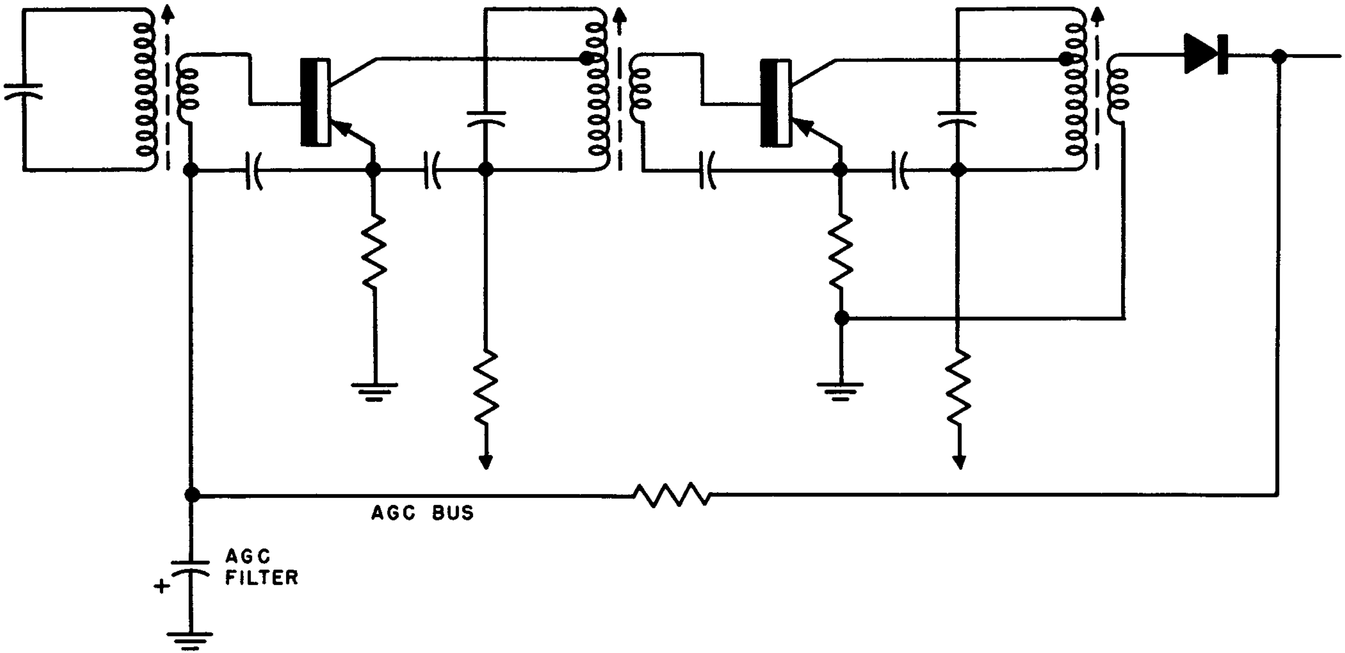

Fig. 810. *Defective resistors and capacitors in the agc bus can result in oscillation.*

discuss realignment at this particular time since complete alignment instructions for a typical receiver are given in chapter 10, beginning on page 2-77.

In the case of weak signals, you should always check battery voltage with the receiver volume control turned full on. If you have previously checked this and have also determined that none of the audio or detector stages is defective, and have definitely located the cause of the weakness in the if section, then it would be helpful to check the if bias voltages.

Bias voltages in a transistor receiver are not easy to check. As

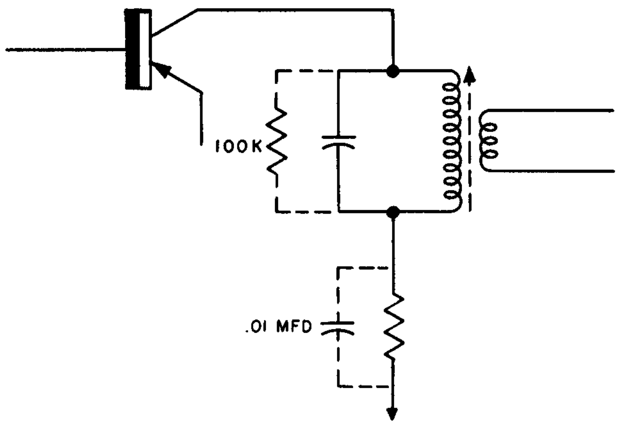

Fig. 811. *A 100,000-ohm resistor shunted across the primary of the if transformer and an additional decoupling capacitor (.01 μf) will help kill oscillation.*

we have mentioned previously, your vtvm must be capable of measuring small voltages, and you must learn to look at the meter needle somewhat more carefully. Although the normal bias voltage for a transistor may be a small fraction of 1 volt, this small fraction is extremely important. A decrease in bias voltage, for example, of only .05 volt (5/100 of 1 volt) is enough to cause a serious decrease in receiver gain.

Open bypass capacitors in the if section can also reduce gain. With the receiver turned on, shunt each bypass capacitor with a similar unit and note any possible increase in gain.

Oscillation in the if

An intermediate-frequency amplifier stage means just that. The transistor is supposed to amplify the signal fed to it and not produce any signals of its own. When a transistor stage oscillates, it becomes a generator and from then on supplies its own signal. This signal will sound like a squeal and may very well ride in on top of the signal to which the receiver is tuned. Some receivers

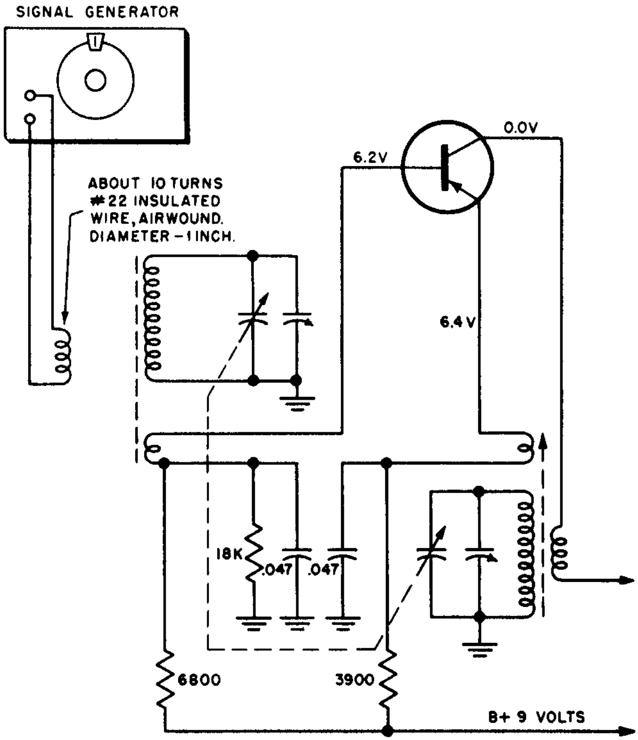

Fig. 812. *Method of checking the converter stage.*

use neutralizing capacitors or neutralizing resistors. Check these to make sure that they are in good condition. A more likely cause is trouble in the agc line. Check all resistors and capacitors in the agc network (Fig. 810).

If the neutralizing resistor or capacitors check good, don't try experimenting with them since this will be time-consuming and may not produce results. Instead, shunt a 100,000-ohm resistor across the primary of each if transformer (one transformer at a time) until you have managed to kill the oscillation. A decoupling capacitor should also be added. This should be done even if the receiver has an existing decoupling unit (Fig. 811).

Oscillation is sometimes caused by substituting an equivalent type of transistor instead of an exact replacement. Use the transistor type specified by the manufacturer. Transistor substitution can also lead to distortion since the biasing may be different.

Converter stage

The converter stage can also supply its own share of problems. As a quick check, set the dial of the signal generator to the low-

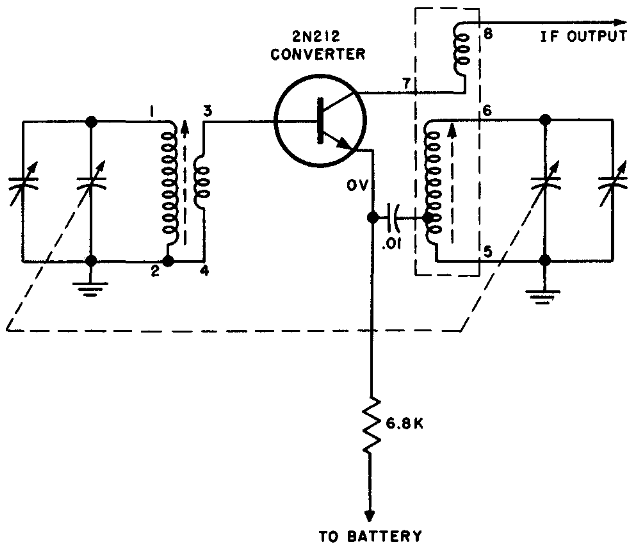

Fig. 813. *To check the mixer and oscillator coils with an ohmmeter, test across the numbered points.*

frequency end, somewhere in the region of 600 kc (Fig. 812). Tune the receiver to the same frequency. With the modulation of the generator turned on, the output should be heard in the speaker. To get a complete check across the broadcast band, run a similar test at 1000 kc and also at 1500. If you get no signal output or if the signal is extremely weak, connect the signal generator lead to the output of the converter and change the frequency setting of the signal generator to the intermediate frequency of the receiver. If at this time the signal comes through loud and clear, then trouble in the converter is definitely indicated.

Front-end troubles

In speaking of the front end of a transistor receiver we refer to the converter or, where they are used, a mixer and local oscillator.

Since most transistor receivers do not use an rf amplifier, troubles in this section will be discussed when we reach Chapter 9. Auto radios do use an rf amplifier.

There are a variety of front-end troubles ranging all the way from complete inoperation to poor reception. In discussing these symptoms, please remember that a single trouble can cause a number of symptoms. For example, a defective transistor used as a converter can cause poor sensitivity or it can make the receiver completely dead. It all depends on what we mean by the word defective. If the transistor is burned out, it is defective. If one of the leads has broken off completely, it is defective. If its gain is much lower than it should be, it is defective. And yet some of these defects permit the transistor to operate (after a fashion) while in other cases the transistor might just as well be out of the circuit.

The word defective covers a tremendous amount of territory. However, the situation isn't as hopeless as it might seem. It is much better to know that a bad transistor can cause a number of different troubles than to imagine that each trouble has one and only one specific cause. Knowing the various troubles that components can produce enables you to narrow your search for the culprit.

Receiver doesn't work

If the receiver doesn't operate and you have localized the trouble to the front end, then you can be fairly certain that either an open or short is the cause. Check the coils in the front end for continuity. Make sure that you do not have a break in the antenna or oscillator coils. Remember, antenna and oscillator coils have primaries and secondaries, so check both (Fig. 813).

If you decide to make a resistance check, you will have to remember that you aren't dealing with a vacuum-tube set. A vacuum tube with no voltage on it, is just a lot of empty space surrounded by a bit of glass or metal. A transistor is quite different, resembling a group of resistances stuck into the circuit. As a result, every time you make a resistance check, some part of the transistor will manage to get into the act, giving you completely misleading readings. If the transistor has a socket, take the transistor out. If the transistor is soldered into place, it is advisable not to tamper with it.

If you can make a resistance check and the resistance check shows that the coils are good, then it is possible that the oscillator isn't working. There are a number of tests that you can perform, depending upon the equipment you have at your disposal. In Fig. 813, we have a typical converter stage using a Hartley circuit as the local oscillator. Set the dial of the receiver to about the center of the scale. Connect your scope "hot" lead to the emitter

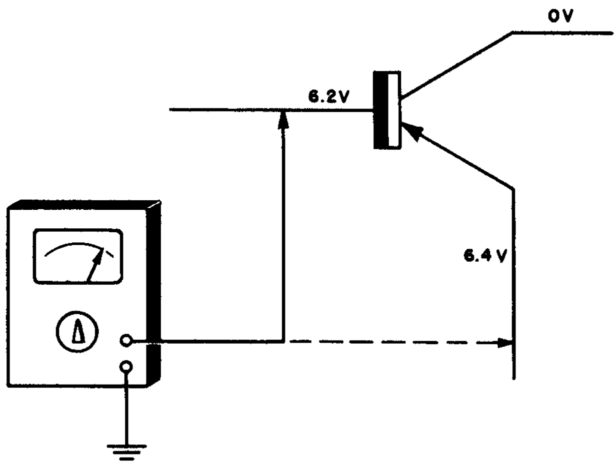

Fig. 814. *To measure bias use a vacuum-tube voltmeter. Set it to read dc volts but use the lowest possible range so that the meter needle will read as far over to the right as possible. The difference between the two meter readings is the bias voltage.*

of the transistor and see if you can pick up the rf voltage being impressed on the emitter by the local oscillator. If you have an rf type of vacuum-tube voltmeter, you can actually measure the rf voltage at this point. Use an isolation probe with your vtvm. The technique which you use for determining oscillator operation in a TV or AM set (by measuring the voltage developed across the grid return resistor of the oscillator) cannot be used in transistor receivers.

If you do not have the test equipment we have just described, but do have a signal generator, you can still run a test on the local oscillator in the receiver. Connect a loop to the test cable of the generator as shown in Fig. 812. The dimensions of the loop are not critical. It can consist of about 10 turns of insulated wire (No. 22 wire). Couple this coil loosely to the oscillator coil in the receiver. Set the dial of the receiver to a point at which a station is normally tuned in. Now set the signal generator to a frequency equal to the sum of the station frequency and the if. For example, suppose you have set the dial to 1000 kc and the if is 455 kc. The sum of these two frequencies is 1000 + 455 = 1455 kc. This is the frequency at which you should set your generator.

The output of the generator should be the rf signal, but with no modulation. If the local oscillator in the receiver is not working (and you have the receiver correctly tuned), you should now hear the station. Rotate the dial of the signal generator back and forth over a narrow range if you do not hear anything.

The next step would be to check the voltage at the base and emitter of the converter transistor to make sure that proper voltages are reaching the transistor. (Another method of checking the local oscillator is described on page 2-62 in Chapter 9.)

If you must replace the mixer transistor, try to use an identical type. An equivalent transistor may work, but sometimes such a substitute unit will work only over part of the broadcast band.

Tweets and birdies

You must first make sure that this condition is originating in the receiver and is not confused with interference picked up from

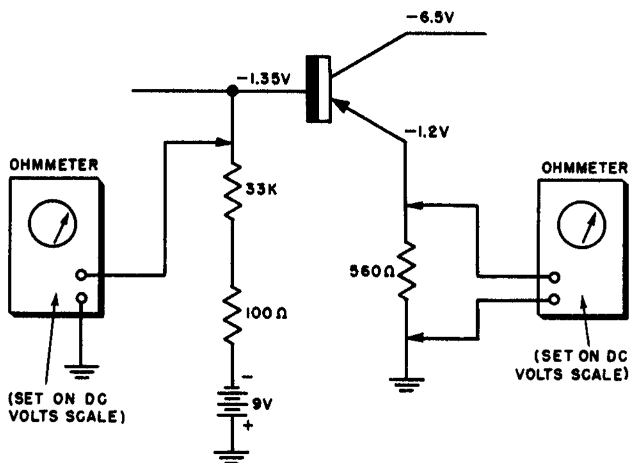

Fig. 815. *An ohmmeter (used to measure voltage) will load the circuit, giving an incorrect reading. Use a vtvm.*

outside sources. If you are checking the receiver on a bench equipped with fluorescent fixtures, turn the receiver on but shut off the light switch. Notice if there is any improvement in receiver operation. If there definitely is, then the cause is outside the receiver.

Tweets or chirps in the sound can be caused if the oscillator voltage of the receiver is too high. This condition can be relieved by using a converter transistor that is not as good as the one you have in the set. In other words, what we are trying to do here is to reduce the strength of oscillation. Of course, if the local oscillator isn't working, no signals will be heard.

Quick check

We have previously discussed the use of a milliammeter in series with the B-plus to measure receiver current under different

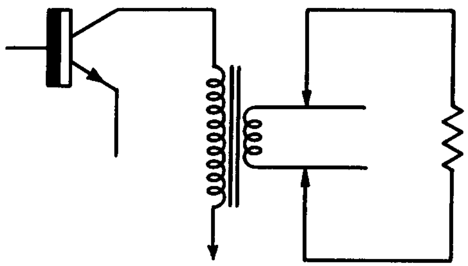

Fig. 816. *Put a dummy load across the secondary of the audio output transformer if you want to make tests with the speaker disconnected.*

operating conditions. Inserting the milliammeter isn't too difficult since all it means is lifting (or disconnecting) one battery lead (either one). If you wish, you can connect the milliammeter leads directly across the switch on the volume control. This will give you the amount of current taken by the receiver under a condition of minimum volume. However, the switch must be kept in the off position since closing the switch would short the milliammeter. No damage would be done to the meter, but it simply would not read. (See Fig. 806 once again.)

As a quick check on receiver operation, connect the milliammeter in series with the battery and measure the total receiver current with no signal coming in. Make a note of the current reading and then turn the volume control to maximum with a strong station tuned in. The current should increase to a little more than three times the no-signal value. For example, if the current without a signal is 8 ma, the current with maximum signal will be about 24 ma or more. This technique was described earlier. We are repeating it here for its value as a quick check.

Insufficient gain

This trouble can be caused by an open bypass. Shunt suspected units with a known good capacitor. Weak signals on all stations can be due to a misaligned if. In aligning if's, remember that some stages may have a double peaked response. That is, while you may have a theoretical flat-top bandpass, it isn't so in reality. Generally, one peak will be higher than the other. To get more gain and selectivity, align for the higher peak. To do this, you will have to use a sensitive output indicator and not rely upon the signal output from the speaker.

Also, instead of connecting your vtvm across the voice coil of the speaker, put it across the volume control instead. Use the two outer terminals of the volume control. Rotate the slug of the if transformer and watch the meter needle. If it swings up, then down and then up again, you have a double-peaked if response. Then just align for the higher of the two peaks.

If the if transformer seems to tune very broadly, its Q is too low. This can be caused by a shorted turn in the if transformer. Also check for open if bypasses connected to the transformer.

Sometimes gain is reduced when a new transistor is used to replace an existing unit. Don't assume that the two transistors are identical. Replacing a transistor may mean that you will have to realign the if. If you transpose transistors, you may also have to realign.

Finally, if you still don't have enough gain, take a look at the diode detector. If, for any reason, it has been turned around, the agc voltage will be incorrect.

Measuring bias

The bias is the voltage existing between base and emitter. However, as we know, the bias is very small — usually a fraction of 1 volt. In a typical case, the bias might be 0.2 volt. This is very difficult to read on a meter.

An easier technique for measuring bias is illustrated in Fig. 814. Measure the voltage between base and battery using the correct reference point and then make a voltage measurement between emitter and battery. The difference between the two voltage readings will be the bias. The advantage of this technique is that it moves the meter needle further up on the scale where it can be read more easily. However, the difference in the two volt-

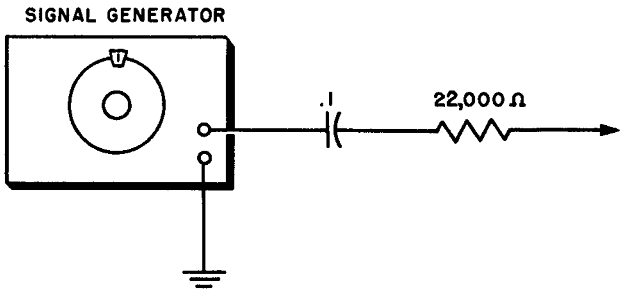

Fig. 817. *Use a blocking capacitor in series with the hot lead of the generator. A 22,000-ohm ½-watt resistor will provide isolation when checking in rf or if stages. The resistor isn't needed for audio circuit testing.*

age readings will be slight, so you will have to make the test with care.

Test instruments

For servicing transistor radios, both the volt-ohm-milliammeter and a vacuum-tube voltmeter are needed. It is true that both the volt-ohm-milliammeter (vom) and the vacuum-tube voltmeter (vtvm) can measure voltage, but you need the vom for measuring current. (A few vtvm's also measure current.)

However, since the vom also has voltage scales, it might seem offhand that we could dispense with the vtvm and work with just one instrument. The whole point hinges around the sensitivity of the test units. A vom may have a sensitivity as low as 1,000 ohms per volt. But what are the voltage ranges we will encounter in a transistor receiver? Seldom will we get above 9 volts, with many receivers working at voltages lower than this! Now suppose we would wish to measure the voltage at the base of a transistor and that this was indicated on the manufacturer's circuit diagram as −1.35 volts. We would set our vom on its lowest dc range. But at 1,000 ohms per volt, the meter represents a resistance of only 1,350 ohms. However, in making a voltage measurement, what we are really doing is putting the meter in shunt with the circuit being checked. In Fig. 815 we see that doing this has the effect of reducing the 33,100-ohm base resistor to an equivalent of 1,280 ohms.

If you use a vom having a sensitivity of 20,000 ohms per volt, this would be 100,000 ohms on the 10-volt scale (full-scale deflection). Making the test indicated in Fig. 815 reduces the base resistor to an equivalent of 14,900 ohms. The situation is a little better (but not good enough) since the more sensitive vom does not load the circuit as much. A vtvm would be best since it is

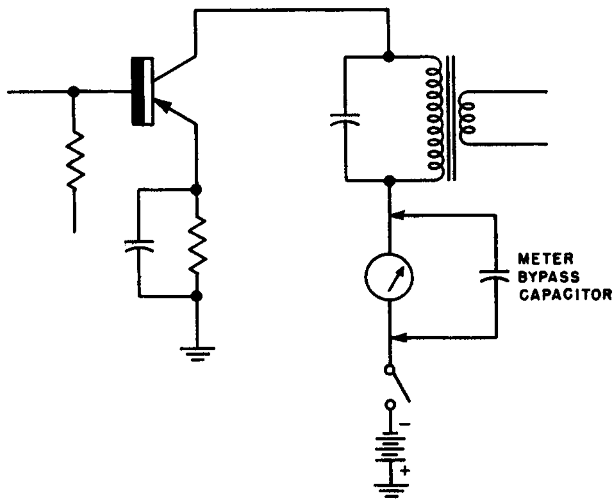

Fig. 818. *Use a meter bypass capacitor when making current measurements.*

rated in megohms and has practically no effect on the circuit being tested.

If you do use a 1,000-ohms-per-volt meter, the bias readings you measure will have no significance. They will not be correct since the very act of connecting the instrument will change the bias.

Some testing suggestions

Never operate a transistor without a load. If you must remove a speaker, do not assume that keeping the test instrument leads connected across the secondary of the output transformer is sufficient. Keep a 5-ohm 2-watt resistor handy for connecting across the leads to the secondary of the transformer (Fig. 816).

Always use a blocking capacitor in series with the hot lead of your signal generator. Some technicians put a 22,000-ohm resistor (Fig. 817) in series with a 0.1-µf capacitor to isolate the signal generator from the circuit being tested. The resistor is not needed for audio circuits.

When using a milliammeter to make a current measurement, it is always good practice to bypass the meter for if or rf. Use a .01-μf capacitor for these frequencies. Use a 10-μf capacitor when measuring current in audio circuits (Fig. 818). While this technique is a desirable one, it isn't always observed.

Transistor receivers can be click-tested but you must be careful not to short the input bias of the transistor. You can hum-check by holding the metal shank of a screwdriver and then touching the metal end of the screwdriver to the base lead.

When checking collector-to-emitter voltage, connect a vtvm between collector and emitter. Watch polarity, depending on the type of transistor used. The voltage should be not less than 50% of the battery voltage, and most probably in the order of 80%.

chapter

9

auto radios

As you might expect, transistors lend themselves very well to use in an automobile radio. They can operate with considerably lower power drain from the automobile battery; the transistor auto radio takes up much less room and, finally, the vibrator power supply is completely eliminated. Obviously, since the vibrator power supply is a source of noise and trouble, its removal is very worth while.

Fortunately, most of the servicing procedures and troubles we have analyzed earlier are also applicable to the transistor automobile receiver. We still need to study the transistor automobile radio though, since it has a few problems of its own.

A few differences

The transistor automobile radio is a superheterodyne and so are the various portable and home receivers. This means that the fundamental circuitry of all of these sets is the same and yet the receiver designed to work in the home certainly has better operating conditions than one that is forced to compete with an automobile engine. The auto engine not only moves the vehicle, but it also does a very good job of acting as a miniature transmitter. The program it sends out, however, is nothing for us to get happy about. It not only consists of noise but of noise that is somewhat difficult to eliminate at times.

Because the auto radio is placed within a shield (the body of the auto) it must have an external antenna. Since it isn't possible to have an antenna of any great length, a loading coil is sometimes used in series with it, as shown in Fig. 901. The loading coil produces an effect equivalent to the use of a longer antenna.

Practically all auto radios have an rf amplifier stage. This stage usually does not appear in low-cost home radio receivers. But

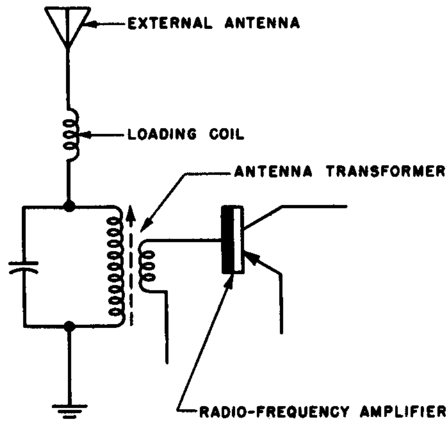

Fig. 901. *The loading coil is placed in series with the antenna. The loading coil occupies a small space but makes the antenna effectively longer.*

it is invariably used if the receiver is designed to work in an auto.

Not all auto radios have transistors throughout. Some, known as hybrid auto receivers, make use of both vacuum tubes and transistors. When vacuum tubes are used, you will find that they may be the types which will operate with 12 volts or less on the plate and screen.

In place of the vibrator power supply, some auto radios make use of what is known as a dc-to-dc converter. Finally, there are auto radios that come equipped with search tuners. A search tuner is simply an automatic tuning circuit, permitting the operator of the car to keep both hands on the wheel, letting the receiver select and tune in the signal.

In Fig. 902 we have block diagrams showing the essential difference between home and portable receivers and receivers used in autos.

Fig. 903 is a schematic of a representative auto radio using transistors throughout, while Fig. 904 is the schematic of a hybrid auto radio.

