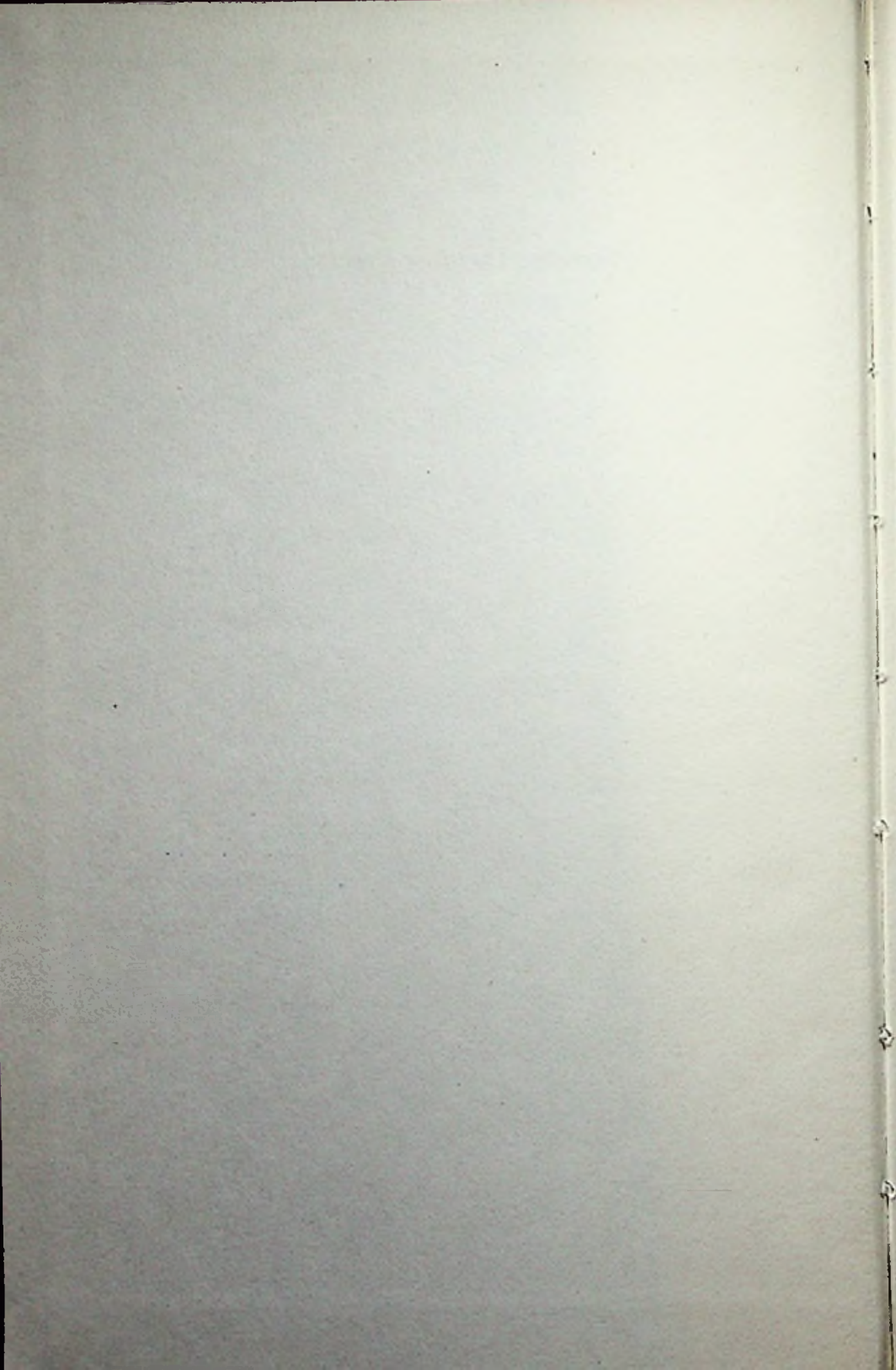Servicing
Transistor
Radios and
Printed
Circuits

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LANE

Servicing
Transistor Radios
and Printed Circuits

LEONARD LANE

Edited for this edition by

E. A. W. SPREADBURY, M.BRIT.I.R.E.

Technical Editor, *Wireless and Electrical Trader*

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Contents

Preface

This book, a revised version of a Transistor Radio Repair Course offered by a leading manufacturer in co-operation 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 analysed.

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 forced 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 valve 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 practising 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 part.

In the second half of the book, the emphasis is on the practical applications of the semiconductor fundamentals presented in the first half.

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 valve parameters, small voltage changes are just as troublesome in these low-impedance circuits as the more apparent changes caused by defective valve components.

Special consideration is given the unique problems of hybrid and all-transistor car 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 valve servicing techniques adapted to the low-impedance and low-voltage characteristics of transistor circuitry.

Printed-circuit boards are evaluated, and their advantages and disadvantages analysed 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 this book be a stepping-stone to a better and more prosperous future for everyone.

LEONARD LANE

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Introduction

In anglicizing this book from the American edition I have tried to retain the author's original style as far as possible, but the differences between the American idiom in which it is written and general English usage in the United Kingdom have resulted in modifications to the text.

As far as possible the author's free and easy style have been retained, and even in many cases a looseness of phrasing to which a scientifically minded purist might take exception. But this book is not addressed to the purists. It is written for the novice, be he an apprentice service engineer, a keen amateur or even a young boy, anxious to learn something about those remarkable little sets that work off a torch battery.

In this respect the author succeeds admirably. He is obviously a practical man himself, and he talks and writes in a practical manner that the novice can easily take in. Often he uses the novices own language, and if the purist questions the wisdom of this, let him try to explain the working of a transistor to a novice.

This little book is an easy-to-read explanation of the subject, embracing all its aspects from the domestic receiver angle, including printed circuits, and I confidently recommend it to the type of enthusiast for whom it was written.

E. A. W. SPREADBURY