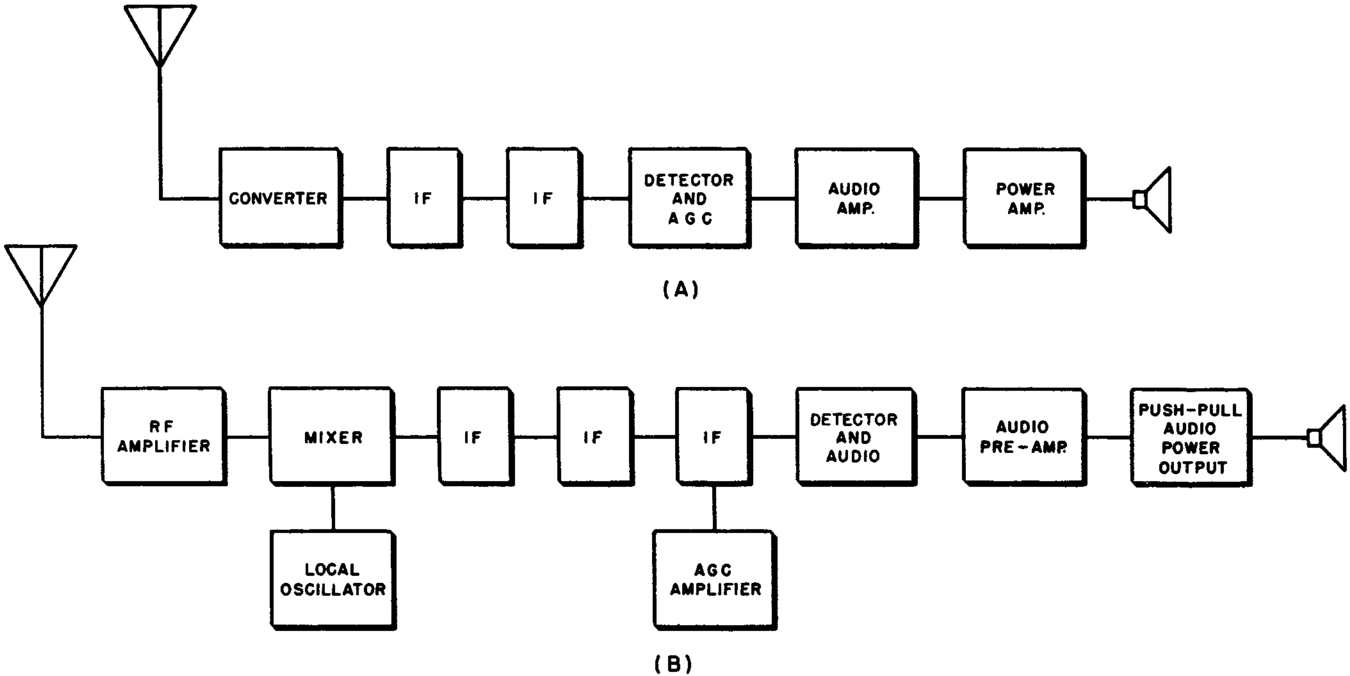

Fig. 902. *The portable or home radio (A) is not as elaborate as the auto radio (B).*

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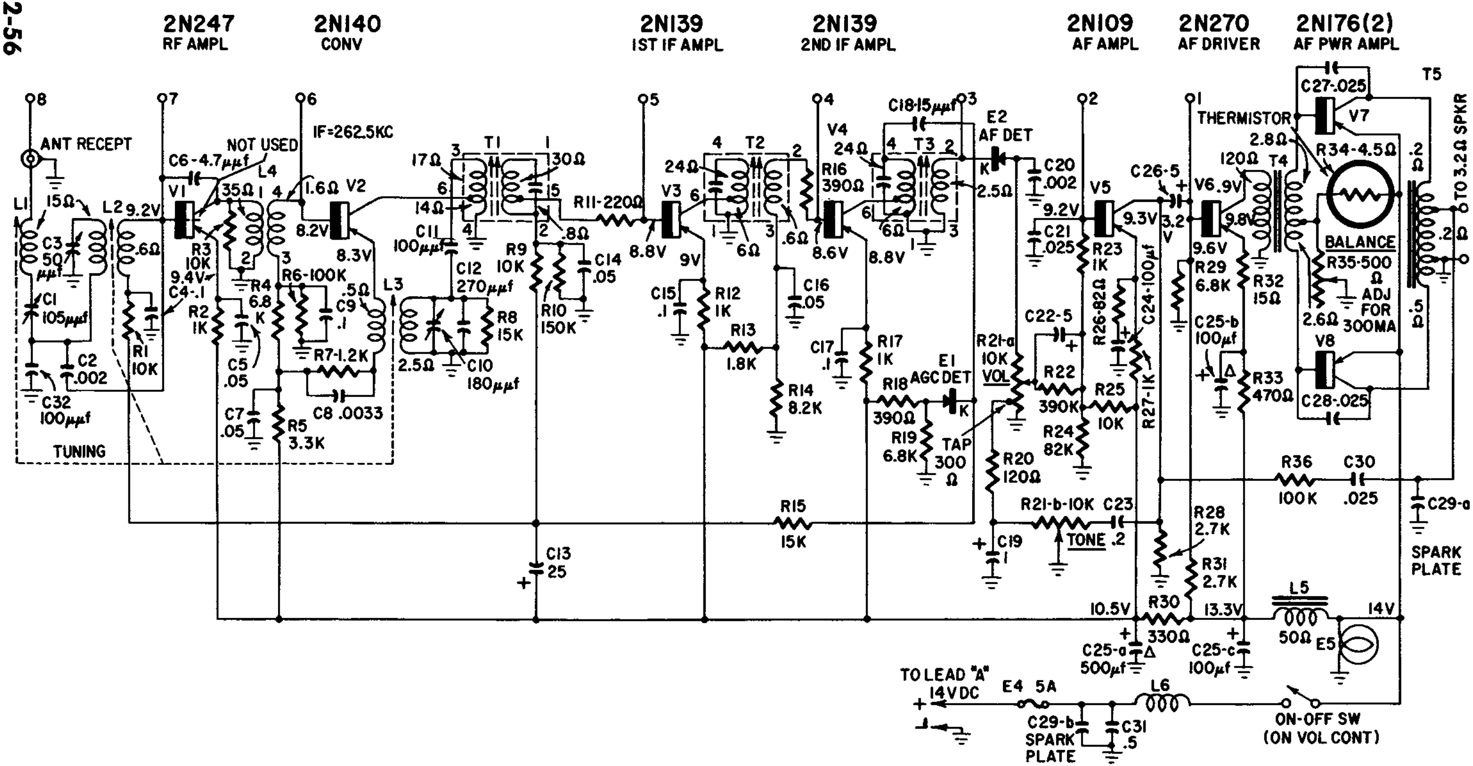

Fig. 903. *Auto radio using transistors only.*

Power consumption

Auto radios using transistors but no tubes do not put a heavy drain on the car battery. A typical transistor audio radio will draw a total of about 2 amperes compared to about 8 to 10 amperes for a tube type auto radio.

The front end

For best operation, it is important to get the maximum amount of signal into the first stage of the transistor auto receiver, the rf amplifier. Fig. 905 shows a typical front end.

This receiver is permeability-tuned. The rf amplifier, the mixer and the local oscillator are all tuned simultaneously. All of the iron-core slugs are moved in and out of their respective coils by a suitable mechanism. The emitter of the rf amplifier is connected into the agc bus through a resistor. The loading coil generally has a value of less than 20 μh, while the trimmer capacitor across the primary of the rf transformer generally has a range of 3 to 30 μμf.

The setting of the trimmer is simple. This is usually a screwdriver adjustment and can be made without removing the receiver from its cabinet.

A hole in the chassis is provided to allow the use of a small screwdriver. Set the dial of the receiver to approximately 1400 kc, tune in a very weak station and then adjust the trimmer until the volume is maximum. If you should happen to tune in a strong station, it will seem to you that the trimmer tunes broadly. This is a deception. The agc will operate to keep the signal strength constant. If, however, you select a weak station, the agc voltage will be such that the receiver will be working with maximum sensitivity and, as a result, you will be able to make a very fine adjustment with the trimmer capacitor. This trimmer compensates for the variations in capacitance of antennas (and their lead-ins) of different models and manufacturers.

The rf amplifier stage has tuned input and also tuned output. The stage, however, isn't transformer-coupled to the mixer in the circuit of Fig. 905. In this case, an R-C network is used to transfer the signal from the collector output of the rf amplifier. Sometimes, however, transformer coupling is used as shown in the drawing of Fig. 906. The agc bus in this instance is fed into the base of the rf amplifier. The output transformer in the collector circuit is tapped down to provide a better impedance match between the transformer and the collector.

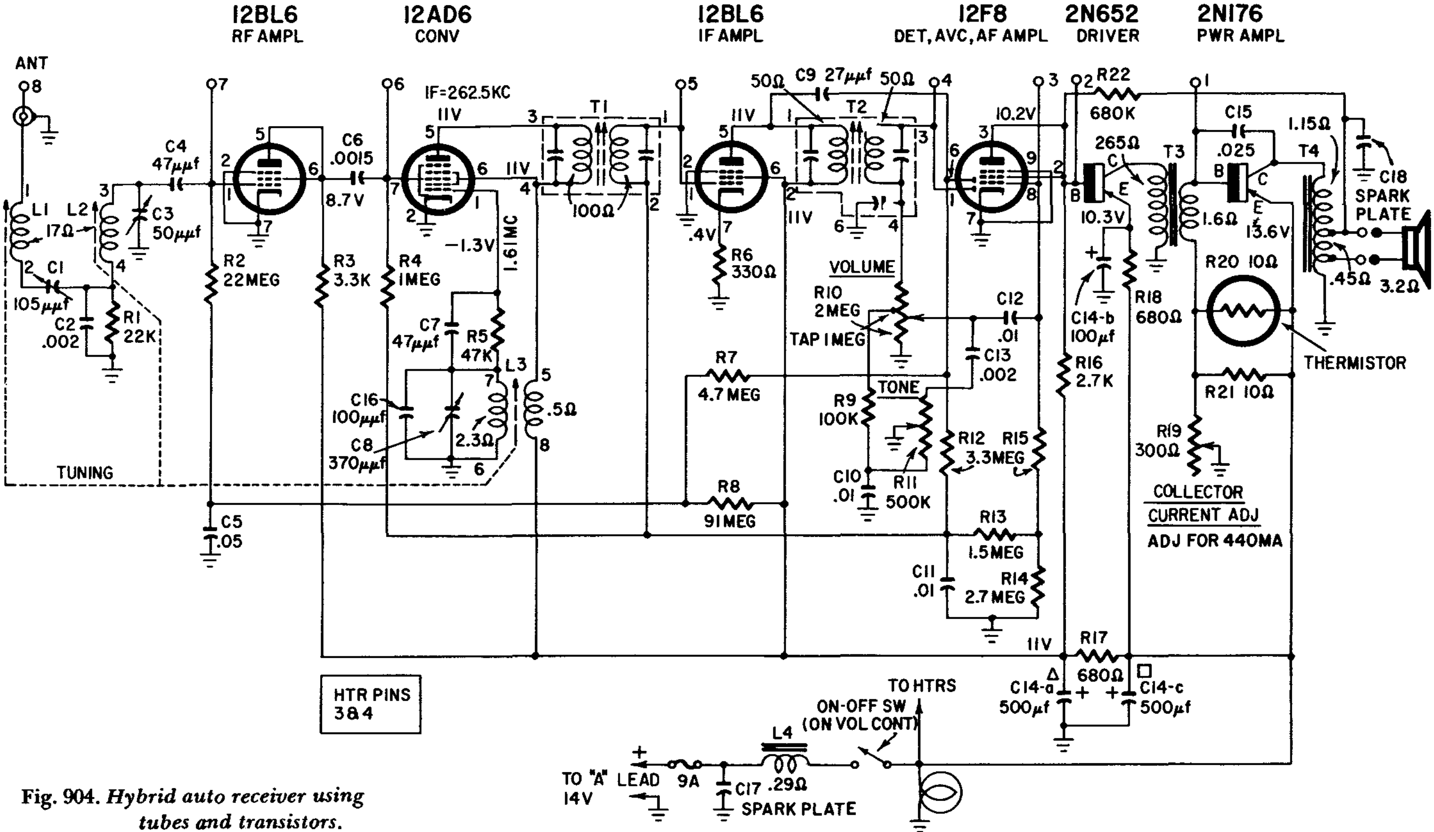

Fig. 904. *Hybrid auto receiver using tubes and transistors.*

The local oscillator

The local oscillator stage (Fig. 907) oscillates because of energy fed back from the output (collector) to the input (base). The

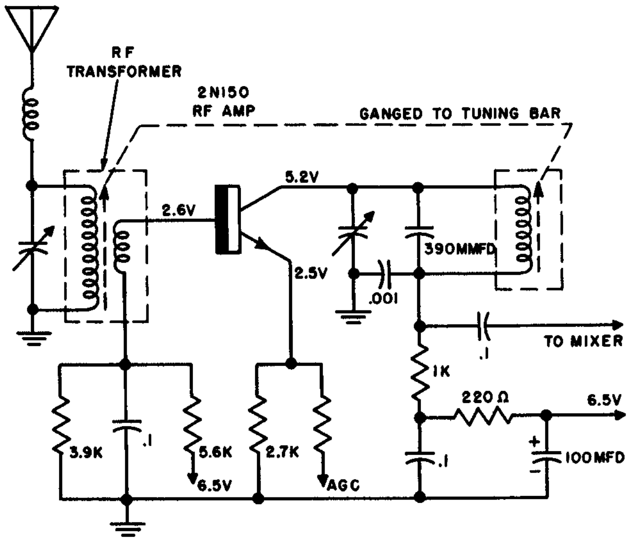

Fig. 905. *Typical auto radio rf amplifier stage.*

oscillator voltage is injected into the mixer circuit by capacitive coupling (C1). The output coil of the oscillator is shunted by two series capacitors, C2 and C3. These two capacitors form an impedance-dividing network, permitting impedance matching between the oscillator and the mixer. C1 is connected to the emitter of the mixer. The emitter is a low-impedance point, hence the lead going to the oscillator must also be attached to a low-impedance point. Using C2 and C3 as shown permits such a connection. An alternative technique would be to omit the capacitors and to tap down on the coil of the local-oscillator collector circuit.

The resistor in the emitter circuit of the local oscillator has a stabilizing effect on the collector current. The bias developed across the emitter resistor helps prevent collector-current runaway.

In auto radios the local oscillator usually operates at a frequency of 262.5 kc above that of the incoming rf signal. Note also that

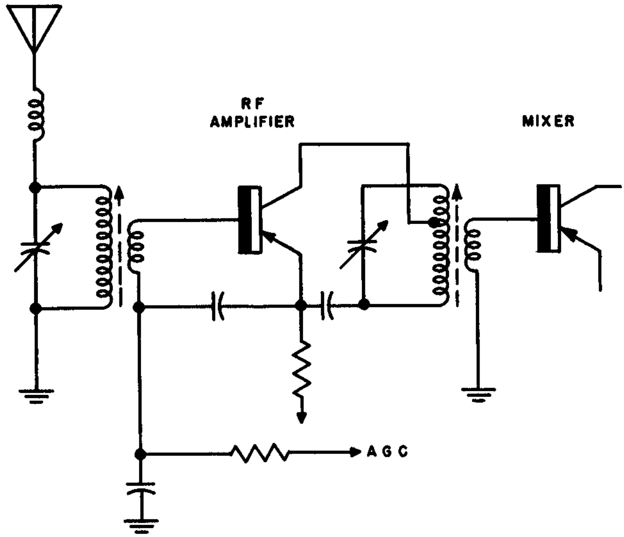

Fig. 906. *Rf amplifier stage transformer-coupled to the mixer circuit.*

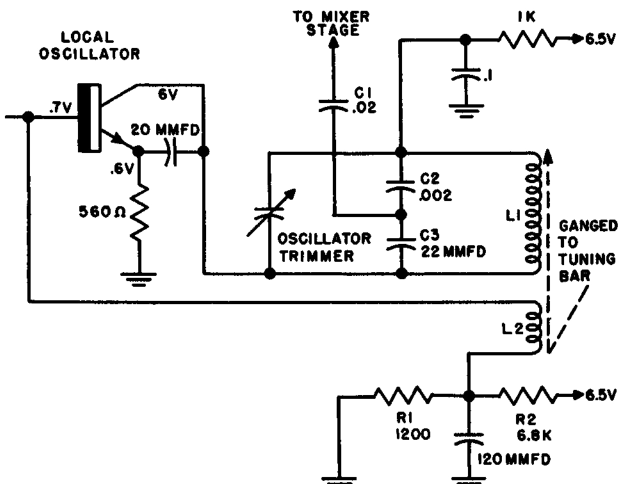

Fig. 907. *Local-oscillator stage.*

resistors R1 and R2 are connected in series and that the base is connected to the junction of these resistors through feedback coil L2. R1 and R2 are connected across the battery and act as a voltage divider to provide the proper forward biasing voltage

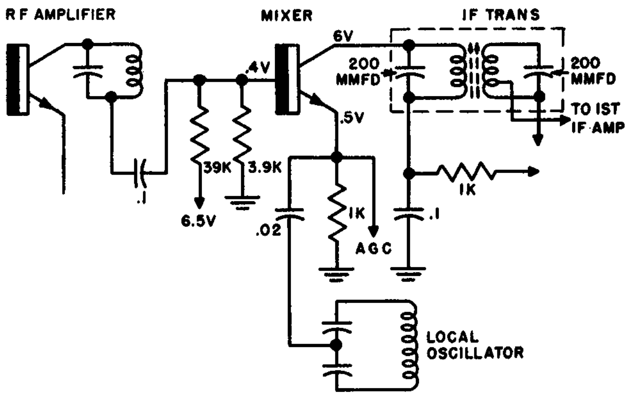

Fig. 908. *The triode mixer receives a number of dc and signal voltages.*

for the base. L2 is used only for feedback. The frequency of the oscillator is determined by the inductance of L1, the position of the tuning slug and the values of capacitors C2 and C3.

The mixer stage

The mixer is quite a busy circuit. It receives rf and local-oscillator voltages; it gets its own dc voltages from the power supply, and (in some sets) receives an agc voltage. A mixer circuit is shown in Fig. 908.

The function of the mixer is to heterodyne (or mix) the rf and local-oscillator signals. The output of the mixer contains four main frequencies, one of which is selected by the tuned circuitry of the following stage.

In Fig. 908, the rf signal is injected into the base of the mixer while the local-oscillator voltage is fed into the emitter. The transistor used in this circuit is an n-p-n type. The voltage on the emitter is higher than that on the base. Part of this voltage on the emitter is due to the voltage furnished by the local oscillator. If, for any reason, the local oscillator should stop working, the voltage on the emitter will decrease. If, in making voltage checks, you should find that the emitter voltage is less than that of the base, you can be fairly certain that the local oscillator has stopped working — especially if you get no signal output from the receiver.

A mixer circuit is often referred to as a first detector. Mixing takes place because the mixer transistor is made to act in a nonlinear manner. The mixer stage operates as a class-B unit, or very close to it.

As in the case of the local oscillator, the resistor in the emitter circuit produces a bias which opposes undue increases in collector current.

The if stages

As a general rule, you will find that auto radios have at least one more if stage than a portable or home transistor receiver, and certainly more than a vacuum-tube set. Auto radios use more if stages to supply additional gain and selectivity. Transistors do not have as much gain as the pentodes used in vacuum-tube if's, hence more circuits are needed.

A representative if stage is shown in Fig. 909. Because the base is a low-impedance point, it is connected to a tap on the secondary of the first if transformer. Compare this method of impedance matching with the capacitance impedance divider described in connection with the local oscillator. Another technique for impedance matching is shown in the construction of the second if transformer. The primary has more turns to match the impedance of the collector. The secondary has fewer turns to match the impedance of the base input of the following if stage.

R1 is part of the agc filter. R2 and C1 form a decoupling unit inserted between the collector of the first if stage and the battery.

The detector

As you can see in going through this chapter, circuits used in auto radios are quite similar to those we have examined previously in connection with portable and home receivers. The detector is no exception. The only difference is that in auto radios there is a tendency to use a transistor as the detector (instead of a diode), to take advantage of the gain supplied by the transistor. This isn't a fixed rule, however, and you may very well find auto radios with diode detectors and portable sets using transistors for this purpose.

A typical detector circuit using a transistor is shown in Fig. 910. This circuit has a few unique features that were not discussed when we studied detectors previously. For example, the last if transformer has three windings instead of the usual two. The primary couples the if signal into the secondary, connected to the detector. At the same time, the primary winding is also coupled to a coil which is connected to a separate agc rectifier.

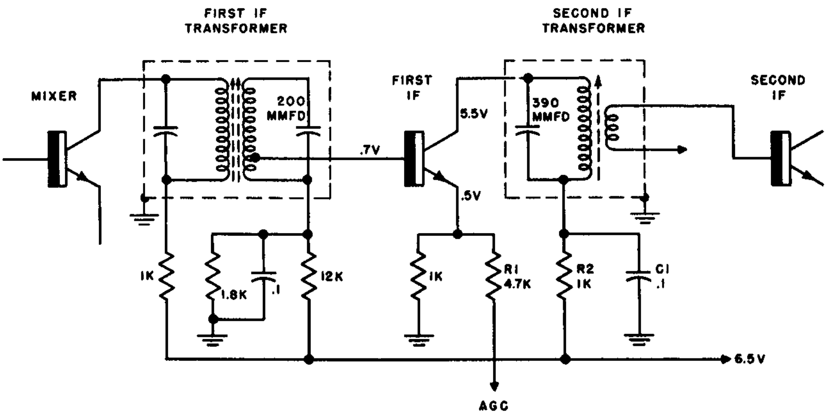

Fig. 909. *Typical if stage in an auto receiver.*

If you will examine Fig. 910 somewhat more closely, you will see that there is no bias voltage connected to the base (that is, between the base and the emitter). You will recall that the purpose of biasing a transistor was to put its operating point on the proper portion of the characteristic curve. The bias that is usually put on the base is forward bias — that is, the transistor is so biased that collector current flows. If we do not place this bias voltage on the base, collector current will be almost zero.

In other words, by not biasing the transistor we have reduced collector current to cutoff or almost to cutoff. But, as you know, this is class-B operation, which is exactly what we want in the case of a detector.

The base of the detector is connected to the secondary of the if transformer. When the incoming signal has the proper polarity, the detector transistor will conduct. Since the incoming signal is positive half of the time and negative during the other half, one half of the signal will have no effect. In the circuit shown in Fig. 910, only the positive portion of the if signal voltage will have any effect. For this reason, the transistor will act as a recti-

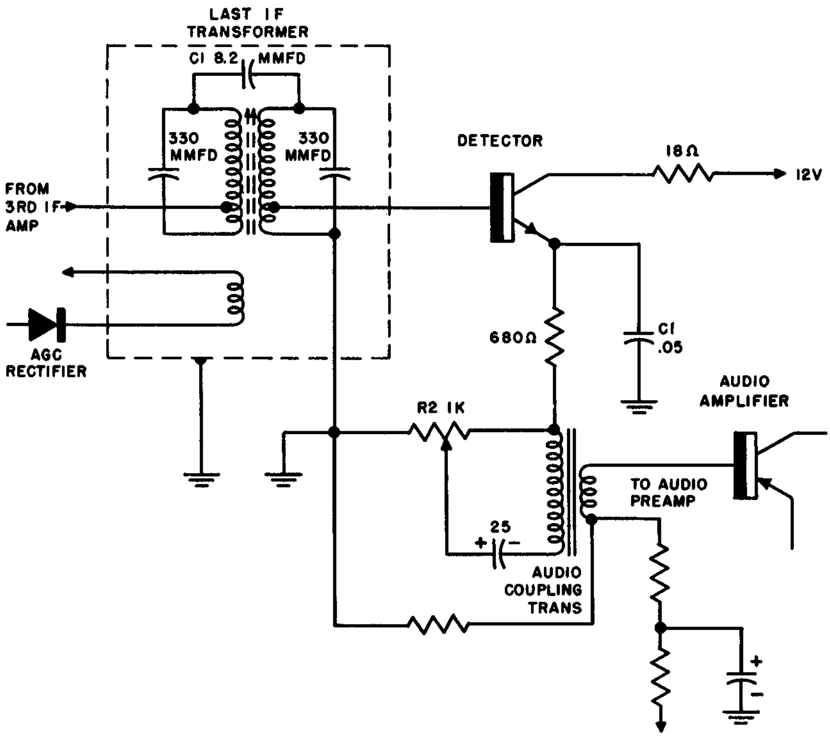

Fig. 910. *Transistor detector. Note the use of a separate agc rectifier.*

fier (or detector). Only the rectified portion of the if signal will appear in the output of the transistor detector.

The output of the detector is in the base-emitter circuit. Capacitor C1 acts as a bypass for it. The volume control, R2, is a 1,000-ohm potentiometer. The signal is coupled from the volume control through an electrolytic capacitor to the primary of the audio transformer. Sometimes the transformer is omitted, the detector being coupled to the audio amplifier through an R-C arrangement.

In Fig. 910 and earlier drawings, you will see that the if transformer is surrounded by a dashed line. This represents a shield can. (All components inside the dashed lines are inside the shield can.) The small capacitor, C1, connected between the primary and the secondary of the if transformer improves the bandpass of the unit. Most if transformers do not have this capacitor. When making a transformer replacement, make sure that the transformer has this capacitor if it was included in the original unit, as indicated on the schematic for the receiver.

Sometimes, as shown in Fig. 911, a crystal diode is put in series with the base input of the transistor detector. This unit is usually

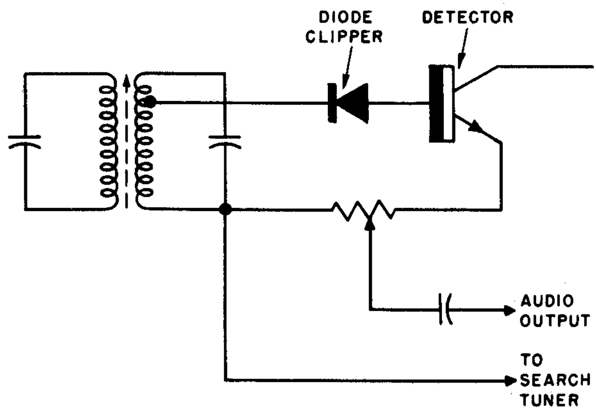

Fig. 911. *A diode is sometimes placed in series with the base of the detector transistor.*

included in auto receivers using search tuners (described later in this chapter). The diode acts as a clipper, helps prevent mis-tuning and supplies a certain amount of isolation.

Automatic gain control (agc)

You will find a variety of agc circuits used in auto radios. Some of these are quite simple, as shown in Fig. 912, and simply consist of one or more resistors and capacitors fed back from the collector output of the transistor detector. In this arrangement, the agc setup is almost the same as the type you will find in most vacuum-tube ac-dc radio sets.

A somewhat more complex arrangement is shown in Fig. 913. The if signal is coupled into the detector, as usual, through the secondary of the if transformer. However, there is another coil, coupled to the primary of the if transformer, and it is this coil which feeds the signal voltage to a crystal diode which acts as the agc rectifier. The rectified agc voltage is then fed into a transistor working as an agc amplifier.

The agc amplifier operates very much like a transistor detector circuit. Note that neither the base nor the emitter of this amplifier is connected to any source of dc voltage. This means that the transistor has no forward bias and so the collector current is extremely small. However, when the if transformer couples some

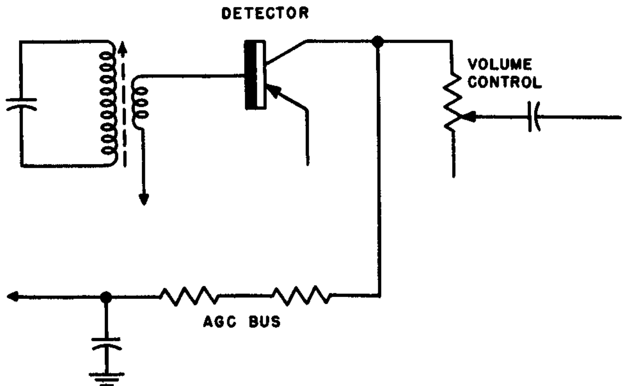

Fig. 912. *Simple agc system used in some auto radios.*

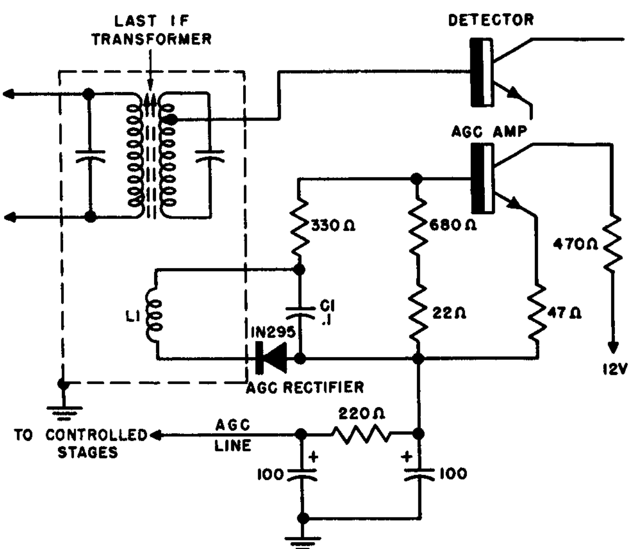

Fig. 913. *Some auto receivers use a separate crystal as the agc rectifier.*

signal voltage into coil L1, it will be rectified by the agc diode. The voltage produced by this action will be dc and will appear as a bias between the base and the emitter of the agc amplifier. The agc rectifier is placed into the circuit in such a way that the bias developed by the rectifier has the proper polarity. Capacitor C1

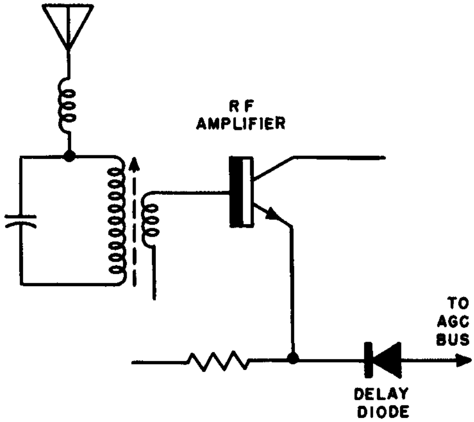

Fig. 914. *A crystal diode can be used to delay the application of agc voltage to the rf amplifier.*

is a filter unit, making certain that the output of the agc rectifier is smooth dc.

Agc delay

Sometimes a diode is used in series between the agc bus and the rf amplifier transistor. The gain of the rf amplifier is important since it is multiplied by the gain of all the following stages. In other words, the rf amplifier is much more sensitive to agc voltage and the results of the application of agc to this transistor are more drastic than those of the following stages. For this reason, it is advisable to delay or prevent the application of agc to the rf amplifier for weak signals but to permit it for strong signals.

A simple delay arrangement is shown in Fig. 914. It is just a diode connected between the agc bus and the emitter input of the rf amplifier. The diode acts as an open circuit or very high resistance until the agc voltage reaches a certain point, produced by a moderately strong signal. When the agc voltage becomes strong enough, the high resistance of the diode suddenly becomes very low, connecting the emitter of the rf amplifier into the agc line.

Audio amplifier (driver)

Practically all auto receivers use push-pull output. While it is true that portable transistor receivers also have push-pull output, many of the less expensive portables do not. The output of the detector stage in an auto radio, even though an amplifying transistor is used as the detector, is not enough to drive push-pull transistors. For this reason, auto radios insert an audio amplifier stage (known as a driver) between the detector and the push-pull power output circuit.

A typical audio driver circuit is shown in Fig. 915. Resistor R1, placed across the primary of the audio input transformer, helps maintain stability and prevents possible ringing or oscillation. It lowers the Q of the transformer and helps broaden its bandpass.

A feature of interest in the output transformer (this is really the interstage transformer for the following stage) is winding L1. This winding is inductively coupled to the output winding L2. Because of the coupling, a voltage is induced across L1. This voltage is injected into the emitter or input of the audio transistor.

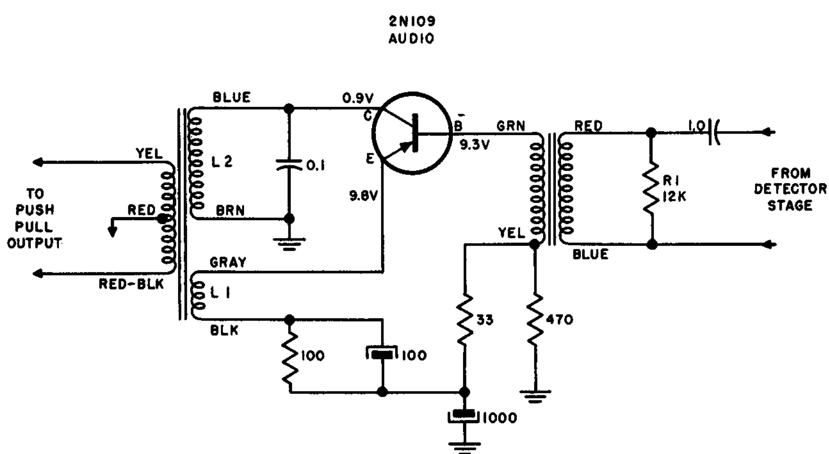

Fig. 915. *Audio driver circuit used in some auto radios.*

This fed-back voltage is degenerative, providing negative feedback and stabilizing the audio amplifier. The capacitor placed across L2 is a simple form of tone control. It bypasses higher

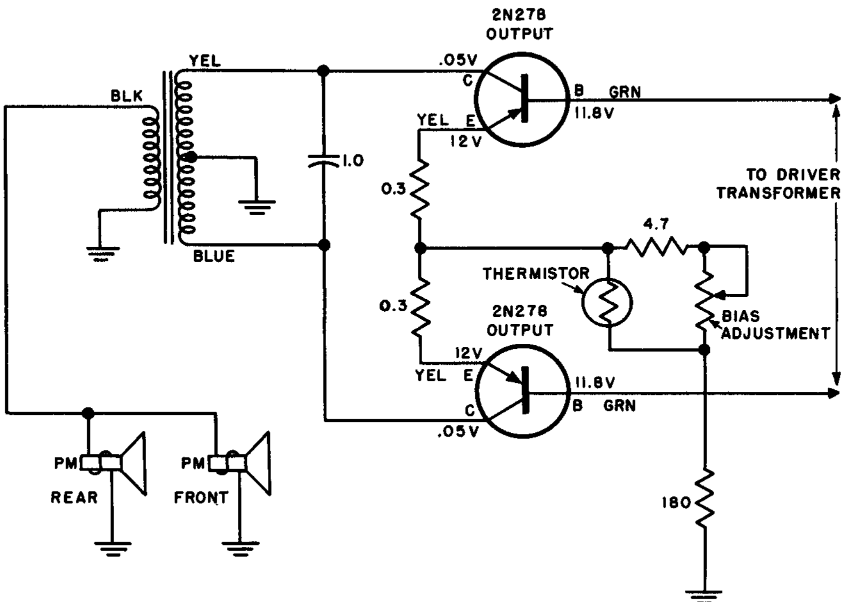

Fig. 916. *Push-pull power output circuit.*

frequencies, giving the output a low-audio-frequency emphasis that many persons find quite pleasant.

In the previous chapter, we discussed audio transformers used in home and portable receivers and mentioned that these had either four or five leads. In the case of an auto radio, however, we see that at least one of the transformers (the one between the audio driver and the push-pull output) can have seven leads.

Audio output stage

The audio output stage is similar to those we described for portable and home receivers (Fig. 916). There are a few differences, however. This stage uses a thermistor, described in an earlier chapter. The push-pull circuit operates two speakers, one for the front of the car while the other is a rear-seat speaker.

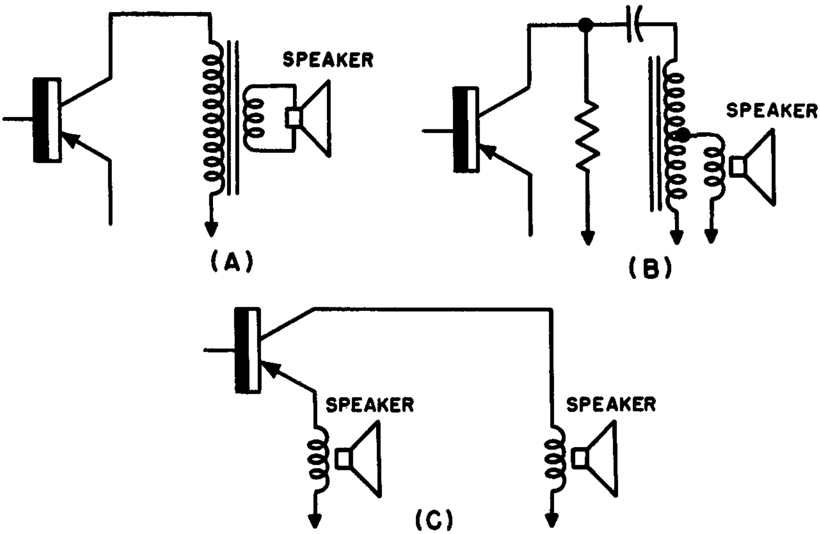

Fig. 917. *Three methods of coupling a speaker to the output stage. That shown in (A) is most common. (B) is rarely used while (C) is a possibility being explored for future sets.*

Idling current

The amount of current that a power output transistor will draw will depend upon its class of operation. If a transistor is operated in class A, its idling current (current in the absence of a driving signal) will be about ½ ampere. If a transistor auto radio has a single power output transistor, it will most probably be operated class-A. If two transistors are used in a push-pull circuit, the arrangement will undoubtedly be class-B. The idling current for a class-B stage will be less than 100 ma, with 50 ma as a common value.

Power output circuits in transistor auto receivers come equipped with a bias adjustment control (Fig. 916). When replacing a power transistor, vary this resistor until the power stage draws the amount of idling current recommended by the manufacturer.

Coupling arrangements

There are a number of ways in which a transistor can be connected to the voice coil of a speaker (Fig. 917). The most common technique is to use an output transformer. In some instances, however, a choke is used. This is impedance coupling. The speaker is connected to a tap on the choke for better impedance matching. Finally, the voice coil can be connected directly in the emitter or collector circuit.

Transistor power supply

Where an automobile radio uses transistors only or where the receiver makes use of 12-volt tubes in conjunction with transistors, the 12-volt battery serves directly as the power supply itself. However, in hybrid receivers, where tubes that are used require plate voltages in excess of 100, a dc-to-dc converter is needed.

The primary source of power can be either a 6- or 12-volt system. Chokes and capacitors are used in the power line to keep hash picked up by the 6- or 12-volt bus from getting into the set. The capacitors that are used generally have a large value — 15 μf or more. One or more pilot lights are generally shunted across the power line coming from the automobile battery. Immediately preceding the on-off switch, you will find a plate (spark plate). This operates as a filter capacitor in the dc bus.

The dc-to-dc converter

As we mentioned earlier, you will find the dc-to-dc converter only in hybrid auto radios in which ordinary tubes (those requiring plate voltages in the order of approximately 250) are used. Actually, the dc-to-dc converter behaves like a conventional vibrator power supply. However, it does not have any moving parts and so the noise and hash produced by a vibrator are conspicuously missing.

A representative dc-to-dc converter is shown in Fig. 918. Note that the circuit makes use of a pair of transistors. The arrangement in the primary is that of a blocking oscillator. The emitters of the transistors are tied together, and this common line is connected to the battery in the automobile. The return connection is made through the center tap of the primary of the transformer. Since each of the collectors of these two p-n-p units is tied to the negative side of the 12-volt supply, the transistors will conduct. The design is such that collector saturation current will be reached.

However, the transistors will not reach saturation current simultaneously. As long as collector current increases, the magnetic field around the primary of the power transformer will continue to grow and will induce a voltage. Each of the transistors will help induce a voltage across the secondary of the power transformer. At the same time, the magnetic fields caused by

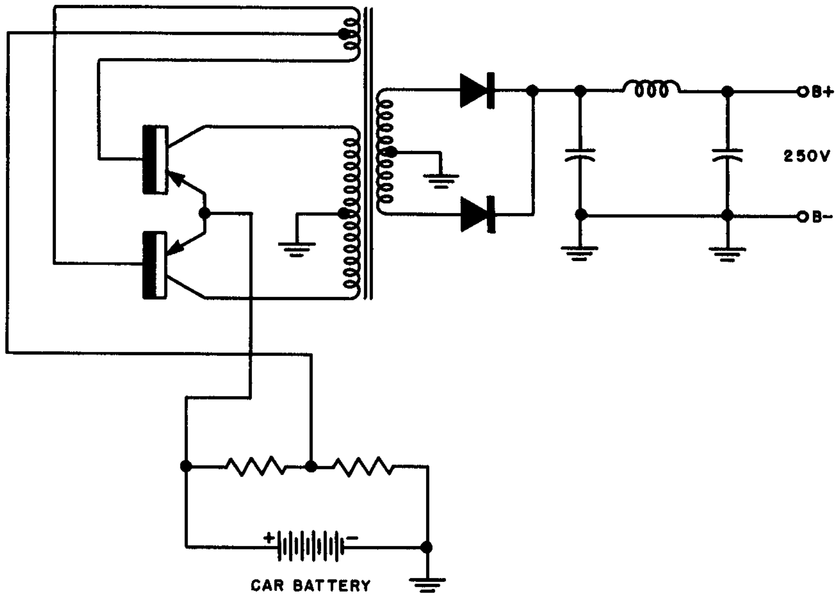

Fig. 918. *Dc-to-dc converter changes 12-volt dc input to 250-volt dc output. This arrangement is a substitute for a vibrator.*

collector current flowing in the primary will affect transistor operation. That is, the magnetic field initiated by the first transistor will determine the operation of the second transistor, and vice versa. Each transistor will run the range from cutoff to saturation.

For example, let us suppose that the upper transistor functions. It helps produce a magnetic field which induces a voltage across the lower half of the primary winding, but the lower half of the primary winding is connected to the collector of the lower transistor. This induced voltage opposes the negative voltage of the battery and, as a result, the lower transistor is cut off. However, when the upper transistor reaches its saturation level, its magnetic field reaches a steady-state value, and can no longer induce any voltage. This releases the lower transistor from cutoff and it begins to conduct. The lower transistor current induces a voltage into the upper winding, such as to drive the upper transistor into cutoff. Thus, each transistor conducts alternately. This, in turn, produces a magnetic field that will induce a voltage across the secondary. The secondary consists of a pair of rectifiers, connected as a full-wave rectifier unit.

The frequency of operation in the primary of this circuit is about 20 kc. Since we are using a full-wave rectifier, this operating frequency is doubled and so the ripple frequency is about 40 kc. As a consequence, filter components and filter chokes can be small and compact. For example, the filter capacitors may range anywhere from 0.5 to 1 μf, while the choke can be an air-wound coil having an inductance of about 100 millihenries. The voltage produced by this arrangement is about 250 volts dc, suitable for typical vacuum tubes. We can now see how the term dc-to-dc converter is obtained. The input is dc and so is the output.

Reducing automobile interference

There are two types of interference which can hinder the operation of the automobile radio. One of these comes from within the receiver itself and is due to a moving mechanical rectifier such as the vibrator. In the transistor auto radio, as we know now, this has been eliminated. The other source of interference comes from the engine of the auto.

Interference to an automobile radio can come from the generator and can be caused by a dirty commutator at the point where the segments make contact with the brushes, poor fitting brushes or brushes that are worn out. You can easily tell if you are getting trouble from the generator by listening to the radio while varying engine speed. The sound will come through as a whine, which varies in pitch as the speed of the car is changed. This trouble can be cured by replacing the brushes, by cleaning the commutator segments, by readjusting the brush holder or the position of the brushes, or (much easier) by putting a capacitor across the armature of the generator.

You will find several terminals on the generator. One of these terminals will be identified as the armature terminal. Connect one lead of the capacitor to this terminal. The capacitor should then be fastened directly to the generator so that it makes contact with its metal body. Special suppressor capacitors are manufactured for this purpose. If the generator already has such a capacitor, try replacing it to see if the condition can be cured.

In some cars (especially those of foreign make) no provision is made for a suppressor capacitor. In such instances, you may not be able to mount the suppressor on the generator. In this case, you will have to use some ingenuity. You may also have to run a ground lead from the capacitor to the frame of the car. When using the generator as a ground return, make sure that the ground terminal of the capacitor makes good contact. If there is any paint or oil slick or dirt near where the capacitor is to be mounted, scrape this away to make sure that the ground connection is a good one. If it isn't, you might just as well not mount the capacitor in the first place.

In severe conditions where the commutator segments are badly worn or you can do nothing with the brush holders or the brushes, it may be necessary to replace the generator. Sometimes, placing a choke in series with the lead coming from the armature terminal (terminal marked A on the generator) will help reduce generator whine. This choke has to be the same type that you used in the dc bus going to the receiver. These chokes are small, are usually heavily taped and wound with heavy wire on an iron core. Remember that the turns of wire on this coil must be heavy enough to carry the current.

Static

If the receiver operates well while the auto is in a standing position, but you hear a sound like rapid firing when the automobile is in motion, then what you are listening to is a constant buildup and discharge of voltage by the wheels. This can be cured in several ways. You can install static-collector springs. These can be mounted right on the axle locknut, thus making contact between the axle and the dust cap. Another technique that you may find somewhat easier is to inject graphite powder into the inner tube of the tire. You can buy a complete set of static eliminators consisting of powder and springs, available commercially.

A common method for eliminating ignition noise is to use a suppressor resistor connected between the distributor and the ignition coil. Place the suppressor resistor as closely as possible to the distributor. Suppressor resistors are made of carbon and generally have a value in the region of 10 kilohms. The use of a suppressor resistor will not affect engine performance. However, in some modern cars, the distributor is not easily accessible, so you may have some difficulty in using this technique.

Sometimes interference is picked up by the battery cable coming from the dash to the dc input at the receiver. In some autos, this lead is fairly long and, even though there are filter capacitors hanging from this line, and chokes in series with it, the spark pickup is enough to get past these guardians. In such cases, put this lead into metal conduit, turn the receiver on and

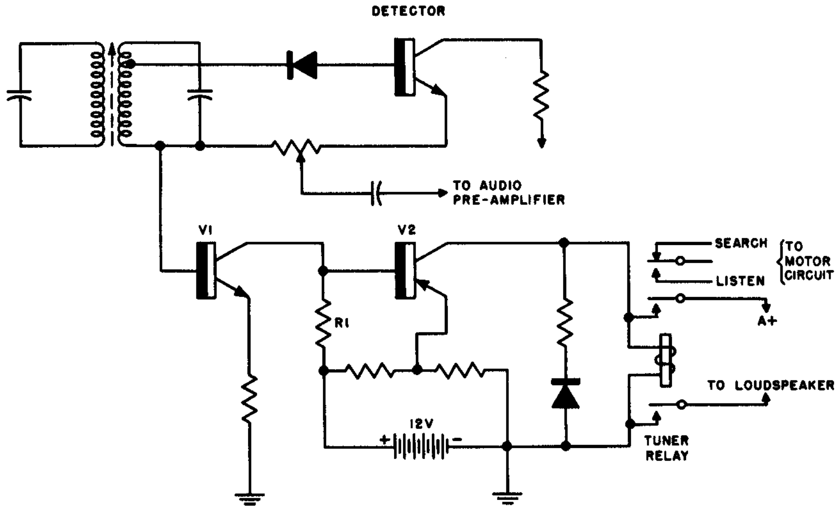

Fig. 919. *Automatic tuner or search system. The unit uses a pair of directly-coupled transistors.*

then, with a wire, probe the most logical point at which to ground the conduit. You will generally find that there is one point at which grounding the conduit will most effectively reduce spark interference. The conduit should not touch the metal frame of the car at any point other than the one at which you make the ground contact.

If the noise refuses to yield to any of these measures, it may be necessary to replace the spark plugs or to adjust the gap. However, the power of the engine is critically dependent upon the distance of separation of the two electrodes of the spark plug. So, unless you are a trained garage mechanic, you had best obtain the help of an expert. In any event, spark gaps must be adjusted with the help of suitable feeler gages.

Automatic tuners

The automatic tuner, also known as the search tuner, is not new. It has been used in conjunction with vacuum-tube type automobile radios. However, the search tuner, as shown in Fig. 919, can be completely transistorized. It consists essentially of two transistors and a relay. The relay controls the power to a motor, which operates the tuner in the receiver. The signal voltage for the search tuner comes from one end of a volume control. The first transistor, marked V1, is called a trigger amplifier. The trigger amplifier is so biased that, in the absence of the signal, it conducts continuously. However, when a signal is received, the polarity of the signal is such that it cuts down the forward bias of the trigger amplifier, thus stopping conduction in the transistor.

Since the trigger amplifier under these conditions no longer conducts, the voltage drop across the trigger-amplifier load resistor (R1) disappears and the voltage on the collector of the trigger becomes the same as that of the battery voltage (12 volts). This voltage is applied to the base of relay control transistor (V2), but, when the relay control transistor receives this voltage, it too is cut off and as a consequence current stops flowing through the tuner relay coil. The tuner relay de-energizes, and the relay armature moves to its open position. This shuts off the tuner motor, leaving the receiver tuned in to the maximum station signal.

By pressing a control (usually a foot button switch) the driver of the car can start the search device on its way to selecting the next station. The moment the audio signal across the volume control disappears, the trigger amplifier goes into conduction. A voltage drop appears across the trigger-amplifier load resistor, and this, in turn, takes the relay control out of cutoff. The relay control transistor will now draw collector current, and this collector current must pass through the tuner relay. When it does, the armature of the relay is closed and this, in turn, operates the motor rotating the tuner dial.

If the speaker were permitted to remain connected during this operation, the transition from one station to the next would be a very noisy process. For this reason, the speaker is automatically disconnected but is turned on again by the relay when the search tuner is operated by the audio signal.

There are other types of signal-seeking circuits, of course, but this one will give you an indication of their general operation.

chapter

10

alignment and measurements

MANY of the servicing techniques and certainly all of the test instruments you normally use in working with vacuum-tube receivers can also be employed for transistor radios. However, as we have mentioned earlier, you will have to revise some of your thinking since a transistor receiver does not mean that transistors have been substituted for tubes. You are now going to deal with very low voltages and so a small shift in voltage, unimportant in a vacuum-tube receiver, means the difference between working or not working for a transistor radio. Screwdriver mechanics will have to throw away that indispensable tool and learn to follow a few of the more regular servicing procedures. Fooling around with the underchassis section of a transistor receiver can be an expensive habit – resulting in the loss of expensive transistors.

The first thing to do with any radio receiver, whether it uses tubes or transistors or both, is to look at it. Sometimes, just an examination of the wiring or the printed-circuit board will reveal the difficulty. Do not take for granted, if a receiver stops playing, that a transistor must be defective or the battery must be dead. These are possibilities, but there is also the chance of a broken wire, a poor connection or a bit of conducting element on a printed-circuit board coming apart. (Troubles in printed-circuit boards are covered in the next chapter.)

Signal generator

Your signal generator should be capable of covering the broadcast band, the if of most home and portable receivers (455 kc), and the intermediate frequency of most automobile radios (262.5 kc). It should also be able to provide an audio voltage.

There are several ways of coupling the signal generator to the receiver for alignment or tests. You can put a small capacitor (generally 300 $\mu\mu f$ or less) (Fig. 1001) in series with the hot lead

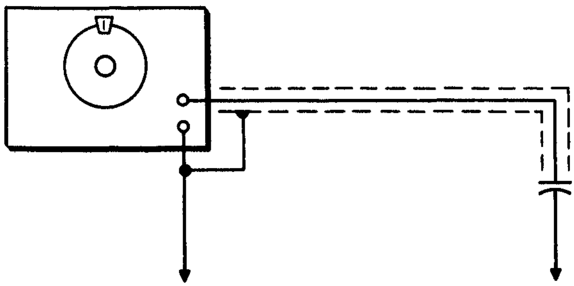

Fig. 1001. *The signal generator can be connected to the receiver input through a small coupling capacitor. Some service technicians simply clip the hot lead close to the loopstick, but no actual physical connection is made. Keep signal generator level as low as possible.*

of the generator cable or you can use a small loop of wire to act as a coupling coil. The loop can be about a dozen turns or more of insulated wire, either enameled or cotton-covered. This coil can then be brought close enough to the loopstick in the receiver to permit signal pickup. Keep the coupling between the signal generator and the receiver fairly loose, since we do not want the generator to overload the receiver (Fig. 1002). If this happens, either the receiver will be unstable or you will find that the overloading effect will detune the receiver. You will also learn that transistor receivers are not as sensitive as vacuum-tube sets.

Transistors, even more than vacuum tubes, are susceptible to hum fields. Since many generators used by service technicians are not too well shielded, there is generally a strong magnetic field surrounding the generator or leaking from it. A good common ground connection between the generator case and the receiver chassis is always helpful (Fig. 1003). A good practice is to run a heavy clip lead between a contact on the generator and a contact on the chassis being serviced. This is in addition to the usual ground connection which is part of the test leads.

Vacuum-tube voltmeter

Most vacuum-tube voltmeters have input impedances ranging from about 11 to 25 megohms. The instrument should have a

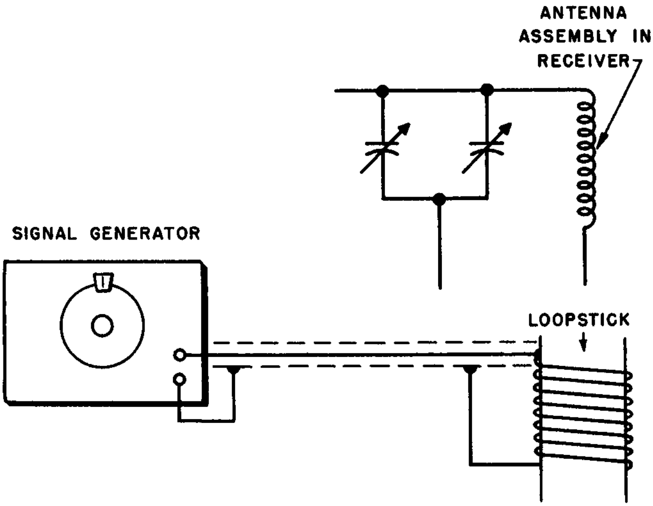

Fig. 1002. *You can use a home-made coil to couple the rf signal into the receiver. A spare loopstick will do the job very nicely.*

low voltage scale and it is preferable that it have a scale reading 1 volt on full-scale deflection.

You will probably have an isolation probe (also known as a dc probe) as part of your vtvm.

The probe (Fig. 1004) consists of a 1-megohm resistor placed inside a probe housing. The probe resistance is counted as part of the input resistance of the vtvm. Thus, if your instrument is rated at 11 megohms, 10 megohms is part of the instrument itself and 1 megohm is in the probe. Use the probe when making dc voltage measurements if you want to get maximum isolation between the receiver and the instrument. Also, the meter has been calibrated for use with the probe. Thus, if the probe isn't used, your readings will be incorrect.

Dc voltage measurements in transistor receivers are quite low. However, you must still be careful. For example, when measuring between base and emitter, you will be checking just a fraction of a volt and will probably be using the 1-volt scale of the instrument. If you then decide to make a battery test (assuming a 9-volt supply) and do not change the range selector on the vtvm, you can easily damage the needle of the meter (Fig. 1005).

Range scales will vary, depending on the instrument. Some have 1-, 10- and 100-volt scales; others have 3-, 30- and 300-volt scales.

These two instruments, the signal generator and the vtvm,

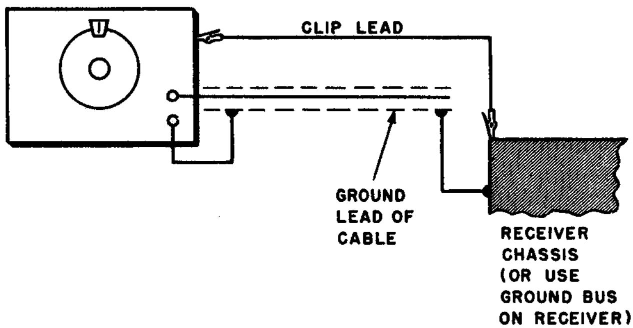

Fig. 1003. *Make sure that the receiver and signal generator are common — that is, the chassis or metal frame of the generator is connected to the receiver chassis. Use a wire with alligator clips at both ends. Connect one end to any metal screw on the generator, other end to ground bus of receiver. It is advisable that the generator have a transformer type power supply.*

are fundamental instruments in any service shop and are practically indispensable. There are other instruments which are desirable because they are servicing time-savers. These would include the oscilloscope, a signal tracer, substitution boxes (capacitor and resistor types) and a substitute speaker.

There is one piece of test apparatus that will be very helpful for transistor radios and which is not ordinarily used for vacuum-tube receivers. This is a 12-volt storage battery. The reason for requiring this is fairly obvious. If you are going to service automobile receivers, you will find that some auto radios are hybrid types, using 12-volt tubes (that is, approximately 12 volts on the plate) and using a power transistor for the output stage. These receivers are designed to work from a 12-volt storage battery.

A good servicing technique is to bring leads from the storage battery up to a panel on your servicing bench so that you can tap off either 12 volts or fractions of it. Remember, however, that storage batteries can give off corrosive fumes, so the place for the storage battery is not as a foot rest under your bench. The best way to make sure that the battery will have long life is to put a trickle charger across it and to take regular specific gravity readings with a hydrometer. A voltage check of a storage battery (except under a heavy load) is practically useless. Even a dead storage battery will show a voltage reading with a high-impedance voltmeter. This is a snare and a delusion, and means absolutely nothing.

Some technicians prefer using low-voltage power supplies in place of the storage battery. This is fine, except that most of these low-voltage supplies cost as much as, if not more than, the storage battery and some do not supply enough current to operate receivers using power transistors (auto receivers).

There are a few other considerations you should remember. If you have been accustomed to servicing tube sets, you know that certain voltages are critical, others are less so. A difference in plate voltage of, say, 15 or 20 volts will not generally affect the operation of the set by much. But in a transistor receiver voltages

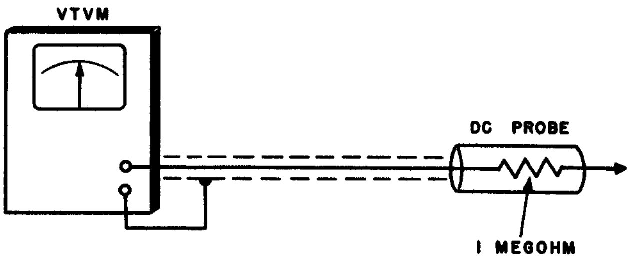

Fig. 1004. *The dc probe contains a 1-megohm resistor. This is part of the input resistance of the instrument.*

are low, hence a very small change in voltage might mean a large percentage difference. If a receiver needs 9 volts to operate, a 30% drop would be 2.7 volts. Subtracting this from 9 volts gives us 6.3 volts. This would be about the limit you could go and expect the set to work. This means that you should not only have a voltmeter shunted across the output of the low-voltage supply, but the meter should have an easy-to-read scale so that you can see what you are really getting.

If you do decide that you would prefer using a low-voltage supply instead of a battery, keep a few precautions in mind. Make sure that the supply is adequately filtered. It is important that the output of the supply be as nearly pure dc as possible. Also, do not use a transformerless supply. Get a transformer type so that you have adequate isolation from the power line. And don't

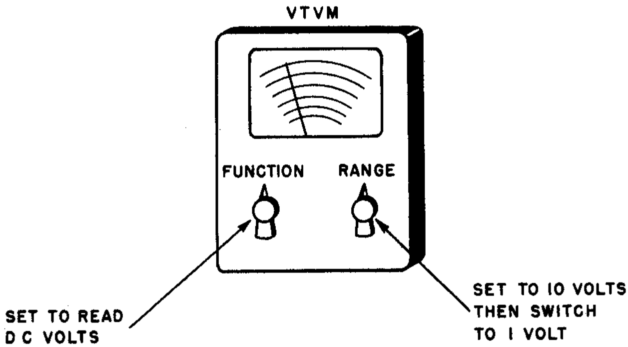

Fig. 1005. *When measuring dc volts, first set your function selector to the proper position. Put your range selector so that the meter will read 10 volts full-scale deflection. Then switch to the lower range if necessary. Always keep the range selector set at the higher range so that you will not accidentally damage the meter needle.*

take for granted that the electrolytic filters in such supplies will remain good forever. Every now and then, connect the output of the supply to the input of your scope and note if the ripple voltage is normal or if it has increased since you made your last test.

Now let us go back to the storage battery for just a moment. As the battery is used or as it gets older, its internal resistance increases. This internal resistance (or impedance) can affect your tests. For example, the impedance of the battery can act as a common element between stages. This common element is a sort of coupling unit, causing an undesired transfer of signal voltage between receiver stages. Generally, this trouble does not exist with a good, freshly charged battery.

You can avoid this difficulty by shunting the battery with a low-voltage, high-capacitance unit as shown in Fig. 1006. The capacitor should be about 2,000 μf and have a working rating of at least 12 volts dc. The plus side of the capacitor is connected to the plus terminal of the battery. You do not have to disconnect this capacitor when charging the battery. However, you must be sure that the peak ripple voltage of the charger does not exceed the working voltage rating of the capacitor.

When a receiver uses carbon penlight cells or mercury cells,

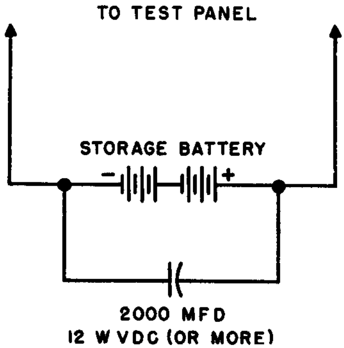

Fig. 1006. *A high value of capacitance shunted across the test storage battery keeps the overall impedance low.*

discard them when they have served their purpose. Attempts have been made to recharge such cells, but they have not been very successful. A few receivers do use rechargeable batteries of the nickel-cadmium type. Such sets come equipped with a charging unit as shown in Fig. 1007. These have a rating of 2.5 to 3 volts. If the batteries show a drop in voltage when checked under load, all you need to do is to plug the charging unit into the ac power line. The charger shown in Fig. 1007 uses a germanium rectifier. The unit is a half-wave rectifier and uses a single resistor to lower the voltage and limit initial charging current surges.

Alignment

When aligning a receiver, you need some sort of output indicator to let you know just how alignment is progressing. With a transistor receiver, you can use one of five types of indicator, two of which are generally provided by the receiver itself (Fig. 1008). You can use a speaker or you can plug in a pair of earphones in a jack generally provided on the set or you can connect an output meter, scope or ac vtvm across the voice-coil leads. A plug with the load resistor connected can be inserted in the phone jack.

Of these indicators, the speaker is the least sensitive. The meter or scope are best; sensitive, responding to small signal changes, and quiet. Earphones are also sensitive and relieve you of the necessity of keeping one eye on the meter and the other on the receiver, sometimes a difficult bit of eye acrobatics.

Most receivers of the transistor type permit alignment without removing the receiver from the cabinet. You will generally find that the receiver has a case which opens out, making the various trimmers readily accessible.

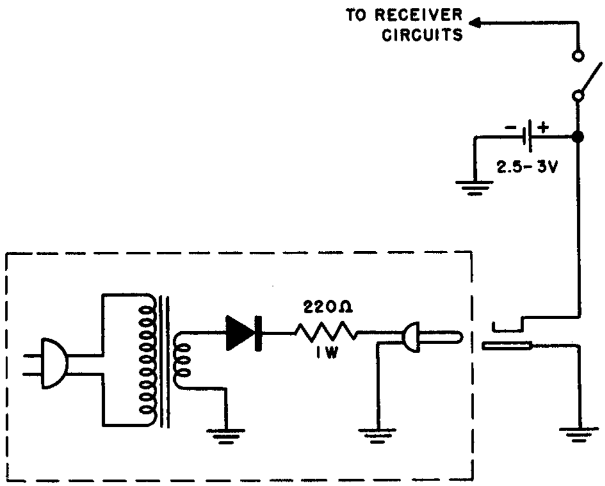

Fig. 1007. *Charging unit is used in receivers having nickel-cadmium batteries.*

Fig. 1009 shows the location of the if transformers, oscillator transformer, oscillator and antenna trimmers in a typical receiver. Couple the signal generator to the receiver, making certain that the frequency of the receiver and that of the signal generator are the same. Set the receiver volume control to maximum. The signal generator modulation control should be turned on — that is, the rf signal coming out of the signal generator should be modulated by the audio tone. If you use an output meter across the voice coil of the receiver, adjust the attenuator of the signal generator so that the output, as indicated on the meter, is approximately 1 volt. If you are using the speaker or headphones as an indicator, adjust the attenuator for a comfortable (not too loud) tone.

If the tone coming from the speaker is very weak or if the meter reading is very low, even though you may have set the attenuator on the signal generator for maximum output, then it is entirely possible that the if section of the receiver needs realignment. (We are assuming, of course, that there is no receiver defect.)

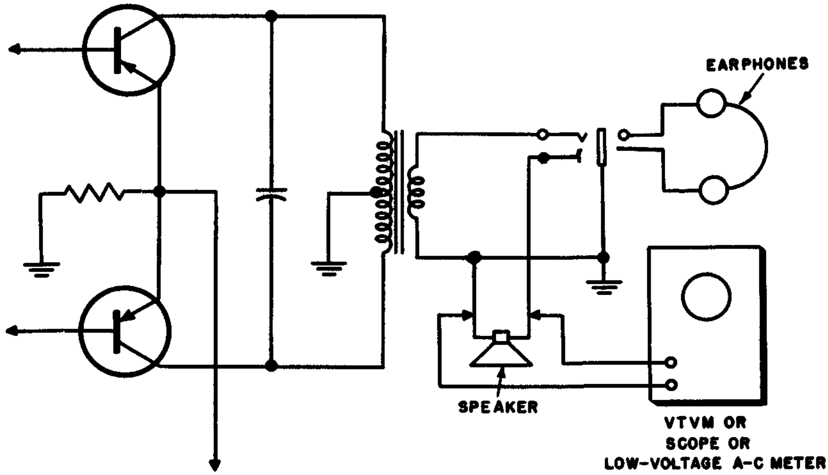

Fig. 1008. *Five types of indicators that can be used during alignment: speaker, earphones, vtvm, scope or low-voltage ac meter.*

Set the signal generator to 455 kilocycles, modulation turned on. Rotate the tuning dial of the receiver to the high-frequency end. Starting at the output if transformer, adjust the slugs and, in turn, the interstage and input if transformers, similarly. As the volume increases, adjust the attenuator to bring the volume down to a low level. Do not work with a strong output signal. The lower the signal used out of the signal generator, the better, since under these conditions, agc will either be very weak or completely absent, thus permitting the receiver to be in its most sensitive condition. When aligning the receiver, it is always best to use the batteries in the receiver as the power supply. That is, you should not use external batteries that do not form part of the receiver proper.

After the if's have been aligned, it is always well to repeat the procedure, since the adjustment of one if stage will often affect

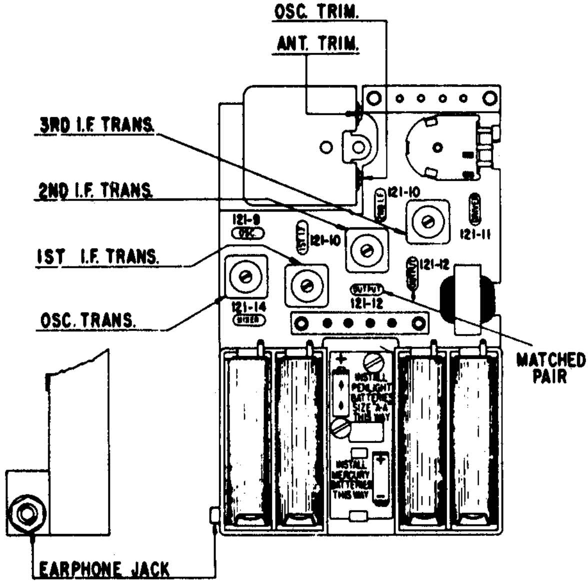

Fig. 1009. *Layout of alignment adjustments in a typical receiver.*

the adjustment of the preceding or adjacent stage. After the if section has been aligned, the only change you will need to make will be in the frequency setting of the signal generator and the receiver. The coupling loop or coupling capacitor from the generator to the receiver need not be disturbed.

If you find that the alignment of the if section has produced a condition in which the signal is extremely loud, simply make the coupling between the generator and the receiver much looser. Just move the coupling coil away from the antenna loop of the receiver. Now set the signal generator at approximately 600 kc. Set the receiver to the same frequency. The local oscillator of the receiver will probably have a slug adjustment and this should be rotated for maximum volume while rocking the tuning capacitor back and forth around this frequency, simultaneously. After you have obtained maximum volume, set the signal generator and the receiver to the high-frequency end of the dial, generally around 1500 kc. Locate the oscillator trimmer capacitor and adjust this for maximum volume.

It is generally best to repeat this procedure at least two times, working back and forth between the low- and high-frequency ends of the tuning scale to get best tracking.

Set the receiver and the signal generator to 1,000 kc and make sure that the signal from the generator is very weak, either by adjusting the attenuator on the generator or by making the coupling very loose. Locate the small trimmer capacitor, connected in series with the antenna lead; that is, between the antenna and the primary of the rf input transformer. Adjust this little capacitor until you get maximum signal output from the receiver.

Now that we have completed our discussion of alignment, let's consider it once again, but this time in a step-by-step fashion.

1. Loosely couple the signal generator to the receiver loopstick. You can use a home-made coupling coil for this (as described in an earlier chapter) or a spare loopstick as the coupling coil. If you prefer, you can use a 0.1-μf capacitor in series with the hot lead of the generator cable. Connect the capacitor to the stator of the tuning capacitor (rf section). The ground lead of the cable should go to the receiver chassis. Set your rf signal generator to the if frequency of the receiver (this will be either 262.5 or 455 kc in most cases). Rotate the tuning capacitor until it is completely unmeshed (open). Connect your vtvm (set to read 1 volt ac full-scale deflection) across the voice coil of the speaker. Do not disconnect the speaker leads. Set the volume control of the receiver to its midrange position.

2. Turn the receiver on. Set the modulation control of your signal generator to the ON position. Set the attenuator control on the signal generator for small signal output. Carefully and slowly rock the signal generator dial back and forth. You should hear a tone out of the speaker, and the meter needle of your vtvm should give you some indication. If the signal is too loud, reduce the strength of the signal generator. Rotate the signal generator attenuator for less output. Also move the coupling coil farther from the receiver. Now turn the volume control of the receiver to maximum.

3. At this time, examine your signal generator tuning dial and make sure that you have the pointer set exactly on the intermediate frequency of the receiver. Do this even though the receiver output sounds much louder at some other frequency.

4. Starting with the last if transformer (the one feeding the detector), adjust the slugs or trimmers for maximum signal out-

put. Then adjust the second if transformer and finally the first if transformer. After you have completed this job, go back and adjust the if transformers once again (and in the same order) until you cannot possibly improve or increase the output. (If your vtvm reads more than about 0.5 volt, your generator output is too high. Fig. 1010.)

5. Note that we have not asked you to disable the agc bus, a procedure quite common in the alignment of vacuum tube

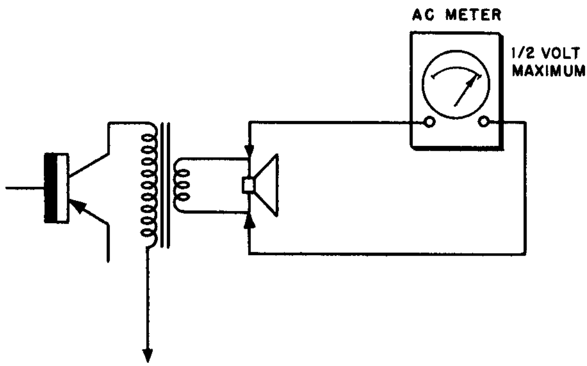

Fig. 1010. *The maximum voltage indicated by your output meter should be about 0.5 volt. If it is more than this, your generator output is too high or one of the stages in the receiver (such as an if) is oscillating.*

receivers. For this reason, it is necessary for you to keep the signal generator output very low. If you do not, you may find that the if's tune very broadly and you will have trouble finding the peak point.

6. In aligning the if's, note that some transformers will give you a double peak. This means that, as you turn the adjustment screw or slug, your output meter will reach a peak, dip and then reach a second peak. The higher of the two peaks is the correct one (Fig. 1011).

7. Set the receiver dial to a high-frequency point such as 1500 kc. Set the signal generator to this frequency, with the modulation turned on. The vtvm should remain connected across the voice coil. Use minimum generator signal and keep the volume control of the receiver at maximum. Now adjust the oscillator trimmer until you get maximum output as shown on the vtvm.

8. Set the receiver and the signal generator to 1000 kc and adjust the antenna trimmer until you get maximum output on the vtvm. Remember, the volume control is at maximum and signal generator output as low as you can use.

9. Set the receiver and the signal generator to 600 kc. Adjust the oscillator slug for maximum signal output as shown on the vtvm. Rock the variable capacitor in the receiver back and forth on each side of 600 kc while you adjust the oscillator tuning slug for maximum output.

10. Set the receiver and signal generator to 1500 kc, just as described in step 7. Carefully adjust the oscillator trimmer. If you cannot possibly increase the output (as indicated by the vtvm) at this time, you can consider the receiver aligned. If, however,

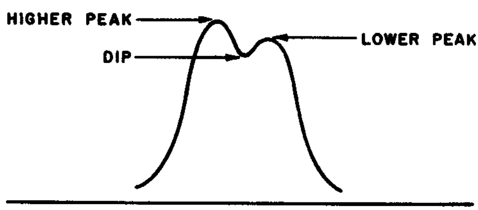

Fig. 1011. *If the if response curve has two peaks, tune for the higher of the two.*

an adjustment of the oscillator trimmer does increase the output, you should repeat steps 7, 8, 9 and 10. You may have to repeat this procedure a number of times.

You may sometimes experience trouble with alignment if you need to replace the converter transistor. In some cases, the receiver will not operate at the low end of the band. This is due to the fact that the transistor has changed the inductance of the loopstick in the receiver to such an extent that the tuned circuit no longer covers the broadcast band. If this does happen, there are a number of cures at your disposal.

You can try a number of different converter transistors until you find one that more nearly duplicates the characteristics of the original unit. If the loopstick has an adjustable iron core, turn the core so that less of it is in the form — that is, move it out of or away from the coil. As a general rule, the inductance of the coil will need to be reduced, and pulling the iron core out will do this. After you make such an adjustment, be sure that the receiver covers the entire band by tuning the dial to stations at the bottom and top end.

If the loopstick is the type that has a fixed core, your only choice is to remove turns until the stations at the bottom end (low-frequency end) of the broadcast band fall into place.

You will note that we have actually given you two sets of alignment instructions. Our step-by-step procedure does not fully agree with our earlier explanation of alignment. You will also find differences in manufacturers' alignment instructions. In all instances, however, it is best to follow the manufacturer's specific procedure. What we have given you here are general instructions. The step-by-step procedure can be used since it is fairly well detailed.

In or out of the set?

Transistor receivers are so constructed that they can be aligned without taking the receiver out of its cabinet. Do not remove the set from the cabinet unless, for some reason, you have no choice. There are two very good reasons for this: (1) You may be making unnecessary extra work for yourself and (2) you may very well find that a receiver aligned outside of its cabinet does not behave as though it's aligned once it has been put back in again.

Sometimes, to get at trimmer adjustments you will need a special tool. For example, you may find that even your smallest screwdriver isn't tiny enough to permit you to get at the oscillator and antenna trimmers. A tiny bit of metal bent at a right angle will do the job for you. Another easy method is to use a paper clip. Pull out one end of the clip so that it makes a 90° angle with the rest of the clip. Put this end in a vise and squeeze it flat. Then use the flattened end of the paper clip as a tool for the adjustment of the trimmers, as shown in Fig. 1012.

Servicing precautions

There are a few precautions which you must follow in servicing or aligning transistor receivers. Do not use test instruments which are ac-dc types or which are transformerless. If you do have such test instruments and use them in conjunction with an isolation transformer, make sure that the isolation transformer is at some distance beneath your bench or away from it. (We are referring to isolation transformers connected in the primary between the instrument and the power line).

Be very careful not to ground the base lead of any transistor, since this invariably results in collector-current runaway and a burned-out transistor.

Remember that leakage current from signal generators, defective soldering irons, isolation transformers, soldering guns or test instruments which are poorly shielded can cause excessive currents to flow in transistors.

When using your signal generator, always make sure that your attenuator control is so set that minimum signal comes out of the generator. If you don't wish to be bothered using the series capacitor or loop that we mentioned earlier, then just clip the hot lead (that is, the alligator clip) to any nearby component and you will get enough leakage signal moving into the antenna loop

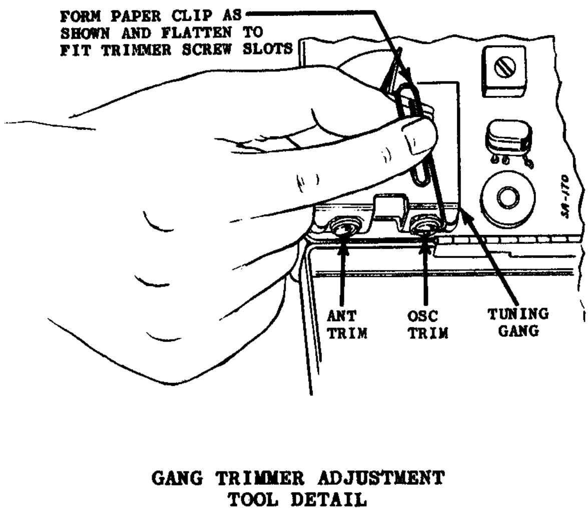

Fig. 1012. *A paper clip can be used for adjustment of the trimmer.*

of the receiver. Never clip onto any metal component. Attach the alligator clip to any bit of insulating material. This technique will keep the signal generator voltage from overloading or swamping the receiver input.

Make a voltage check of the battery before and after alignment, with and without signal input. Proper alignment may not be possible if battery voltage has dropped much more than 25% to 30% below normal.

Measurement of local-oscillator voltage

In vacuum-tube receivers, local-oscillator voltage can be measured by connecting a vtvm across the oscillator grid leak. This cannot be done in a transistor receiver. You can make the check by using an oscilloscope connected between the base of the converter transistor and the chassis. A calibrated scope will be required. The voltage measured will be determined by the type of transistor, the circuit arrangement and the setting of the oscillator tuning capacitor or slug. As a general rule, where the dial of the receiver is set to 1500 kc, you should read approximately 0.5 volt peak to peak. This technique for checking the local oscillator is just one of several we have covered.

Regeneration

The process of alignment increases the sensitivity of the receiver. It is entirely possible for the if stages to break into oscillation after alignment has been completed. If such is the case, a small amount of misalignment may cure the trouble. If not, it may be necessary for you to check any feedback resistors or capacitors that may be present in the receiver.

Transistor pin sequence

Transistors come in quite a variety of packages (this is the name for the case around the body of the transistor). Here are a few techniques for identifying the pins of a transistor, depending upon the type and the manufacturer. One type, shown in Fig. 1013-A, has what is known as an unsymmetrical pin arrangement. The center pin is the base lead. The pin that is closer to the center pin is the emitter. The remaining pin is the collector lead. Another view of an unsymmetrical pin arrangement is shown in Fig. 1013-B. The socket for this transistor is shown in Fig. 1013-C.

Another make of transistor has evenly spaced leads, as shown in Fig. 1013-D. A red dot is placed on the side of the case. The lead nearest to the dot is the collector. The center lead is the base, and the remaining pin is the emitter.

A typical power transistor arrangement is shown in Fig. 1013-E. The shell of the transistor is the collector connection. Hold the transistor so that the pins face you. When you do so, the emitter pin will be the one to the left and the base pin will be the one to the right.

A number of commonly used transistors are shown in Fig. 1014. A few power transistors are shown in Fig. 1015.

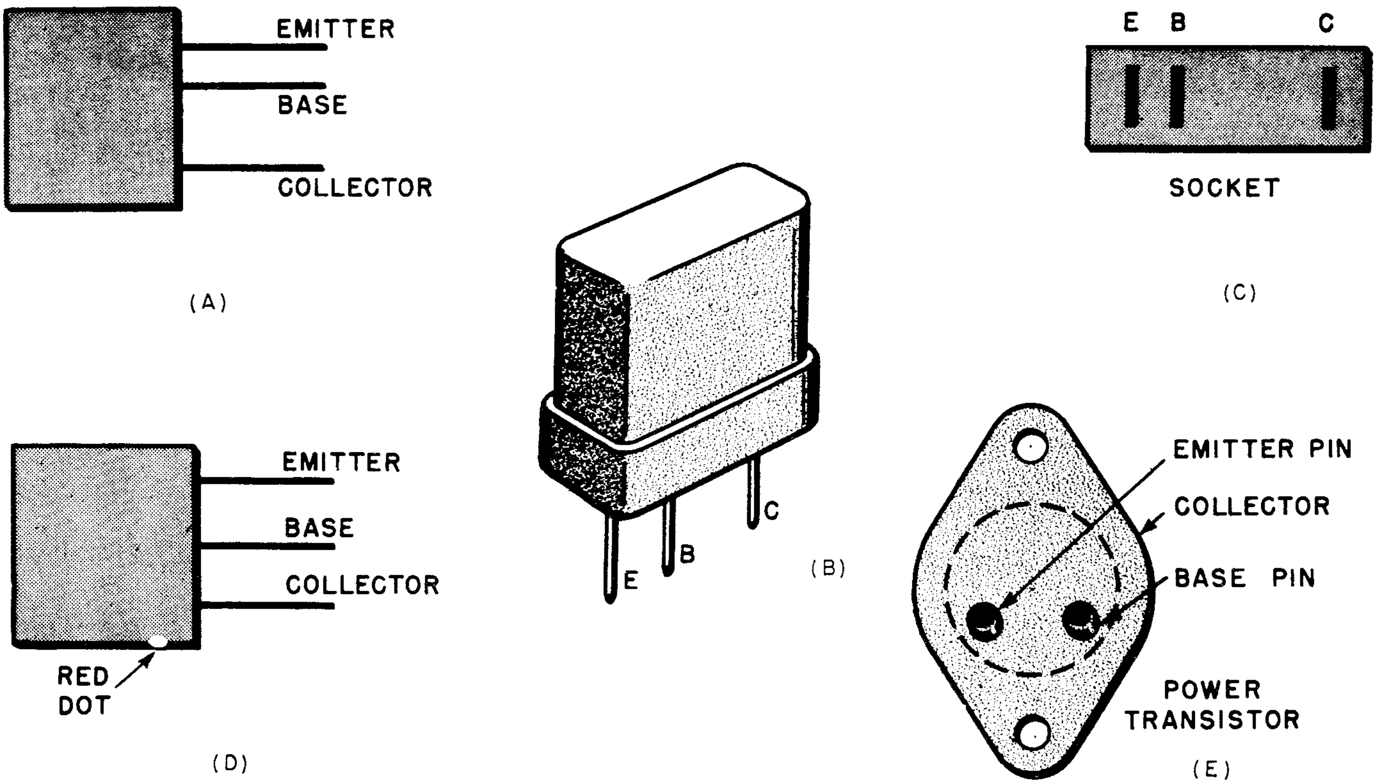

Fig. 1013. *These drawings represent some examples of transistor pin arrangements; others are used.*

Fig. 1014. *Some transistor types.*

Emitter voltages

By making voltage measurements across the emitter resistor (Fig. 1016), you can determine if the associated transistor and its circuit are working properly. But before you decide to make such tests, there are a few things you must determine.

First, these tests are of no value if the battery is run down or if it is on the border line of replacement. Your next step, if the battery is good, is to determine if you are dealing with an n-p-n or p-n-p transistor. Do not assume that p-n-p units are used throughout if you notice that one of them is such a type. Both types can be used in one receiver.

Finally, the only intrument you can use to make such measurements is a high-impedance vtvm. If you have an isolation probe, use it. Do not bother trying to make this test with an ordinary vom.

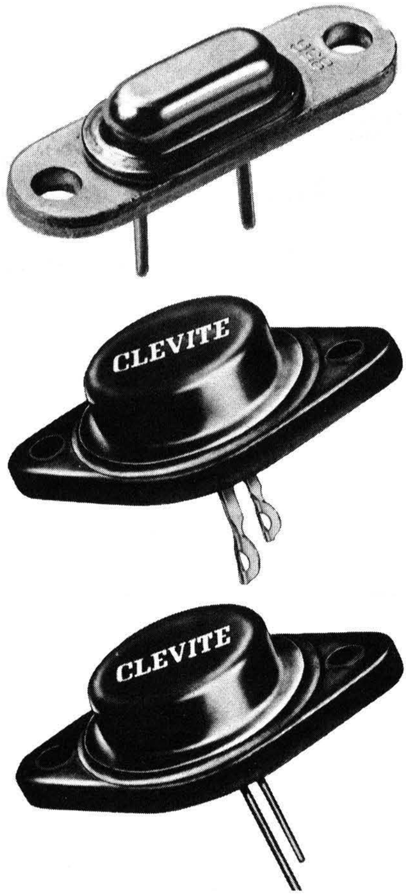

Fig. 1015. *Power transistors.*

When checking the emitter resistor of an n-p-n transistor, touch the positive lead to the emitter and the negative lead to the grounded end of the emitter resistor (Fig. 1017). Of course, for p-n-p transistors, the test leads should be transposed – the negative lead should go to the emitter, and the positive lead to ground. In the n-p-n transistor, current flows through the emitter resistor in one direction, and in the opposite direction for the p-n-p unit.

If you have ever measured voltages across cathode resistors in a vacuum-tube radio, you know as well as we do that they range from small amounts of voltage to large. Every receiver has its own set of bias voltages and it would be physically impossible to prepare such a list of voltages to use as a guide which could always be consulted. The same is true of transistor receivers. The following list shows average voltages (across the emitter resistors) for a typical receiver. These may not necessarily be correct for the set you are working on, but at least they will give you some idea of

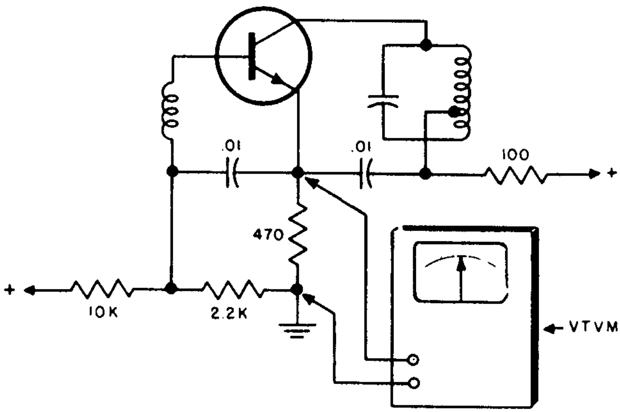

Fig. 1016. *Method for making voltage measurements across the emitter resistor.*

the amounts you should learn to expect. These values are for no signal input, except where otherwise indicated:

Converter: 1-2 volts
First if: 0.22 volt
Second if: 0.7 volt
Audio driver: 0.28 volt
Push-Pull: 0.25 volt (with large signal input).

Whether these values of voltage are positive or negative will depend entirely on whether you are checking p-n-p or n-p-n units. Note also that the voltages are quite small, so you must use a suitable range on your vtvm to be able to read them. Be sure that your vtvm is set to read dc volts.

Converter stage

Let us assume you have your vtvm connected across the emitter resistor of the converter. The current flowing through the emitter resistor will average about 0.5 ma. The amount of current will

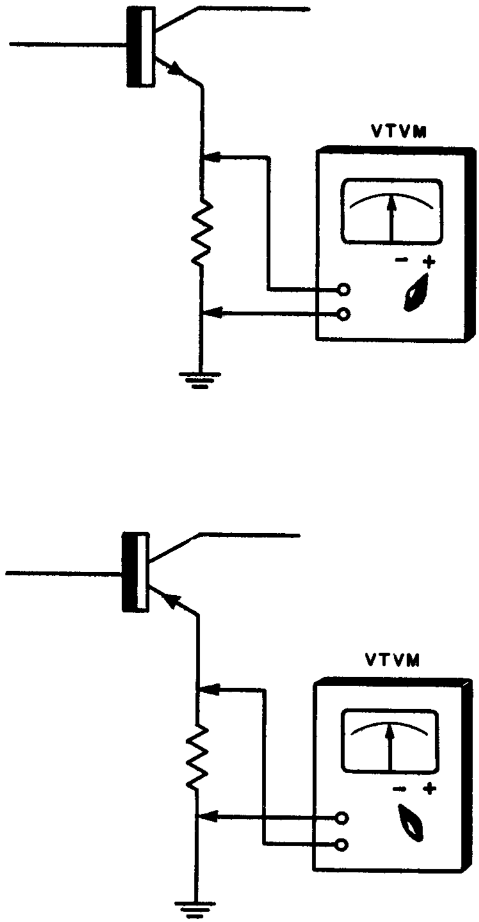

Fig. 1017. *Methods of connecting the vtvm across the emitter resistor for n-p-n and p-n-p transistors.*

vary with the setting of the tuning capacitor. More current will flow when the tuning capacitor plates are unmeshed (that is, at the high-frequency end of the band) and less current at the low-frequency end. Do not expect tremendous differences in current swing – you won't find them. For example, if you measure 0.5 ma with the tuning dial set to 600 kc, emitter current will increase to 0.55 ma when the dial is set to 1,400 kc. The difference isn't startling, but it exists.

There is one peculiarity of the converter stage that we mentioned in an earlier chapter that is important enough to bear repetition. Normally, in a p-n-p unit, the base is negative with respect to the emitter. In the case of a converter transistor, however, the base is positive with respect to the emitter because of the injection of oscillator voltage. If this condition does not exist, the local oscillator section of the converter isn't working.

The voltage which appears across the emitter resistor can give you some clue as to the possible cause of trouble in that stage.

If you want to check local oscillator operation quickly, connect your vtvm across the converter emitter resistor and observe the needle position carefully. Now short the oscillator tuning capacitor plates and note the meter. If the needle kicks back, the oscillator is functioning.

To determine the actual amount of emitter current flowing, you will need to do one of two things: You can measure the current by inserting a 0-1 dc milliammeter in series between the emitter resistor and the emitter. To do this, remove the transistor from its socket, disconnect the resistor from the emitter connection and then insert the leads from the meter. If the transistor is not the type that has a socket (it is soldered into place), do not try to unsolder the transistor lead. Instead, disconnect the end of the emitter resistor that is connected to ground. Insert the meter between ground and the resistor. In either method, you will be measuring the same amount of current. If the meter needle swings backward, transpose the meter leads.

If you don't want to bother with a meter, you can determine the amount of emitter current by doing a bit of arithmetic. Current (I) is equal to voltage (E) divided by resistance (R). You know the value of emitter resistance or can measure it. You know the voltage simply by looking at the vtvm when making the emitter voltage meaurement. Divide the voltage by the resistance and you have the amount of current. There is just one precaution; an error which experts sometimes make. All your units must be basic – if the resistance is in ohms and the voltage is in volts, the answer you get will be in amperes. This will usually be a very small decimal. To change your answer to milliamperes, multiply it by 1,000.

Arithmetic doesn't appeal to many technicians and so, if you are one of this group, you still have a source of comfort. Inexpensive, easy-to-understand Ohm's law slide rules are available which will do practically all of the arithmetic for you. These rules can be purchased at many radio jobbers or direct-mail catalog houses.

In making voltage checks across the emitter resistor, remember that the amount of voltage you read is an indication of the trouble you may encounter. For example, if you read zero voltage when checking across the emitter resistor, it is possible that the resistor is disconnected or open. Examine the resistor to make sure that it is in good condition and check the soldered connections. Remove the transistor from its socket and test the resistor. If the resistor is good but you still read zero volts, examine the base and collector circuits. Check forward bias and also the voltage between collector and the emitter.

Sometimes it is easy to get fooled. You may imagine that you are reading zero voltage, but there will actually be a small emf across the emitter resistor. Make sure you are on the correct range of the vtvm. For example, if there is a defect in some component such that the voltage across the emitter resistor is very low (0.1 or 0.2 volt) and you are on the 10-volt scale of your vtvm, it will be very easy to think that the voltage is zero.

If emitter resistor voltages are extremely low or much higher than normal, check all capacitors connected to the emitter or to the lead of the resistor which is connected to the emitter.

Emitter-current values

Now that we have learned just what we can expect in the way of voltages across the emitter resistor, let us see what currents produce these voltages. Here is a useful check list:

Converter stage: average current about 0.5 ma

First if amplifier: Average current about 0.5 ma (no signal)

Second if amplifier: Average current about 1 ma (with signal)

Audio preamplifier or driver: Average current about 2 ma.

It is rather difficult to give values of emitter current for output stages. The amount of current will depend upon whether a signal is being applied to the push-pull transistors (we are assuming a typical class-B stage) and whether the signal is weak or strong.

Aligning the automobile radio

The alignment procedure for an automobile radio is very much the same as that for a home or portable receiver. However, the auto radio receiver requires a few precautions of its own. For example, earlier in this chapter we mentioned the use of a storage battery as a power source, a necessary item since you will have to pull the receiver to work it. A storage battery is an innocent looking device, but it packs a tremendous wallop. For this reason avoid spark-testing the auto radio. This sort of technique calls for a heavy current flow – and a storage battery is always ready, willing and able to supply amperes, hundreds of them, if necessary. The only trouble is that, when making a spark test, this heavy current will flow through various components in the receiver, probably burning them out in the process. Of course, if you short the base of the transistor, especially in the output stages, you will be removing the base bias. The resulting heavy current flow will permanently damage the transistor.

While alignment instructions will be the same as those we have outlined, remember that auto radios have a radio-frequency amplifier preceding the converter. The amplifier's slugs and capacitors are adjusted for maximum receiver output with the signal generator and the receiver set at the high end of the band. After the receiver is installed in the car, tune in on a weak station, somewhere around 1000 kc. If the antenna is a telescoping type, extend it as far as it will go and then adjust the antenna trimmer until the station signal is at a maximum.

No special instruments are needed for auto receivers. You can use your signal generator and vtvm just as you would for an ordinary portable set. There is just one other precaution, however. Because auto radios have an rf amplifier stage, their overall gain and sensitivity are much higher than for ordinary radios. For this reason, the coupling between the signal generator and the receiver must be much looser. Otherwise you may overload the receiver or you may find alignment difficult. If you find that you cannot cut down on the gain of your generator sufficiently, even though the gain control on the generator is set for minimum output, move the generator as far from the set as the coaxial cable between generator and receiver will permit. Sometimes signal leakage from the generator will be enough to overload a sensitive set if the generator is placed too near the receiver.

When removing auto receivers, be sure to take the speaker along with the set. Do not forget to plug the speaker leads into the speaker receptacle when testing the set. In other words, do not operate the set without its speaker.

chapter

11

printed circuits

IF you ever get the opportunity to examine a real old-timer among radio sets – preferably one manufactured around 1931 – by all means do so. Some of these "antiques," especially those that had more than one tuned rf stage, looked like and were constructed like battleships. Some of them weighed more than a modern television receiver. The underchassis view was especially interesting since it looked like a jungle of wires and parts; a sight that frightened many a potential servicing student right out of the electronics industry.

By comparison, modern radio receivers (and some television sets) look as though they have practically no components whatsoever. This is especially true if the receiver makes used of a printed-circuit board. A printed circuit is nothing more than a sort of prewired arrangement. It consists of conductors so arranged that, when the parts are mounted, they are automatically connected. In this sense, the conductors on the printed-circuit board take the place of connecting wires in the receiver.

Wiring in a receiver can look messy because the wires not only go from one side of the chassis to the other, but are connected in an up-and-down fashion as well. The result is that components are sometimes buried beneath the wiring, and sometimes wiring that is perfectly good must be removed to get at a defective part. In addition, a wiring maze looks confusing, making point-to-point analysis of the receiver a time-consuming job.

A printed-circuit board, on the other hand, has all its conductors in one plane, resulting in a simpler-appearing set. The connections from one part to the next are the same, but because the "jungle look" has been removed, servicing is easier.

Printed-circuit boards lend themselves very nicely to transistor receivers. Transistors are compact little units, and, when combined with a printed circuit board, the entire receiver can be made to occupy a fraction of the space required by an ordinary receiver. Naturally, all the other parts are made proportionately smaller.

The printed-circuit board

There are quite a number of techniques for making printed-circuit boards. The conductors on the printed-circuit board can be put on by spraying, plating, hot-die stamping, printing, painting, embossing, etching, etc.

The board itself is generally a sheet of laminated plastic or phenolic board. In one method a thin sheet of copper is placed over the board and then the copper is fastened to the plastic by a bonding process. The conductors are then made by removing a part of the copper by one of the methods mentioned in the previous paragraph. Holes are then drilled in the boards. You will usually find four holes – one at each corner – for mounting the board. Holes are also drilled in the board for mounting components such as resistors and capacitors. Sockets are also made part of the printed-circuit board assembly.

After the various parts are mounted, component leads are clipped and fastened into place. By means of a dip-soldering technique, the manufacturer is able to make all of the required connections at the same time. (Other manufacturing methods are also used).

Working with printed-circuit boards

We know we need not tell you that every radio part requires its own special handling. If you consider a printed circuit as just one more radio component that requires a little special treatment all its own, then you will have less trouble with it.

First examine the four mounting holes on the board. In almost all cases, some of the printed-circuit wiring goes directly to these holes so that, in mounting the printed circuit on the metal chassis, you have an electrical connection between the chassis and the conductors on the board. The board should drop easily over the four mounting screws. If it does not do so and if you try to force the board into place, tightening the nuts on the holding screws for the board will crack it. Tightening the board's mounting or holding screws and nuts should not place any stress on the board itself. In replacing a board, it may be helpful to hold the board up to a light (such as an electric light bulb) to see if it has any cracks in it before you make any replacement.

There is nothing particularly special about a printed-circuit board that cannot be taken care of by using some thought and care. For example, the conductors on the board are generally fastened fairly securely to it, yet they can be lifted off through improper handling. The conductors can be scored, broken, lifted off, severed, cut off (producing an open-circuit condition). Dropping solder blobs, using too much solder or sloppy soldering can produce a short circuit – and quite easily at that. On most boards you will find the conductors fairly close together. Any excess solder will run right between the conductors, probably fusing them beautifully. If you do run into this trouble, you will need to use your soldering iron and a sharp-pointed tool to clear the short.

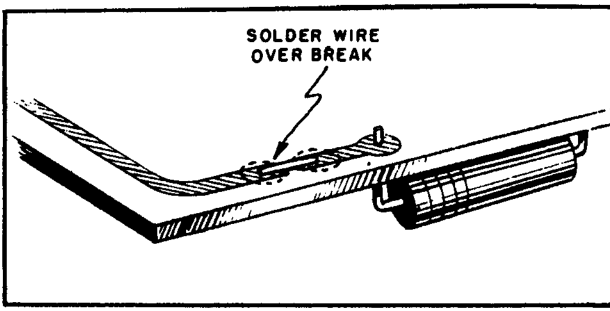

Fig. 1101. *Method for repairing a break in printed-circuit conductor. Solder a small piece of tinned wire right over the break.*

If, by accident, you should break one of the conductors, you can make a repair by bridging the break with a small piece of copper wire as shown in Fig. 1101. Make life easy for yourself. Use tinned wire. Don't use stranded wire unless you are accustomed to doing everything the hard way.

It isn't advisable to remove the board from the receiver unless you feel that you will save time and trouble by doing so. You can mount the board in a vise to leave your hands free to do your work, but remember that a vise can exert a tremendous pressure. Some technicians use a soft copper covering for the vise to prevent marring or damaging the printed-circuit boards. This is good since it prevents the serrated jaws of the vise from tearing the conductors on the board, but you must still be careful not to use excessive vise pressure.

Finally, you should remember that brute force isn't required. Use one of the lighter irons, rated anywhere between 25 and 35 watts. A pencil type iron, light in weight, will give you the necessary hand control for working in close spaces. A heavy iron is not only difficult to control, especially for fine work, but the heat it

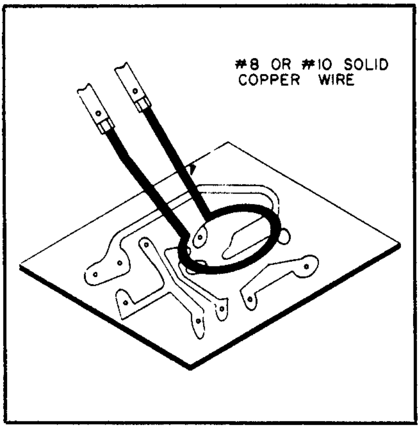

Fig. 1102. *Some No. 8 or No. 10 copper wire can be used as a special tip.*

produces may actually cause the conductor to pull away from the board. Before using the iron, file the tip to a wedge shape and tin the iron. Keep a cloth handy so you can wipe the tip frequently to keep it clean and shiny.

If you prefer a soldering gun, you can make a special tip for work on printed-circuit boards. Remove the existing tip by loosening the holding screws. Get some No. 8 or No. 10 solid copper wire and fashion it into the shape shown in Fig. 1102. Use tinned wire. If the wire doesn't come pretinned, tin the circular loop portion of the new tip. Insert into your soldering gun and you are ready to go to work, first making certain that transistors have been removed from their sockets.

If you do not have a soldering gun but have a high-wattage iron, take some No. 8 or No. 10 wire and wrap it around the iron as shown in Fig. 1103. Make a good tight wraparound so that the wire doesn't slide off the iron. The copper wire will now form the new tip for the iron. Sharpen the end of the wire to a point. Do this by rubbing the end of the wire against a file. Use a file having very fine teeth and roll the wire with a circular motion. Tin the end of the tip, just as you would an ordinary soldering iron.

Some technicians prefer using a 100-watt iron instead of the lighter-weight iron we have just recommended. This is fine, provided you keep in mind that it isn't the iron that produces the damage but the man behind the iron. If you use a lightweight iron, you can damage the wiring on the board if you keep the

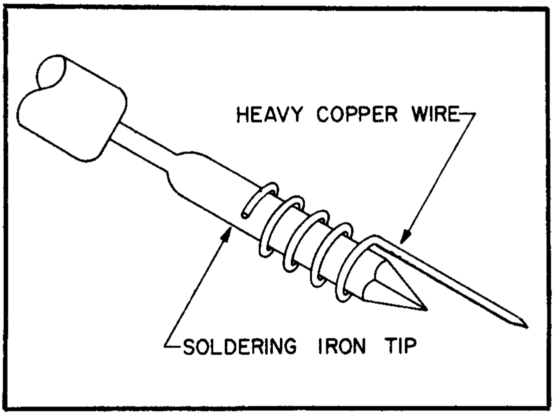

Fig. 1103. *Wrap some heavy copper wire (such as No. 8 or No. 10) around the shank of a heavy-wattage iron to convert it into the equivalent of a low-power iron.*

iron touching the board for too long a period of time. Soldering — and unsoldering — require some skill and know-how.

A 100-watt iron in the hands of an experienced man will cause much less damage than a 25-watt iron in the hands of a beginner. And finally, keep the iron well tinned, well tapered, and thoroughly clean.

Later we will discuss a different soldering technique, using a soldering pot.

Some technicians have the idea that solder is solder and that is that. Why make your work any more difficult than it must be? If you have the proper skill and ability you could use bar solder, but then you would probably be better off connecting heavy telephone cables. Use thin, lightweight solder having a low melting point. High-melting-point solder and 25-watt soldering irons belong together as much as pickles and ice cream. Use rosin-core solder containing 60% tin and 40% lead. Stay away from acid-core solder unless you're the type that likes nonpaying callbacks.

A small wire brush will also be of great help. You can use this

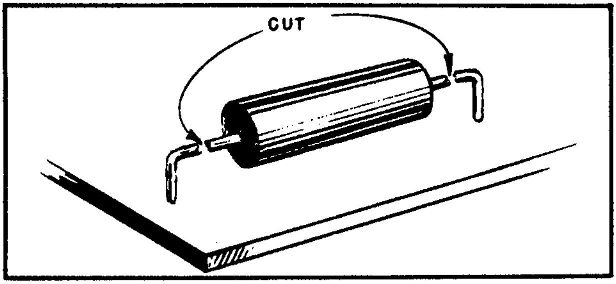

Fig. 1104. *To remove a resistor or capacitor, cut the leads as close to the body of the component as possible.*

to clean away very fine dots of solder that conceivably could cause trouble. Use gently! The idea is to remove unwanted solder and resin and not to buff the printed board to a high gloss. Care-

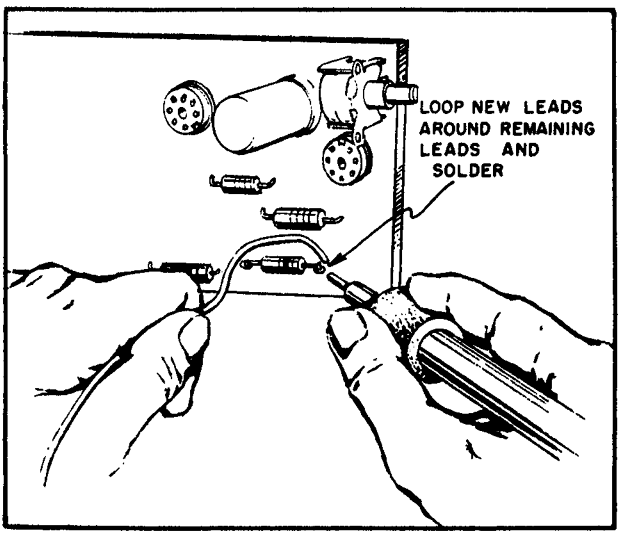

Fig. 1105. *After the old component has been removed, loop the new leads around the remaining leads of the old part.*

less handling of the brush can also remove some of the printed-circuit-board conductors.

Various solvents are made for cleaning printed-circuit boards after working on them, but ordinary denatured alcohol (such as that used to thin shellac) can be used. Put some of the alcohol on the brush and swab the board around the area where you have soldered. This will remove excessive resin.

Other tools you will find extremely helpful include a wire pick and pocket knife. If you do not have a wire brush, use a toothbrush in its place. Be sure to buy a toothbrush having stiff bristles. Also, the needle-nose pliers and "dykes" (diagonal cutters) you use for your other servicing work can be very helpful for printed circuits.

Component replacement

You can save yourself a considerable amount of time by not removing defective components completely. If you try to do so, you may pull away some of the printed-circuit-board conductors. The better technique is to cut away the body of the defective

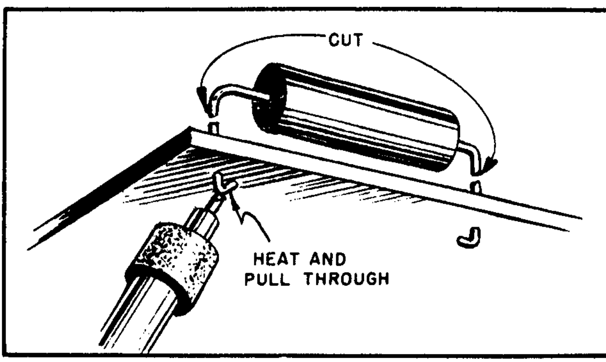

Fig. 1106. *To remove a component such as a resistor or capacitor, cut the ends as shown and then heat the remaining leads, pulling them through the board when they become sufficiently loose.*

part (resistor or capacitor) and allow the leads to remain (Fig. 1104). You will now have two moderately stiff wires sticking up out of the board, to which you can loop around and solder the leads of the new part. Since you will not be soldering to the board itself, the job will be that much easier (Fig. 1105).

However, there will be times when you will not be able to avoid removing the entire defective component body and its connecting leads. This requires some care and patience. Make sure the iron is clean and tinned. Heat the joint or the hole through which the lead of the part is mounted. Before the joint has a chance to cool, use the wire brush to remove some of the solder. Then reheat the joint and use the wire brush once again on the other side of the board. With most of the solder removed, you should now be able to apply the iron and wiggle the component loose. The component should come out smoothly. You must be careful since it is very possible to lift up some of the conductors when removing a part. After the part is removed, clean the mounting holes of any solder threads.

Another technique, as shown in Fig. 1106, is to cut the leads of the defective part. Then heat the remaining bit of lead material on the bottom side of the printed-circuit board. When the lead becomes loose, pull it through from the bottom side, using a pair of long-nose pliers.

A little earlier we mentioned using a small bit of wire to repair an open break on the printed-circuit board. If you have trouble with this method, you might try some silver conducting paint made especially for repairing printed circuits. With a knife or razor, scrape the area of the break. Draw a line of silver conducting paint between the two points to be connected. Don't try to make a heavy conducting line with one stroke of the brush. Instead, build up the conductor by first drawing a faint line, then making it heavier by going over it a number of times.

If a component (such as a resistor) is mounted directly against the board and it is too difficult to cut the leads as described previously, you should not assume immediately that you will have to remove it completely (if a replacement is to be made). Instead, cut the part in half with a pair of diagonal cutters. Using a pair of gas pliers, crack each half of the cut component so that the body is smashed, leaving only the connecting lead. If you do this, you will find that you have enough lead left to mount the new part. Of course, you will have to clean the lead so as to be able to make a good soldered connection.

Whenever you make a repair on a board, always be sure to examine it after you have finished, just to make sure that you don't have any shorts (caused by excess solder) and that there are no breaks in any of the conductors. If there is a break, and the open ends of the printed-board conductors aren't too far away from each other, you might try making a connection just by running some solder between the ends (Fig. 1107). If the distance is too great, use a connecting wire as described earlier.

If, for some reason, the printed-circuit conductor lifts away

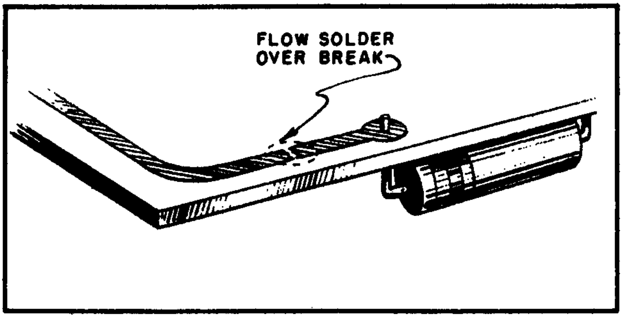

Fig. 1107. *If the break in the conductor is small enough, you can repair it by flowing some solder between the two open ends.*

from the board, cut away the section that has raised. Then solder a small bit of wire between the end of the cut section and the component, as shown in Fig. 1108. Use tinned wire so that you

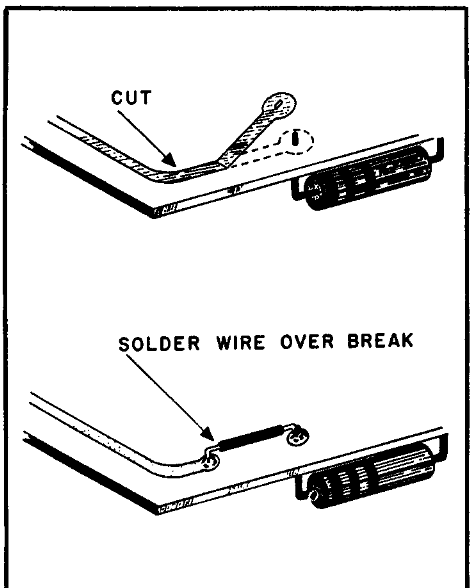

Fig. 1108. *If a small bit of the printed-circuit conductor lifts up, cut it away and replace it with some wire.*

can make a connection with the minimum amount of trouble. Don't use wire that is too heavy. Generally, No. 22 or No. 24 wire will be satisfactory. Use bare wire for short breaks, but, to fix a large break, use insulated wire as shown in Fig. 1109. Insulated wire is needed in this case to keep from shorting against any of the other conductors on the board.

After your repairs are finished, use a toothbrush (or any stiff bristle brush) and a solvent to clean the board. Denatured alcohol is cheap and is a good cleaning solvent. Pour a small amount of alcohol on the area that you have just soldered and scrub gently with the brush. You can use a rag if you wish but a brush is easier, faster and does not leave any tiny pieces of lint. If you have carbon tet available, you can use it in place of the alcohol. Remember, however, that carbon tet fumes are poisonous. Work in a ventilated room and, if possible, use a small fan to blow the fumes away.

After you have cleaned the board with the solvent, cover the under side of the board (the foil side) with a silicone resin spray. This comes in pressurized cans so the only work involved is pushing a button. Spray lightly and gently. When spraying, hold the component side (top side) against the palm of your hand so that only the bottom side (foil side) of the board gets the spray. As further protection, you can cover the component side with masking tape.

Replacing rf and if transformers

You must first of all make up your mind just what it is you want to do. If you plan to replace the defective rf or if transformer, clip away the transformer soldering lugs. These lugs come through holes in the board. Remove the solder from each of the lugs, then cut the lugs with diagonal cutters. You should then be able to remove the transformer. Be careful when pulling the transformer can. Work the can back and forth so that it comes out easily. If it does not, then one or more lugs may require some additional treatment with the soldering iron. After the transformer is removed, clean the through holes so that the lugs of the new transformer will fit through easily.

After mounting the new transformer, twist the soldering lugs to keep the unit firmly in place while the lugs are being soldered.

If the transformer is to be repaired (instead of being replaced), you will have to be a bit more careful. Remove all solder from the soldering terminals. Then straighten the terminals. You may have to file the terminals to remove the last little bit of solder and to make it easier to remove the transformer.

If transformers are symmetrical — that is, they usually have as many terminals on one side as on the other. For this reason, when removing a transformer for repair, make sure that you do not turn the transformer around when putting it back. There are any number of identifying methods you can use — a scratch mark or a dab of ink. It doesn't make any difference which technique you use, just so long as the transformer is inserted in the proper way.

Some if transformers will have a color dot on one of the lugs. The idea of this color dot is exactly the same as the color dot

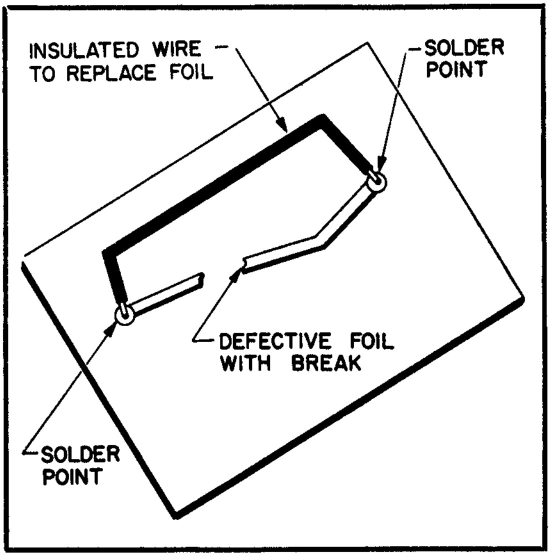

Fig. 1109. *Use insulated wire to avoid causing a short by touching other conductors on the board.*

you will find on the side of the package (or case) of a transistor having a symmetrical lead arrangement. All you have to do is to remember the position of the lug with the color dot on it and then to insert the new transformer in such a way that the colored lug occupies the same position. Sometimes you will find that the manufacturers has put a part number on the side of the can. Do not use this as a positioning guide since the number may be put on any one of the four sides of the can. The number is for component identification only and not as a positioning aid.

One final caution: In soldering, as in almost everything else, you must use some restraint. Don't use too much solder and do not overheat the soldering lugs. Make sure that the solder does not flow into the transformer. There is nothing more exasperating, time- and money-consuming than to replace a component such as an if transformer and to damage it in the process.

Replacing volume controls

Cut the leads going to each terminal on the volume control. Some receivers will have two leads, most will have three. Cut the leads close to the volume-control terminals. After cutting these connections, you will need to free the volume control from the printed-circuit board. This is shown in Fig. 1110. Heat each

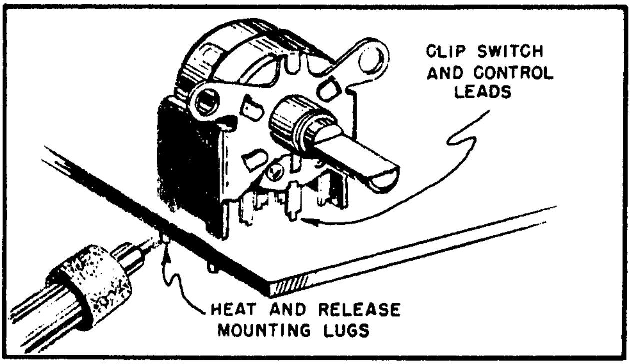

Fig. 1110. *Method of removing a volume control.*

mounting lug and, while you do, brush away the solder on the lug with a toothbrush. Do this with each lug. After all the solder has been removed, straighten each lug (if necessary) with a pair of long-nose pliers.

Now, in turn, heat each of the mounting terminals and pull the volume control up and away from the printed-circuit board. You will not have to use much heat, just enough to free the control from the board. Once the volume control has been removed, you will still have three more terminals to work on. These are the terminals from which you clipped the wires as your first step in doing this job. These terminals on the board were connected to the terminals on the volume control. Just heat them from the bottom side (foil side) of the board and pull them through from the top side (component side) with a pair of long-nose pliers, as shown in Fig. 1111.

After you have removed the volume control, examine the mounting holes and the soldering terminal holes on the board. Make sure they are clean and not filled with any solder before trying to mount the replacement unit.

Troubleshooting

You can make resistance and voltage measurements with printed circuits in the same way and using the same techniques as with regular circuits. However, components are all usually mounted on one side. It will help to shine a light against the reverse side of the board when making servicing or voltage checks. It all depends on how the board is mounted. The printed circuit board is translucent (permits light to shine through). The light will help you trace the conductors from one component to the next.

Because of the closeness of the conductors and because, in some cases, the conductors are rather thin, a magnifying glass will be

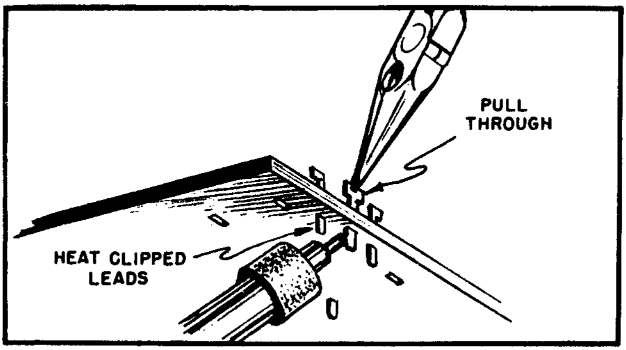

Fig. 1111. *This drawing illustrates the method for removing volume-control connecting terminals.*

helpful. If a continuity check shows a break in the conductor but a visual examination fails to reveal it, look at the board with the magnifier until you find the break.

In ordinary servicing, one of your test leads is equipped with a fastener of some kind, such as an alligator clip. For circuit-board work, it would be helpful to fill the jaws of one of the alligator clips with solder. After the jaws are filled, file them down until they are fairly smooth. The teeth of the jaws will then be unlikely to damage the board while the larger contact area of the filled-in jaws will make good contact with the wiring on the board. The other probe should be a needle-point type to permit good contact to be made in tight places.

Printed-circuit-board troubles

A printed-circuit board should be regarded as a radio component. We might consider it as a resistor or a capacitor or a tube (in the sense that these are also radio parts). And so we cannot be too surprised to learn that this new component, the printed-circuit board, has a few ailments of its own. A printed board might look good but then a tube or transistor might also appear to be in top-notch working condition only to show up as defective when tested.

Leakage resistance

This old bugaboo seems to lift its ugly head everywhere we go. It shows up in capacitors, especially electrolytics. It causes instability in high-voltage circuits. It is a common affliction. And it can cause trouble in transistor receivers using printed-circuit boards.

You can check for leakage with a vtvm. The instrument must be able to read high values of resistance, up to 1,000 megohms. Leakage can be caused by dirt, by a defect in the plastic plate, by resin between conductors on the board. Fortunately, voltages in transistor receivers are quite low so that, if a leakage problem does exist, you should be able to run it down fairly easily with the vtvm. If you do find evidence of leakage, brush the area clean with a stiff brush (and some solvent) and then repeat the test. Sometimes bits of metallic dust or extremely tiny particles of solder will imbed themselves between the conductors. The brush will remove them quite readily.

Poor connections

Printed-circuit boards are mass-produced and, as in any mass-production system, a few clinkers will always get through. It is possible for a connection to be poor as, for example, between a through eyelet on the board and the connector or connectors going to it. Here again, about the only method of checking is to use an ohmmeter.

Intermittents

These are as difficult to find on a printed board as in an ordinary type of receiver. Examine the board carefully before trying any continuity or voltage checks. If you can hold the board up to a strong light, do so. Look for any tiny breaks in the conductors. Also make sure that no part of any conductor has lifted away from the board. Tapping the board gently while the receiver is turned on will sometimes help localize the defect. Some of the conductors on the board will be connected to through eyelets. These may look good, but often the slightest vibration will cause them to make and break contact. Gently tapping each eyelet with an insulated tool will help.

High-resistance conductors

The conductors on the printed-circuit board are supposed to make a low-resistance connection between radio components. However, while the conductor might look good upon casual examination, a magnifying glass might show a lack of uniformity. This means that there might be breaks in the length of the conductor. These breaks do not cause an open circuit, but since they reduce the amount of conductor material, they result in increased resistance. If you measure resistance between two points on the board, when the circuit shows that there should be a direct connection (zero resistance), then a high-resistance conductor might be on the board — especially if there is no other component between the two measured points.

Reading printed-board diagrams

A printed-board diagram shows the various parts in schematic or symbolic form with the printed-circuit conductors as a solid or shadowy outline, or both. See Fig. 1112. The diagram is unusual in some respects. It will show you the location of parts with respect to each other. This is quite contrary to usual circuit diagram practice where the positions of the electronic symbols have no relationship whatsoever to the actual positions of the parts in the receiver. A diagram such as the one shown in Fig. 1112 is of considerable help in servicing.

While the illustration of the printed-circuit board is that of a vacuum-tube receiver, those used for transistor sets are similar.

Replacing tube sockets

Sometimes a tube socket on a printed-circuit board will become defective. You are then faced with the problem of deciding whether to replace the entire board or just the socket. If you put in a new board you will either have to buy it, in which case the repair would be an expensive one, or you might decide to salvage the parts, in which case the repair would be time-consuming. We are emphasizing this so you will realize that, while

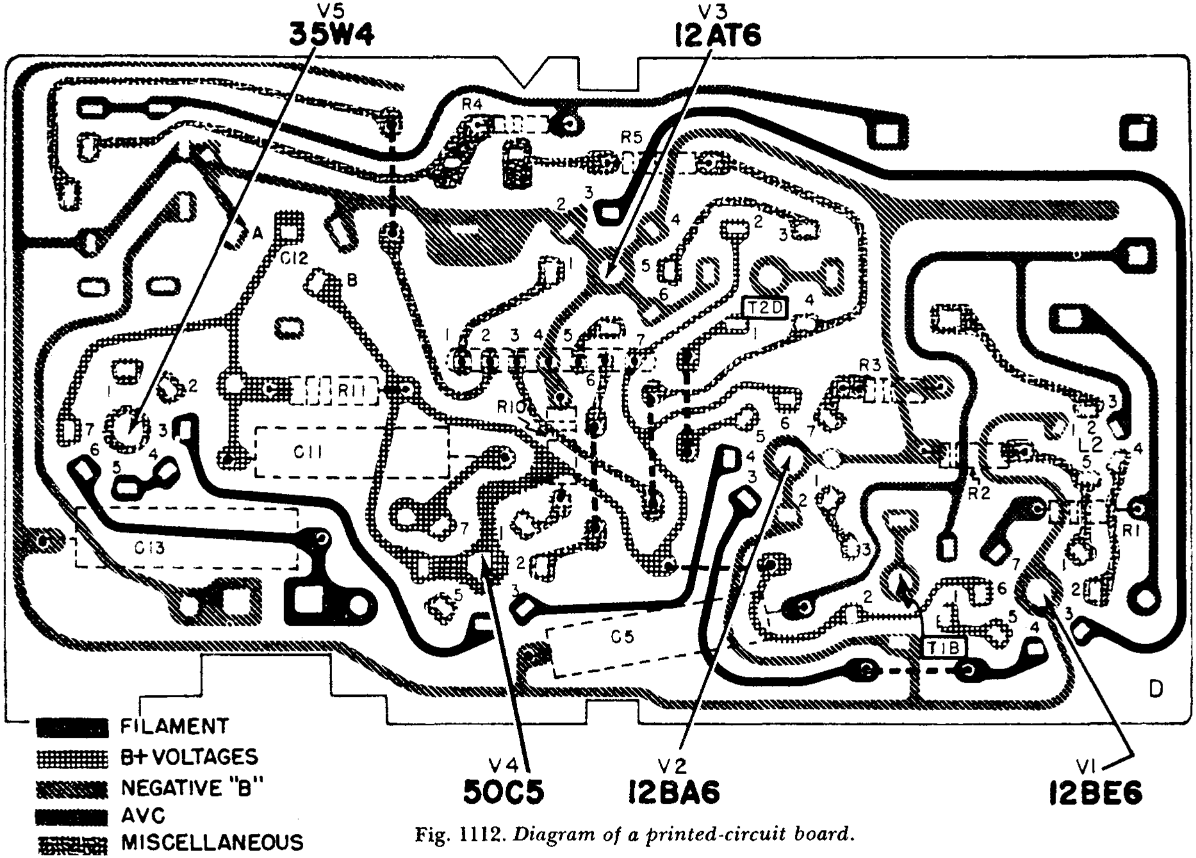

Fig. 1112. *Diagram of a printed-circuit board.*

putting in a new socket isn't the fastest job you might ever do, yet it is often the least bothersome of a number of possible alternatives.

To put in a new socket, you will first have to get rid of the old one. Cut the old socket with a pair of "dykes". Don't get too ambitious. Cut away a small bit at a time. If you don't, you will find that you have a handful of printed-circuit board and its assorted conductors all over your bench. Remember that the copper foil conductors on the board connect to the pin contacts, so go easy with the diagonal cutters at these points. You can remove the pins by heating the lugs. Do this on the printed side of the panel. Now gently pull the pins through the hole from the component side.

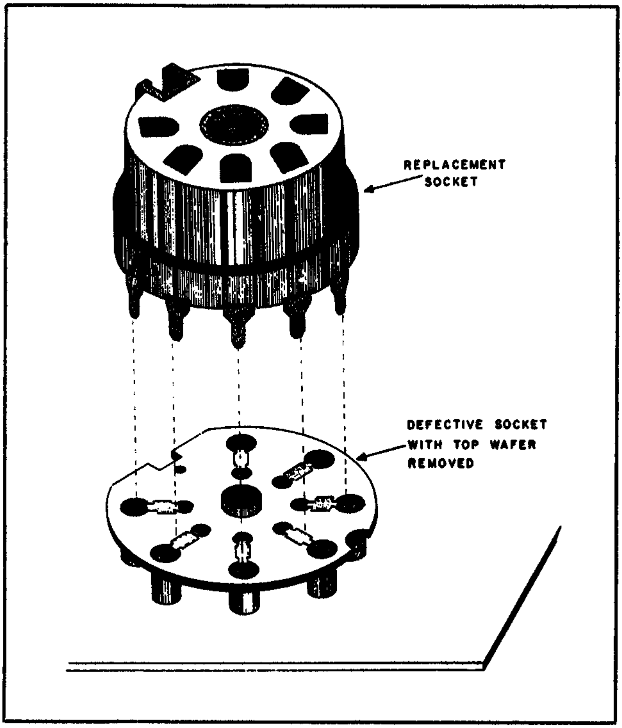

Fig. 1113. *Repair without removal of defective socket by insertion of printed-circuit socket.*

Don't try to do this job holding the printed-circuit board, the soldering iron and a pair of long-nose pliers in your hands. You would need more hands than you have to be successful. Mount the board in a small vise. Put two pieces of cardboard over the jaws of the vise so that the serrated edges of the vise don't cut into the boards. And remember that the purpose of the vise is to hold the printed circuit board, not to crush it. Go easy on the pressure you put on the vise.

After the pins are out, remove the center post in just about the same way. Heat the soldered point and push it through from the component side. With the new socket in place, solder the lugs and the connector to the center post.

Fig. 1113 shows how you can go about replacing a wafer socket. All you need do is to peel off the top layer of the wafer. You will then have a partial socket as shown in the illustration. A replacement socket can then be inserted in the openings.

You may be wondering why we bother telling you about tube sockets in a book dealing with transistors. The answer is quite simple. First, some receivers (such as auto sets) make use of both tubes and transistors. Second, with an eye to the future, no one knows as yet whether tubes or transistors will ultimately take the lead in electronics equipment. Most likely, however, both tubes and transistors will be used side by side in test equipment, receivers, transmitters, industrial apparatus, etc. Transistors are wonderful – but so are tubes. Taken together, they make an unusual team.

Making voltage checks

Once you become experienced in working with receivers that use printed-circuit boards, you will note a number of advantages over ordinary wiring. You will be working with a flat surface with all connections readily visible. You won't have to worry about lead dress since the conductors are fixed into place. Voltage test points will be easily available and you won't have to probe around trying to find a suitable spot for a voltage check.

There will be some disadvantages, too, especially if you have had considerable experience in working with ordinary wired circuits. The conductors on printed boards are close together. Since for most boards components are on one side and conductors on the other, it isn't always easy to see which conductor goes where. The arrangement of conductors on the board will appear strange – but try to remember the first time you saw the cluttered combination on the bottom of an old radio or not-so-old TV set.

As in ordinary receivers, you can take your voltage readings right at the pins of the transistor or tube sockets. Most boards will have components on one side only, others on both sides. In either case, you can still use the exposed lead of a component, such as a resistor or capacitor, as a test point. Don't jab a test prod — even if it is a needle point — into any of the conductors on the board. Trace the conductor over to the nearest component lead and make that your test point. The conductors on a printed-circuit board won't absorb the punishment that copper wires in an ordinary receiver take in their stride.

Another reason for doing your testing in this way is that the printed board may be covered with resin. Because the conductors are so close to each other, it wouldn't take very much moisture or dirt to cause a short or to produce excessive leakage. The resin coating keeps moisture and dirt from causing leakage or shorts. If you make a test directly on the conductor, using a needle-point test prod, you will be breaking the resin seal. You may be able to make the measurement you have in mind, but the small puncture in the resin may lead to trouble later on.

Advantages of printed circuits

If you have the idea that printed circuits are just a passing fancy, all you need to do is to spend some time in servicing transistor radios. The printed-circuit idea has caught on so well that the modern ac-dc set also uses it extensively.

Printed circuits have quite a number of advantages. Probably one of the most important is that they eliminate errors in wiring. Since every printed board that goes into a particular model of a receiver is a "carbon copy" of the original, you can be quite certain that all of the "bugs" have been taken out of the original unit. At the same time, the manufacturer must make sure that his design is a good one. Changes based upon experience in the field aren't so easy to make when using printed-circuit boards.

With the printed-circuit board, you don't have a confusing jungle of wires. You can see all the leads (or conductors), and all of the capacitors and resistors mounted on the board can be reached easily. The board is just like a miniature chassis but, instead of being made of metal, this particular chassis is an insulating material. You cannot look through a board but, if you want to work on the top side of the board, just put an electric light bulb behind the board, turn it on and you will be able to see all the wiring. Use a 60-75-watt bulb, preferably a clear type so that you get the maximum benefit of the light.

Replacing components by using a soldering pot

A dip soldering pot is simply a small cylinder having a diameter of about $1\frac{1}{2}$ inches. Somewhat larger than a thimble (but having smooth walls), the solder pot holds just enough molten solder to make quick repairs on printed-circuit boards. The heat of the solder is regulated by a temperature control device so that you can get a solder temperature range of 300° to 600° Fahrenheit.

The soldering pot is extremely useful since with its help you can remove or replace components much more easily, much more quickly and professionally. To remove a part, all you have to do is to put the two soldered connections of the part right over the solder pot. The two connections must make contact with the molten solder in the pot. When you do this, the bottom side of the board will be facing the pot. Now, from the other side, gently pull on the component that is to be removed. Because its connections have been loosened by the hot solder, you will find it very easy to slide the component right out of its mounting holes.

Of course, when working with a soldering pot, you won't want to keep the printed-circuit board dipped into it any longer than necessary. If you do, you may damage the board.

Replacing a part such as a resistor or a capacitor is simple. Bend the leads of the component so that they fit into the mounting holes. If the holes are clogged with solder, just bring the holes (on the bottom side of the board) in contact with the solder in the pot while gently pushing on the component from the other side. You will find that the leads go through very easily. And now that you have the component in place, put the bottom side of the board right over the top of the solder pot so that the holes (through which you have just pushed the two leads) come into contact with the solder in the pot. Hold for a second or so, and you will then have two beautifully soldered joints. Clip away any excess solder or remaining leads. When using the soldering pot you may get a few stray wisps of excess solder or you may have missed a spot. If so, you can use your lightweight soldering iron for touchup.

Now you might very well ask whether a soldering pot has any great advantage over a soldering iron. To answer this question, remove a component (such as a resistor) by the soldering-iron method and then try a soldering pot.

When using a soldering iron, you know that a certain amount of common sense and caution are needed. You would never dip a soldering iron into water to cool it. To do so is dangerous and might also damage the iron. A soldering pot must also be handled with respect. You must make absolutely sure that no water can get into the pot. Even a drop of water will produce a violent reaction, spattering hot solder in all directions.

When a soldering pot has been in use for some time, a surface film known as "scum" will form. Remove this with a small metal spoon. Hold the end of the spoon with a cloth or other heat-insulating material. Do not throw the scum into a sink since this is dangerous and can clog the sink. Let the scum cool and then you will be able to lift it off as a solder blob to be thrown away.

To be fully useful, the solder pot must be kept full. Use 60-40 bar solder for this. Bar solder, however, does not contain flux so occasionally put in some rosin-core solder.

Soldering pots come in a number of sizes and shapes to meet your working needs. Some are round, others are rectangular in shape.

Mounting of boards

You will find printed-circuit boards mounted in every possible way. In some receivers you will have the usual metal chassis, but

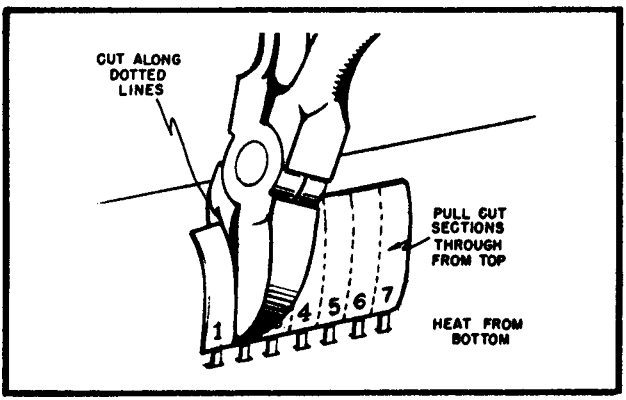

Fig. 1114. *Vertically mounted printed-circuit boards can be removed in sections, if necessary.*

on the metal chassis there will be a rectangular cutout. The printed-circuit board will be mounted on this cutout and will be generally held in place by means of mounting screws. In other arrangements the printed-circuit board will be vertical and will be held in place by mounting terminals at the ends. In some cases there will be a number of lugs as shown in Fig. 1114. To remove the board, heat each lug. Use a stiff bristle brush or a wire brush to clean each of them. Disconnect each wire coming into the circuit board from other components in the receiver. Sometimes there will be no supplementary connecting wires, the only connections being made when the board is mounted. After the mounting terminals and the lugs have been heated and cleaned, gently tug on the board until you feel it working free. You may have to heat one or more lugs again to get the board out.

If you are removing the board and expect to put the same board back into the receiver, you will need to be quite careful that you do not damage the board. If you expect to replace the board, you will find it much easier to remove the board one section at a time. Do this by cutting vertically down the board as shown. After the board is removed, make sure the mounting holes are clean and free so that you can mount the new board.

chapter 12

transistor types

HISTORY has a habit of going around in circles. If you want to know what's going to happen in the electronics industry in the near future, you can make a fairly good guess by considering what has happened in the past. For example, the most commonly used vacuum tube between 1920 and 1930 was the triode. It wasn't until the early 1930's that multigrid tubes came into use. Today, the most widely used transistor in receivers is the transistor triode. However, "multi-element" transistors are being made and it won't be too surprising to find the equivalent of the pentode at work in future transistor receivers.

However, we aren't so much concerned with the future as we are with the present and with what is going on at the moment. We have spent quite a bit of time studying transistor radios, but there are also many opportunities in the electronics industry for those who know a bit more than routine repair work. We cannot possibly hope to cover all of the new kinds of transistors (that would take a book in itself) but we can at least become acquainted with a few of the more important developments.

This last chapter is important for another reason. At the end of it you will find a chart covering many of the troubles you will meet in servicing transistor radios. Listing symptoms and their cures, the chart serves as a ready reference enabling you to cut down on servicing time. Theory references, by chapter, are also given. This is done so that we can avoid a "cookbook" approach. We want to be able to service transistor receivers, but we should also know why the receiver behaves the way it does.

The phototransistor

If you are familiar with the phototube, you know that it is somewhat like a radio tube except that current flow is caused

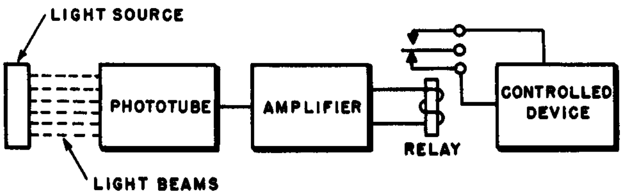

Fig. 1201. *An ordinary phototube must usually be followed by an amplifier to build up the current until it is strong enough to operate a relay.*

by a beam of light. We say that the tube is light-sensitive. Phototubes are widely used in industry. They are used on automatic door openers and light dimmers. They are used as silent guardians where valuables must be stored, or in any circuit where flashing a light on (or off) will cause some circuit to go into operation. The trouble with a phototube, though, is that it delivers a very small amount of current, hence it must be accompanied by suitable amplifiers. The output of the amplifier is then large enough to operate a relay. This is shown in block form in Fig. 1201.

The phototransistor does the same job as the phototube, but it has an important advantage. The phototransistor supplies more output current than the phototube, enough to operate a relay without an amplifier, as shown in Fig. 1202.

A drawing of the phototransistor appears in Fig. 1203. Fundamentally, it consists of an emitter, base and collector, just as in an ordinary transistor and, as you can see from the illustration, it is a p-n-p type. A bias battery is connected between the collector and base, with the negative terminal of the battery connected to the collector and the positive terminal to the base. Under these conditions, very little current flows in the collector circuit.

The input circuit consists of the emitter and the base, although there is no physical external connection between them. The emitter is made of a light-sensitive (photosensitive) material. When a beam of light shines on the photosensitive emitter, the resistance of the *output* circuit decreases and more output current flows. The current carriers (electrons) move in the direction shown by the arrows. A relay coil can be connected in the output circuit. Then, by shining a beam of light on the emitter, we can cause enough current to flow in the collector circuit to operate the relay. The relay, of course, is nothing more than a switch and can be used to turn on a circuit (or turn it off). For example, the relay can be used to turn on a motor (operating a machine) or it can set in motion any number of other operations.

Surface-barrier transistor

Fundamentally, all vacuum tubes and transistors are alike — but so are human beings. However, tubes, transistors and human beings are individualistic so that, while they are basically alike, they also have enough characteristics of their own to make them different. Some transistors work well at low frequencies. Others work well at higher frequencies.

One of the transistor types that does very well at high frequencies is known as the surface-barrier transistor. A cross-section view of the unit is shown in Fig. 1204. The difference between this transistor and those we have studied is in the method of construction. The surface-barrier transistor is a triode, with an emitter, collector and base and has flat electrodes made of metal. These are plated on the transistor base material, forming the emitter and collector, respectively. Note the shape of the base. The unit is actually very small. The drawing is exaggerated in

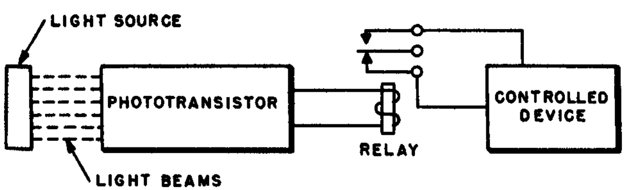

Fig. 1202. *Because the phototransistor supplies more output current, it can operate the relay directly, without the necessity of using an amplifier stage.*

size to enable you to see what has happened. The region of the base located between the emitter and collector is extremely thin. Because of this, the time required for electron movement is very small; hence the transistor can be used for high-frequency work.

The surface-barrier transistor is identified by the prefix SB (surface barrier). Thus we have types such as the SB-101, SB-102, etc. However, EIA type numbers have been assigned to these

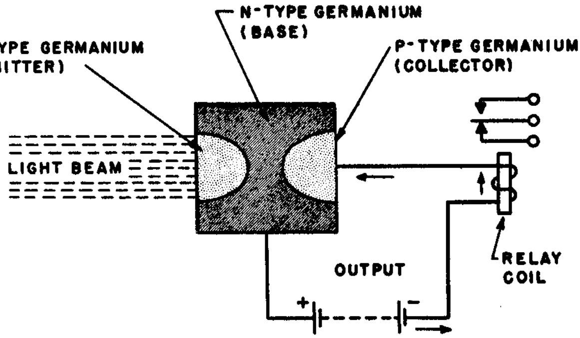

Fig. 1203. *Cross-section of the phototransistor.*

transistors so you will also find them as part of the 2N series. For example, the SB-101 is also identified as a 2N344, the SB-102 as 2N345, and the SB-103 as 2N346.

A surface-barrier transistor such as the SB-101 has a symmetrical lead arrangement, as shown in Fig. 1205. A red dot is placed on the side of the package (transistor casing) to act as a guide for lead identification.

Micro-alloy transistor

This transistor type may be classified in the surface-barrier family. The emitter and the collector electrodes are made by putting an impurity on the semiconductor, alloying a thin film of the substance on the germanium.

Micro-alloy diffused-base transistor

If the impurity is diffused instead of being alloyed, the transistor is then known as a micro-alloy diffused-base transistor (see also the section on diffused-junction transistors).

Silicon transistors

Like germanium, silicon (properly treated) is a well known semiconductor. After the silicon is purified, controlled impurities are added to form silicon transistors.

Silicon has a number of advantages over germanium. It is capable of working in higher temperature ranges. Silicon transistors have lower leakage currents than germanium transistors.

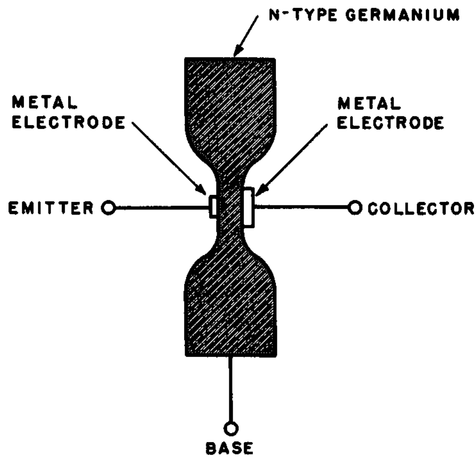

Fig. 1204. *Cross-section of the surface-barrier transistor. This is just one type of a group that have been developed for high-frequency operation.*

The circuit arrangements used for silicon units are the same as for germanium transistors, but the values of associated resistors and capacitors may be slightly different. Generally speaking, germanium transistors work better at higher frequencies; silicon works better at higher power levels.

Silicon transistors are useful for industrial applications. Such applications would include servo-motor control, magnetic core switching, solenoid operation, dc-to-dc converters (used in hybrid auto radios), and low- to medium-power oscillators in transmitters. In receivers they can be used in single-ended or push-pull output stages.

A drawing of a silicon transistor is shown in Fig. 1206. This is a medium-power n-p-n unit for switching applications, or it can be used as an amplifier. An index on the transistor package helps identify the position of the emitter lead. The center lead is the base, while the remaining lead is the collector. In some silicon transistors the collector lead is connected to the case of the unit.

If the chassis is positive, this means that the case will have to be insulated from it.

Tetrode transistor

The very first vacuum tube was just about the simplest type you can imagine – a diode. A big forward step was made when the control grid was added. In time, the inside of the vacuum tube became quite a busy place with more and more elements being added. As you might suspect, history is busy repeating

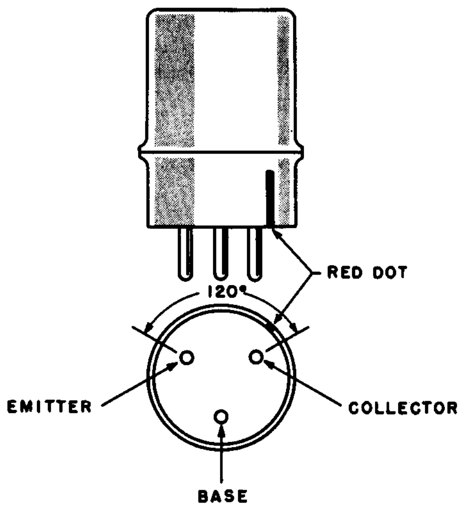

Fig. 1205. *Surface-barrier transistor.*

itself. And, while the triode transistor is used almost exclusively, we do have tetrode transistors, also known as double-base junction transistors.

A diagram of the tetrode transistor is shown in Fig. 1207. The transistor has the usual emitter, base and collector, but two connections are made to the base. The transistor is a p-n-p type, the base being made of an extremely thin layer of n-type germanium. N-p-n types are also made. The advantage of the tetrode transistor is that it can work at much higher frequencies than the usual triode transistor. For example, a type such as the 3N29 can work at 30 mc while the 3N30 operates at 120 mc. Fig. 1208 shows the bottom view, side view and the electronic symbol for the tetrode.

Diffused-junction transistor

The diffused-junction transistor in itself is not a specialized type. The name of the transistor refers to the technique by which it is manufactured. Briefly, a diffused-junction transistor is made by permitting an impurity to melt into a thin region of germanium or silicon. The heated impurity will spread or diffuse into the semiconductor material – hence the name. The diffusion process is just one method for forming a p-n junction.

A diffused emitter-collector transistor is one in which both the

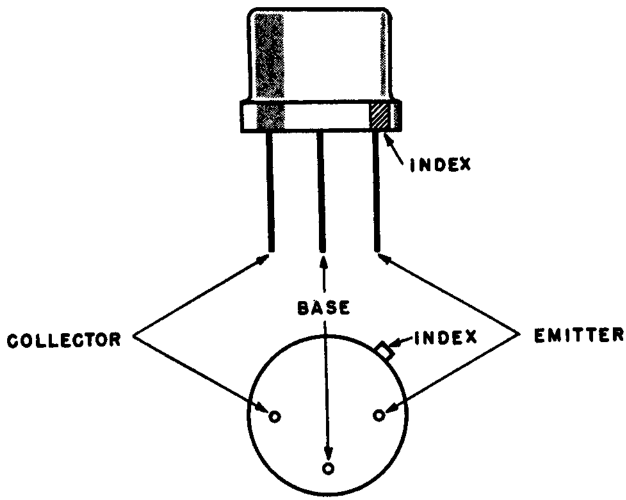

Fig. 1206. *Silicon transistor.*

emitter and the collector are formed by using the diffusion technique just described. A diffused-base transistor is one in which the base is formed by the diffusion process. From what we have said thus far, you can see that the diffused-base transistor and the diffused-emitter transistor come under the general heading of diffused-junction transistors.

Fig. 1209 shows the outline drawing of an n-p-n diffused-junction silicon power transistor. This transistor supplies high power output. As an example, a matched-pair working in class-B push-pull will supply as much as 15 watts of audio power. The transistor has four mounting holes for connection to an external heat sink.

Keep in mind that transistors can be made in many different ways, and that there might be just slight differences in manufacturing techniques between transistor types. In some cases the manufacturers have named the transistor after the technique used

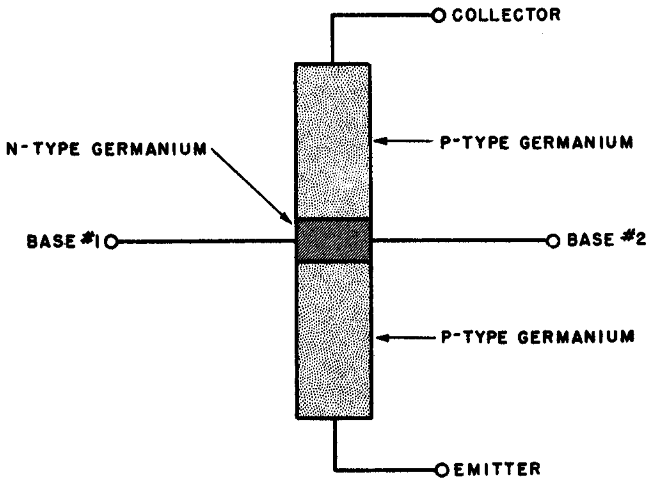

Fig. 1207. *Cross-section of the tetrode transistor.*

in its production. Other manufacturers have identified their transistors from the way in which the transistor operates, and in some

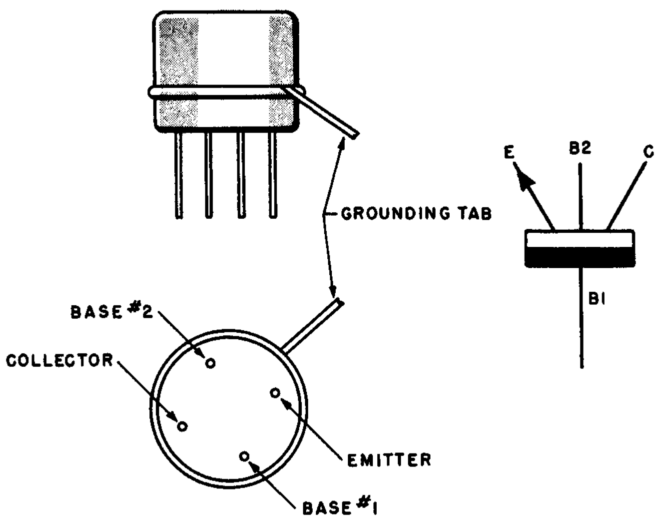

Fig. 1208. *The tetrode transistor and its electronic symbol.*

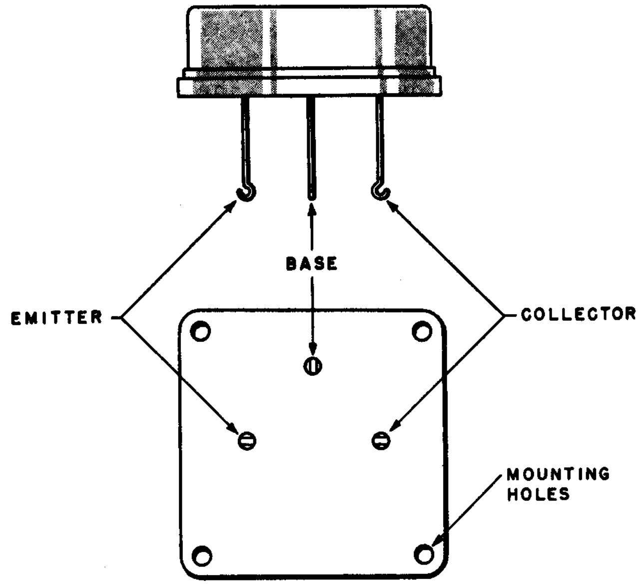

Fig. 1209. *Outline drawing of an n-p-n diffused-junction silicon power transistor.*

cases the transistor is named after both its production method and its operating technique.

Now add to this the fact that new processes and manufacturing methods are constantly being developed, and you can easily see that identifying the transistor by name is getting to be quite a mixed-up business. For example, transistors can be known as fused-junction, diffused-junction, diffused, alloy-junction, fused-alloy, diffused-alloy or diffused-alloyed, micro-alloy, grown diffused-junction, micro-alloy diffused-base, etc. These do not represent all of the names and certainly, as time goes on, the list will expand. We cannot describe all of these for you, but we can cover enough of the various types to give you an idea of what is going on in this industry.

Grown-junction transistor

During one stage in the manufacture of pure germanium it is in molten form. The material is not allowed to cool but remains in a melted state in a crucible. A small bit of pure, solid germanium – known as the seed – is attached to the end of a rod and is then dipped into hot germanium. The hot germanium sticks to the seed and is pulled up and out of the crucible. The germanium, during this process, cools and forms a crystal. However, before the germanium crystallizes, certain impurities are added. Thus, a grown-junction transistor is one in which the junctions are made by putting controlled impurities into the melt during the time of formation of the germanium crystal. Germanium n-p-n grown-junction transistors supply high gain in the if stages in automobile receivers.

Grown-diffused transistor

We can take a grown junction and, by using the diffusion process, obtain a grown-diffused transistor. Some of these have

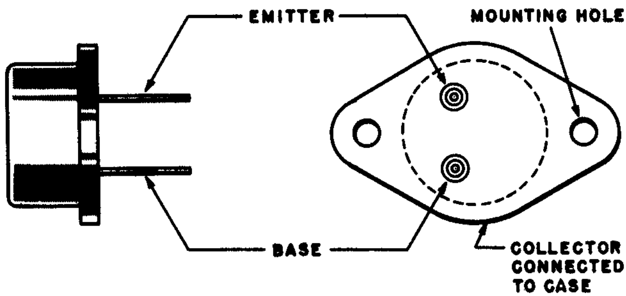

Fig. 1210. *P-n-p high-frequency power transistor for use in television deflection circuits.*

been designed for application in television circuits. Such a type is the 2N1046, a p-n-p high-frequency power transistor made for use in vertical and horizontal deflection circuits in television receivers (Fig. 1210). The package or case of the transistor is made of welded metal. The emitter and base leads are brought in through a glass-to-metal seal on the bottom side of the transistor. The collector is connected to the case. The transistor is rated at 15 watts.

Color-coded transistors

One type of transistor has a shape somewhat like a crystal diode. This is the HA7501 shown in Fig. 1211. The unit is a p-n-p silicon type designed for switching, control and audio applications. The color coding is used to identify the transistor, different colors being used for different transistor types in this series.

Hook transistor

A hook transistor, shown in Fig. 1212, is one having two layers of p-n germanium. This special arrangement is designed to supply an amount of amplification greater than that of the usual triode arrangement. The hook transistor resembles the point-contact type in that it has an alpha greater than one — that is,

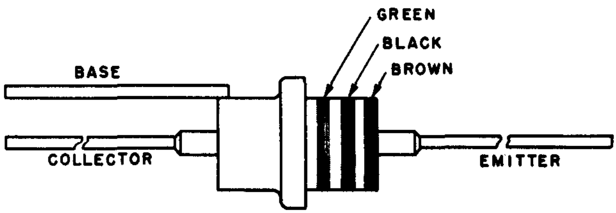

Fig. 1211. *P-n-p silicon transistor identified by color coding.*

the collector current is many times greater than the emitter current. But like the point-contact transistor, the hook transistor does have some instability in certain circuits.

The intrinsic semiconductor

When we started this book, we learned that by using acceptor or donor impurities we could make either p-type or n-type ger-

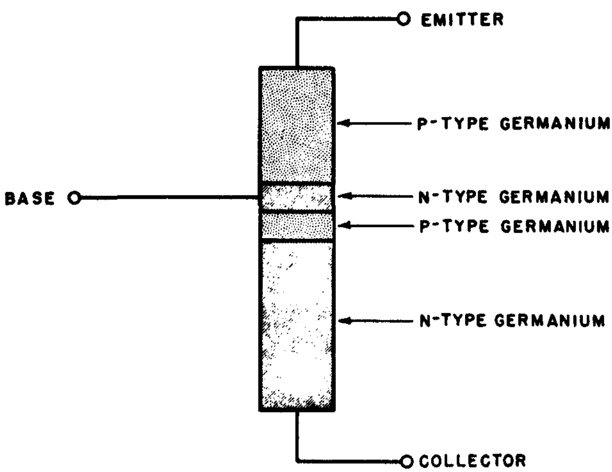

Fig. 1212. *The hook transistor is a two-layer unit.*

manium and that our current carriers — holes or electrons — would be determined by the type of impurity added to the pure germanium. However, the doping process can be so controlled that the germanium contains, approximately, an equal number of both types of current carriers — holes and electrons. We cannot call germanium treated in this way as p-type or n-type since it is actually neither. This type of semiconductor is called an intrinsic semiconductor or i-type. Thus, we now have three types of semiconductors available — p-type, n-type, and i-type.

Intrinsic-junction transistor

As you might suspect, the i-type semiconductor wasn't developed without putting it to work. As a result we now have the intrinsic-

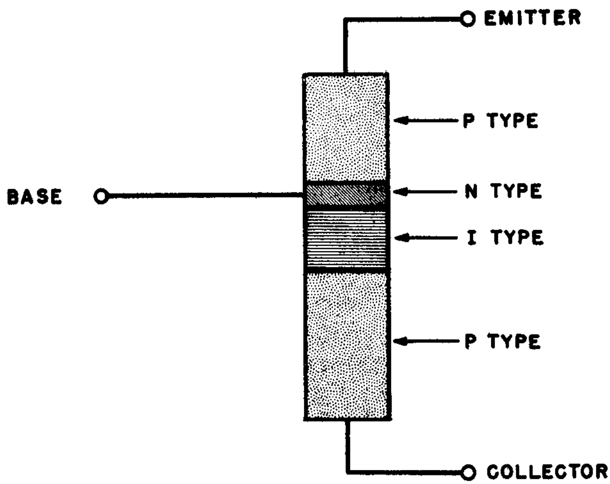

Fig. 1213. *Intrinsic junction transistor.*

junction transistor, illustrated in Fig. 1213. This is really a p-n-p transistor with a layer of i-type material sandwiched between the base and the collector. This makes it a four-layer transistor or a p-n-i-p type. Intrinsic-junction transistors are also made in the form of n-p-i-n.

Drift transistors

One of the big problems confronting transistor designers and engineers has been the need for getting the transistor to work at higher and higher frequencies. The surface-barrier transistor and the intrinsic-junction transistor are big forward steps in this respect. Another transistor that represents a big improvement in high-frequency response is the drift transistor (also known as the diffused-base transistor).

You will recall from our earlier descriptions that transistors are made conductive by doping them with selected impurities. In the drift transistor, an impurity is added to the base. The amount of impurity is carefully controlled so that the maximum amount is close to the emitter, gradually decreasing so that there is only a small amount near the collector. The impurity material that is added is of the type that has excess electrons. When these electrons move away they will leave holes. But holes, as we have learned, represent positive charges. The base region is then said to have

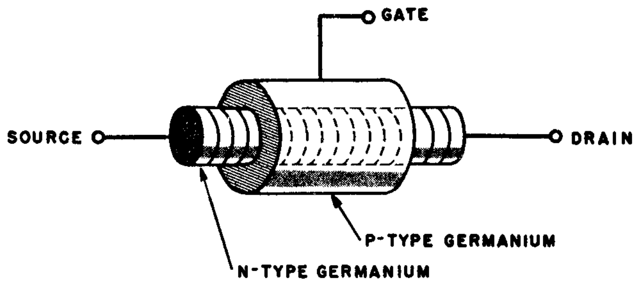

Fig. 1214. *Field-effect transistor.*

an electric field (somewhat resembling a charged capacitor). This electric field will accelerate the movement of current carriers from the emitter to the collector. And because the current carriers have been speeded up, the drift transistor can operate at higher frequencies than ordinary types. At high frequencies the movement of current carriers must be fast. In technical language we say that we have shortened the transit time. The difference is like going cross-country by auto or by plane. Both will get you there, the only question being "How long will it take?"

Field-effect transistor

The use of an electric field to control the flow of current carriers may sound new to you, but it really should not be. Consider the more familiar vacuum tube. The current flow between cathode and plate is controlled by an electric field. You know it more familiarly as the input voltage on the control grid. In the drift transistor described in the previous paragraphs, the electric field is actually "built in" the transistor, but there is no reason why an external electric field cannot be used. The field-effect transistor, shown in Fig. 1214, is such a unit.

The field-effect transistor is somewhat unusual and has a few names for its component parts that are new. Current starts at the *source* and flows to the *drain*. Consider source as emitter or cathode, and drain as collector or plate and you'll have no difficulty. Going from the source to the drain, we have a cylinder of n-type germanium. Surrounding the n-type germanium is a sort of sleeve made of p-type germanium. A lead going from the p-type germanium is called the gate. This corresponds to the base in the transistor or the control grid in the vacuum tube. A voltage is placed on the gate to control the flow of current from the source to the drain.

The current carriers in the field-effect transistor are electrons.

Unijunction transistor

This transistor is another one of a rapidly growing group of unusual types. A cross-section view of the Unijunction transistor

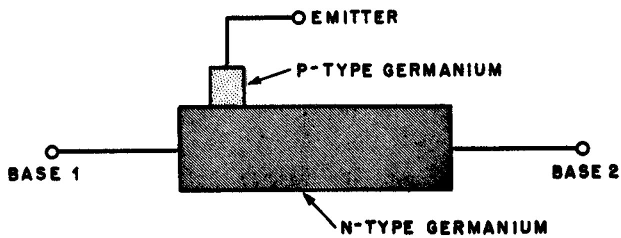

Fig. 1215. *Cross-section of the Unijunction transistor.*

is shown in Fig. 1215. The transistor consists of an emitter and, instead of having a collector, has a double base connection. For this reason, the transistor was originally known as a double-base diode. As shown in the drawing, the body of the transistor is made of germanium or silicon. An n-type semiconductor material is used. Coming out of the ends of the semiconductor are two leads, one for base 1 and one for base 2. The emitter, p-type material, forms a junction with the n-type base.

Thus, as indicated in the drawing, we have two diodes with a common emitter. Actually, the two base leads could be soldered together, resulting in an ordinary diode rectifier. To operate the unit as a transistor, a bias voltage must be connected between the two bases. The negative terminal of the bias battery is connected to base 1 and the positive terminal to base 2. The emitter is also biased positively with respect to base 1.

With this arrangement, the transistor has a very high resistance and so the amount of current flowing is negligible. But when the emitter voltage is increased (this voltage is between the emitter and base 1), the resistance will suddenly drop to a very low value, resulting in a very sharp increase in current. This "all or nothing at all" arrangement means that the Unijunction transistor is very well suited for use as an oscillator.

Spacistor

One of the chief efforts of transistor manufacturers has been directed toward getting the transistor to work at higher frequencies. The Spacistor was designed to supply high gain at frequencies

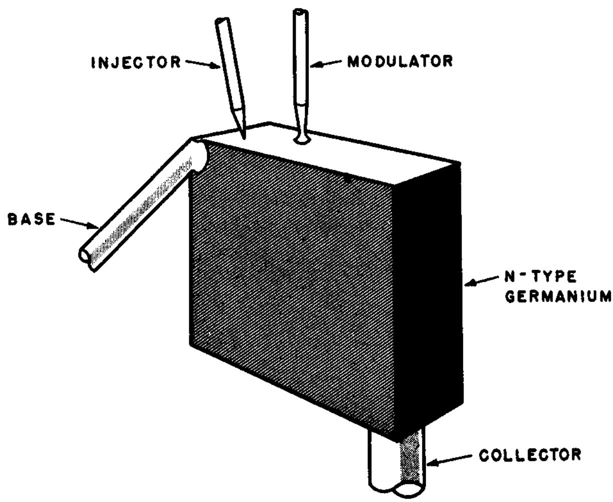

Fig. 1216. *The Spacistor resembles a vacuum tube in its operation.*

above 1,000 mc. Unlike other transistors, the collector operates at a comparatively high voltage. The Spacistor is a four-terminal device, having a base and collector. In place of the usual emitter, this transistor has an injector (Fig. 1216). The final electrode is called the modulator. Electrons are injected by the injector. Because of the high voltage on the collector, electron movement between injector and collector is speeded considerably.

The body of the transistor consists of n-type germanium. The modulator electrode forms a small p-n junction in the n-type germanium.

The Spacistor seems to resemble a triode vacuum tube much more closely than other types. The injector can be compared to the cathode, the modulator to the control grid and the collector to the plate.

The input signal is applied to the modulator. This, in turn, varies the number of current carriers passing at any moment between the injector and the collector.

Transistors at work

The number of commercial and industrial jobs a transistor can do is limited only by the ingenuity of technicians and engi-

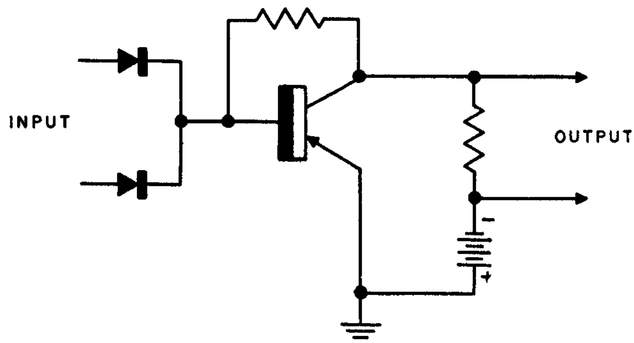

Fig. 1217. *Simple transistor gate circuit.*

neers. A transistor is often developed because a particular industrial problem cannot be solved through the use of existing units. The newly developed transistor is explored fully and is then made applicable to many new jobs. Quite often, you will find the same transistors used in radio receivers at work in industrial applications.

Here are a few of the many possible uses to which transistors can be put: analog computer circuits, flight simulators, Geiger counters, garage-door openers, hearing aids, vibration measurement devices, servomechanisms, digital computer circuits, missile control, instrumentation (test instruments), counting circuits, pulse-forming circuits, trigger circuits, electronic organs, FM transmitters, radio teletype, mobile radio units, telephone-line amplifiers, etc.

Gating circuit

A gating circuit is an electronic on-off switch. Where a device must be switched on and off several thousand (or many more) times per second, a manual switch is obviously impossible. Fig. 1217 shows a simple gating circuit using a p-n-p transistor. There are two inputs, tied in parallel. The signal voltages for the inputs could come from a multivibrator or from any other electronic device that could supply a driving voltage. The transistor gate circuit is normally nonconducting. When a pulse is applied to the input, an output voltage is developed across the collector load resistor. The gate can be used to put a particular circuit into action or to keep it from operating. For example, a gate is used in color television receivers. When only a black-and-white

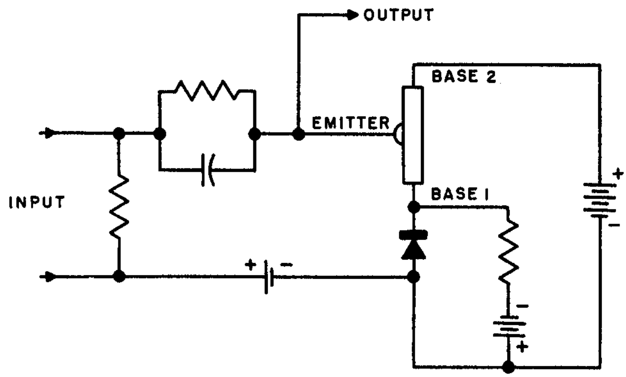

Fig. 1218. *Pulse amplifier using Unijunction transistor.*

signal is received, the gate is "closed," preventing the color circuitry from operating and interfering with the black-and-white picture. When a color television signal is picked up, signal voltage is used to "trigger" the gate. With the gate in action, the color circuits are permitted to do their job.

Unijunction transistor pulse amplifier

The Unijunction transistor described earlier can be used as an amplifier to build up pulses. Pulses are widely used in television transmitters, in counting circuits and in radar units. Pulses are also used in television receivers.

A simple Unijunction pulse amplifier circuit is shown in Fig. 1218. The pulse (or trigger voltage) is applied across a small resistor. This resistor is connected in series between the emitter and base 1. When a voltage (such as the trigger voltage) is put across the resistor, the polarity of the voltage is such that the resistance of the emitter-to-base circuit is drastically reduced, permitting a heavier flow of current. The output current is fed into an R-C network, the charge and discharge thus adding a sawtooth component to the pulse.

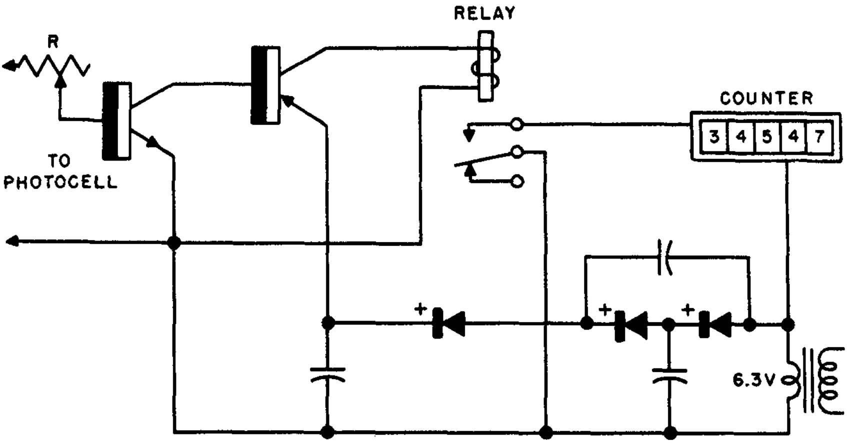

Fig. 1219. *Photocell and transistors operating to work a mechanical device, such as a counter.*

Counting device

A pair of transistors can be used in conjunction with a photocell and a relay to operate a mechanical type of counting device. This is illustrated in Fig. 1219. Every time a beam of light strikes the photocell, the transistors go into operation. The two transistors are direct-coupled. Enough current flows in the collector circuit of the second transistor to operate a sensitive relay. The mechanical counter is of the type that will work from low-voltage ac. Every time current flows through the relay, the relay armature moves, closing the counter circuit. A record can thus be kept of the number of times the photocell is illuminated by a beam of light.

Spacistor amplifier

A simple circuit arrangement for a Spacistor amplifier is shown in Fig. 1220. Three bias supplies are shown, one each for the injector, the modulator and collector electrodes. The input signal is supplied between base and modulator. The output circuit is standard, the amplified signal being taken from across the collector load resistor.

Tetrode amplifier

An amplifier circuit using a tetrode transistor is shown in Fig. 1221. The transistor is a p-n-p alloyed-junction type, actually a power type capable of supplying up to 5 watts output. The variable resistor is adjusted for optimum collector-current output.

The stage can be connected directly to a speaker as shown and has the advantage that no output transformer is required. The circuit can also be used as a modulator in transmitting circuits.

Your servicing chart

A service technician is an electronic detective. A competent service technician doesn't need too many clues to help him find the villain. We have given you many clues as to why a transistor receiver will become defective. But we cannot possibly expect

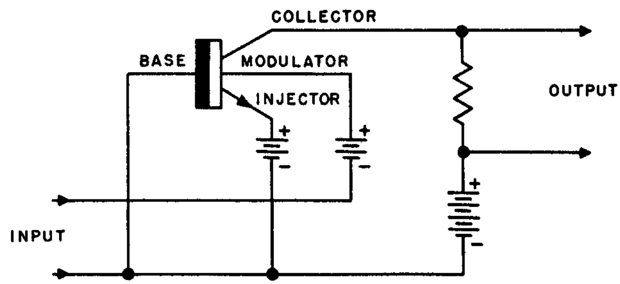

Fig. 1220. *Simple Spacistor amplifier circuit.*

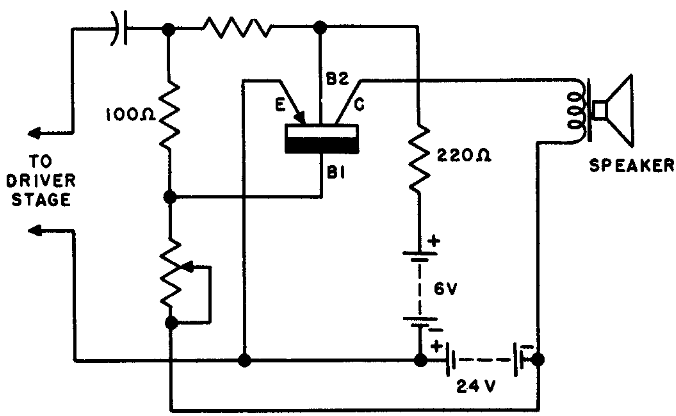

Fig. 1221. *Amplifier circuit using a tetrode transistor.*

you to remember every page of every chapter. We know you will want to refer to this book from time to time to help you in your work. Since we have been preaching constantly about "saving time," we cannot expect you to waste time looking for information. And so, for your benefit and convenience, we have compiled a servicing chart.

troubles	servicing techniques
AGC voltage missing Ref. Chapter 4 Chapter 5 Chapter 9	Make sure that the receiver is tuned to a station. If you are using an output meter but have the speaker disconnected, a meter reading doesn't necessarily indicate the presence of a station. The receiver may be oscillating (one of the if stages may be regenerative). If, however, you do have a station but no agc voltage, check the agc filter resistors and capacitors. If the set seems unusually sensitive, overloads easily and distorts, but agc voltage is missing, trouble is definitely caused by some defect in the agc network. The crystal diode will sometimes pass enough audio signal to make you think that it is good, but, if a check of the agc system does not reveal the trouble, try replacing the diode. Missing agc voltage may not necessarily indicate a defect. The set may be using delayed agc, in which case no agc voltage would appear until the signal level is strong enough to overcome the amount of delay voltage.
Audio instability Ref. Chapter 8	Refer to the section on Motorboating.
Audio output, low Ref. Chapter 3 Chapter 5 Chapter 6 Chapter 8	Usually caused by some defective component in the detector, driver or push-pull (or single-ended) output stage. Check the battery. This must be done under full-load conditions. Use signal tracing, starting at the detector. Tune receiver to a number of different stations. If all stations come in loudly, except one, then trouble is not in the receiver. Weak audio can also be caused by defects preceding the detector. Connect audio generator across the volume control. Set the control for maximum audio output. If signal is strong, then trouble is not in the battery or the audio section but exists somewhere before the volume control. If trouble is in audio section, check components; also voltages at transistor elements. Make sure speaker is in good condition by click-testing it or by using substitute speaker. Earphones, sometimes used, may have defective jack. Put on earphones. If volume is

troubles	*servicing techniques*
Audio output low (continued) Ref. Chapter 3 Chapter 5 Chapter 6 Chapter 8	good but sound of speaker is weak, then check the speaker. Transistors are usually the last item to check.
Battery life too short Ref. Chapter 7	The battery in portable transistor receivers is usually shunted by an electrolytic. If excessively leaky, this could put a severe drain on the battery. The on-off switch might be defective. These switches are small devices and sometimes have mechanical difficulties. For a quick test, turn the receiver on and tune in a strong station. Put on the receiver earphones (if set is so equipped) or keep your ear close to the speaker. Now turn the set off. The switch should make a definite clicking sound as it is turned off and the sound should be absolutely dead. If you hear weak sound faintly in the background, you are getting leakage through the switch. Put a dc milliammeter in series with either side of the switch. Turn the receiver on and note if the current is as recommended by the manufacturer. Now turn the set off and note if current drops to zero. Short battery life is sometimes caused by improper operation of the audio section of the transistor receiver. If the audio transistor or transistors draw excessive idling current, battery life will be shortened. In a class-B amplifier, the idling current should be less than 5 ma. This will rise to about 40 ma (or more) with signal. Some sets use batteries which can be charged. If battery voltage is weak, it may simply mean that the battery has run down. Rechargeable nickel-cadmium batteries can be recharged repeatedly. Remember also that penlight type cells will not last as long as mercury batteries. Mercury batteries should have a life expectancy at least several times as long as penlight cells. When making voltage checks on mercury or nickel-cadmium batteries (where these have

troubles	*servicing techniques*
Battery life too short (continued) Ref. Chapter 7	been used to replace penlight cells), keep in mind that mercury and nickel-cadmium types supply about 15% lower voltage.
B-plus voltage too low Ref. Chapter 2 Chapter 7	Batteries may be weak. Check batteries under full load. Do this by turning receiver on and tuning to loud station. If battery voltage is 30% below no-load voltage, replace. If batteries are of rechargeable type, try giving full charge and then make full-load test. If batteries will not take a charge, replace them. If, however, batteries take a full charge and maintain voltage under load but batteries get weak very rapidly, look for defective component that puts heavy load across the battery. Low B-plus voltage can also be caused by a short in the receiver or leaky electrolytics. If the voltage across the battery terminals is good but you get less than normal voltage at the transistor pins, then some component has either changed its value or become defective. Transistors are the last item to suspect. If the set uses transformers, resistance check from each winding to the transformer shield. A high-resistance leak here will put a drain on the battery. In auto receivers, if B-plus is too low, check the storage battery and the dc-to-dc converter in hybrid sets.
Birdies Ref. Chapter 8	Refer to the section on Tweets
Dead receiver Ref. Chapter 7 Chapter 8	Refer to the section on Inoperative receiver
Distortion Ref. Chapter 3 Chapter 5 Chapter 6 Chapter 7 Chapter 8	This symptom may or may not be accompanied by weak signals. If the signal is distorted on all stations then the trouble is usually in the detector, audio driver or output stages. Distortion can be caused by a changed value of emitter resistor, by an incorrect replace-

troubles	servicing techniques
Distortion (continued) Ref. Chapter 3 Chapter 5 Chapter 6 Chapter 7 Chapter 8	ment value of emitter resistor or by a shorted emitter bypass capacitor. To check, measure the voltage across the emitter resistor.

Check resistance-capacitance decoupling filters where used. If the capacitor is open, the distortion may be accompanied by motorboating. If the capacitor is leaky, there will be a heavier than normal voltage drop across the decoupling resistor. The collector voltage will then be insufficient.

If the receiver distorts only when the set is tuned to a strong signal, check the automatic gain control circuit. Shunt the existing agc filter capacitor with a similar unit. If the distortion clears, then the original capacitor is at fault.

If the detector also supplies agc, try replacing the detector. Make sure the detector hasn't been inserted with reverse polarity.

Distortion can also be caused by a battery which just about needs replacement.

If the receiver uses earphones and the signal as heard in the earphones sounds good, but is distorted when the speaker is used, check by using a substitute speaker.

Check the base bias of each transistor. It doesn't take much of a change in bias to produce distortion. If the voltages are incorrect but the battery voltage is good, then resistance-check the bias voltage divider network. Do not make this check with the transistor connected.

Distortion can also be produced if the rf bypass capacitor at the detector output is open. This causes overloading of the first audio amplifier stage.

Electrolytics are often used as coupling capacitors. If these become excessively leaky, the base bias of the following stage will be changed. Shunting the capacitor with a known-good unit is of no use. Open one end of the suspected capacitor and then connect in the new unit. Suspect coupling capacitors especially if the bias of the following stage is incorrect but voltage divider and battery check OK.

troubles	*servicing techniques*
Distortion (continued) Ref. Chapter 3 Chapter 5 Chapter 6 Chapter 7 Chapter 8	Distortion can be caused by the speaker. The cone may be torn or the voice coil can be rubbing against its pole piece. Cones have a habit of drying out. To extend the life of a cone, moisten the cone with a sponge. Do not soak the cone but wipe it gently once or twice with the sponge. The sponge should be damp, but squeezed out. Putting lacquer or shellac on the cone will help extend its life. Keep the lacquer from running into the space between the voice coil and the pole piece. Distortion can be caused by a defective driver or output transformer. This may be caused by a shorted turn or excessive leakage or a high-resistance short between the winding and the case. A shorted turn is almost impossible to detect with a resistance check. Distortion can be caused by misalignment. Screwdriver-happy customers are often responsible for this condition.
Fading	If the receiver fades after it has been on for a short while, the trouble is usually due to a weak battery. This is sometimes deceiving since a weak battery, if not used or loaded, often seems to regain its strength. To check, turn the set on until you notice the fading condition. Then turn the set off for at least an hour. If the fading condition repeats again after you turn the set on, replace the battery. A condition resembling fading is caused in car radios when the car passes near a structure containing a large amount of metal. In passing through a tunnel, the signal may disappear completely. A portable transistor receiver will often operate inside a car provided you are not too far distant from the station. You will get best results if the portable is kept close to the window. Do not confuse fading with an intermittent condition. In fading, the change is a gradual one, but the condition in an intermittent is much more abrupt. With an intermittent, the sound may go suddenly from full volume to a whisper.

troubles	*servicing techniques*
Inoperative receiver Ref. Chapter 4 Chapter 7 Chapter 8 Chapter 10	Check the battery. If it has dropped below 30% of its full-load voltage, replace it. Check to make sure that the entire receiver isn't dead. Inject a signal (audio) across the terminals of the volume control. If you get a signal output, the trouble precedes this point. Signal-trace through the entire set. Any stage that doesn't pass the signal is at fault. If the local oscillator isn't functioning, there will be no signal output. The receiver may be inoperative if transistor voltages are incorrect. If signal tracing shows a particular stage to be at fault, check bias voltages. If these are not correct and battery is good, check all resistors and capacitors going to the transistor of that particular stage. The trouble may be due to an open decoupling resistor, open or changed values of voltage-divider resistors, open emitter resistor, open collector resistor, open if transformer winding (or a short in the if). Check the ferrite-core antenna. It may be open or the connections to it may be broken. Every receiver will show a certain amount of resistance across the battery clips. To check, remove the battery. Connect your vtvm (set to read ohms) but make sure that the plus lead of the meter goes to the plus wire clip of the battery. If the resistance as measured agrees with that indicated by the manufacturer, the trouble is in the battery or else the battery connections are broken or corroded or the on-off switch is broken. If the resistance is much lower than normal, look for a shorted condition in the set. The trouble may be caused by an open or shorted phone jack.
Interference Ref. Chapter 9	Interference in an auto receiver can be caused by any mechanical component in motion and by many electrical components as well. Noise can be produced by the distributor, generator, spark plugs, ignition coil, wheels. Noise voltages are often radiated by the wiring of the car.

troubles	*servicing techniques*
Interference (continued) Ref. Chapter 9	Since auto radios have a tuned-radio-frequency amplifier stage, interference between stations is not particularly noticeable. However, in portable receivers having low selectivity, you may get such interference. If this is due to the design of the receiver, there isn't much you can do about it. Try turning the portable in one direction or the other to favor the desired station. In a home receiver, usually occupying a fixed position, it may be necessary to move the receiver to a different spot. Realignment may help. If the customer prefers certain stations, realignment can be done to favor those stations, but at the expense of others.
Intermittents Ref. Chapter 11	Rotate the volume control. If the set operates best at one particular spot of the control, the control is dirty or worn. Clean with carbon tet or commercial lubricant cleaner. If pressing hard on the volume control knob removes the trouble, the wiper arm inside the pot has pulled away from the resistance element. It may be easier to replace than to fix. Intermittents are often caused by poor mechanical contacts. Spot-soldering of any and all riveted connections may help. Make sure that the battery is securely mounted in its holder and that the battery snap connections are tight and secure. If the battery is corroded, replace it. Before inserting the new battery, clean away all corrosion, using steel wool. Make sure no fragments of the steel wool drop into the set. Intermittents can be due to poorly soldered connections, either produced during the original manufacturing of the set or because of prior servicing. Spot-solder any doubtful connections. With the receiver turned on and the volume turned down partially, put your ear near the speaker and then rotate the tuning dial from one end of the broadcast band to the other. If you hear any scratching during this time, either the rotor and stator plates are scraping or else the tuning capacitor mounting has become loose. Sometimes the trouble

troubles	servicing techniques
Intermittents (continued) Ref. Chapter 11	is simply due to dirt or metallic dust or particles that have become imbedded between the stator and rotor plates. Examine both the oscillator and rf tuning sections of the variable capacitor. Also check the wiper contact of the capacitor. Some sets have switching arrangements. Listen to the set while manipulating the switch. You will hear a crackling sound or the set may become completely inoperative if the switch contacts are dirty, worn or loose or poorly soldered. If the set has an earphone jack, make sure that its contacts are clean. An intermittent can be caused by a loose lead going into some component. Check by tugging gently on all component leads. You can also do this easily by tapping on the leads with the rubber end of a pencil. If the volume changes or breaks when any lead is so touched, check that component.
Motorboating Ref. Chapter 6 Chapter 8	This is an intermittent sound, often accompanied by squealing. Check for an open decoupling capacitor. Also check the electrolytic shunted across the battery. If the electrolytic is leaky and the battery has begun to age, you have a combination that can produce this trouble. This condition is sometimes produced by a change in the value of the feedback resistor or capacitor. Motorboating is also caused by high-resistance joints. Spot-soldering the rivets on the printed-circuit board or on the battery holder will help cure this trouble. Make sure that the tuning capacitor is securely mounted.
No output signal Ref. Chapter 8	Refer to the section on Inoperative receiver.
Noise (See Interference) Ref. Chapter 9	
Noise but no signal Ref. Chapter 8 Chapter 10	The local oscillator may not be functioning. You can check the local oscillator by any of the techniques previously described in detail

troubles	*servicing techniques*
Noise but no signal (continued) Ref. Chapter 8 Chapter 10	in these chapters. If the oscillator isn't working, check the voltages at the base and emitter of the converter transistor. Also check the voltage at the collector of the converter. If any of these voltages are missing or are incorrect, check voltage-divider and dropping resistors connected to these elements. The trouble might be due to a defective oscillator coil. Check all other oscillator components also. Sometimes the trouble is due to a defect in the oscillator section of the tuning capacitor. Rotate the capacitor to the high-frequency end of the dial. If stations come in at this point but not at the low-frequency end of the dial, the capacitor plates are shorting. If the reverse is true—that is, if the set works for low frequency station but not for the higher frequency ones—then the rotor plates of the oscillator tuning capacitor are shorting against some metal component.
One station only over entire tuning range Ref. Chapter 8 Chapter 10	The if stages may be severely misaligned. Someone may have tampered with all alignment slugs and screws. This condition can sometimes happen when the local oscillator isn't working. The misaligned if can pick up a broadcast station, with the entire receiver acting as a fixed-tuned rf receiver. Check the local oscillator.
Oscillation Ref. Chapter 4 Chapter 8	The symptom in this case will be squealing. The set may be very touchy and sensitive. Look for an open in the neutralizing network (resistor or capacitor or both) if the set has such a network. The trouble may be in the agc system. Make sure that the detector diode isn't reversed. Check all agc filter capacitors. This trouble may be caused by a weak battery. Oscillation can be caused if the ground connection of the printed circuit doesn't make good physical contact with the ground of the receiver.

troubles	*servicing techniques*
Poor sensitivity at low end of broadcast band Ref. Chapter 10	This may be caused by misalignment of the oscillator or rf section. It sometimes results also when the converter transistor is replaced.
Poor sensitivity at the high-frequency end of the broadcast band Ref. Chapter 10	This trouble may be caused by poor alignment in the front end of the receiver. It can be caused when the converter transistor is replaced.
Regeneration Ref. Chapter 8	Refer to the section on Oscillation
Scratching sound Ref. Chapter 6	Sometimes due to controls that are worn or dirty. Check by rotating the volume control. Some sets also have variable tone controls, although these are less likely to produce this trouble since they aren't used as much as the volume control. Clean all controls with a lubricant cleaner. Some tone controls use a switching arrangement. Dirty, loose or broken contacts can cause this trouble.
Sound distortion Ref. Chapter 6	Refer to the section on Distortion
Sparking Ref. Chapter 9	Refer to the section on Whine
Squealing Ref. Chapter 8	Refer to the section on Motorboating
Static in auto sets Ref. Chapter 9	This is a noise produced only when the car is in motion and is caused by wheel friction. Eliminate by using static-collector springs or graphite powder. The powder is injected into the inner tube. Refer also to the section on Interference
Tweets Ref. Chapter 8	This condition can be caused by defective lights, particularly fluorescent fixtures. Turn the light off but keep the receiver turned on. If the condition disappears, the trouble may be due to the light or to the fluorescent starter. This trouble can also be caused if the local-oscillator voltage is too high.

troubles	*servicing techniques*
Volume changes considerably as receiver is tuned from one station to next Ref. Chapter 5	Check the agc system, including all filter resistors and capacitors. Try replacing the detector.
Weak signal Ref. Chapter 5	Refer to the section on Audio output, low
Whine Ref. Chapter 9	This is a condition in automobile radios. It is generally noticed as the car is accelerated or slowed. In this case the trouble is caused by the generator. It can be eliminated in several ways. The easiest is to put a suppressor capacitor on the generator. Connect one lead of the capacitor to the terminal marked A on the generator. The other lead of the capacitor should go to the metal frame of the generator or the car. Some capacitors have only one lead and depend on the mounting clamp for making a good ground connection. The single lead coming out of the capacitor should go to the A-terminal on the generator. Another method of eliminating whine is to replace the generator brushes. Try cleaning the commutator segments. Sometimes the mica segments between the commutator segments work their way up. The mica must then be ground down. In severe cases, it may be necessary to replace the generator. Make sure that the line connecting the armature of the generator to the regulator is kept away from the antenna lead to the receiver.
Whistling	This condition may appear on all stations. It can be caused by a weak battery. The trouble can also be caused by a receiver that is misaligned or by a defective neutralizing capacitor or resistor. Also check the agc circuit. Examine the antenna coil. If the polyiron slug is cracked, replace it or put in a new antenna coil.

index

This is a cumulative index. It contains listings for volumes 1 and 2.

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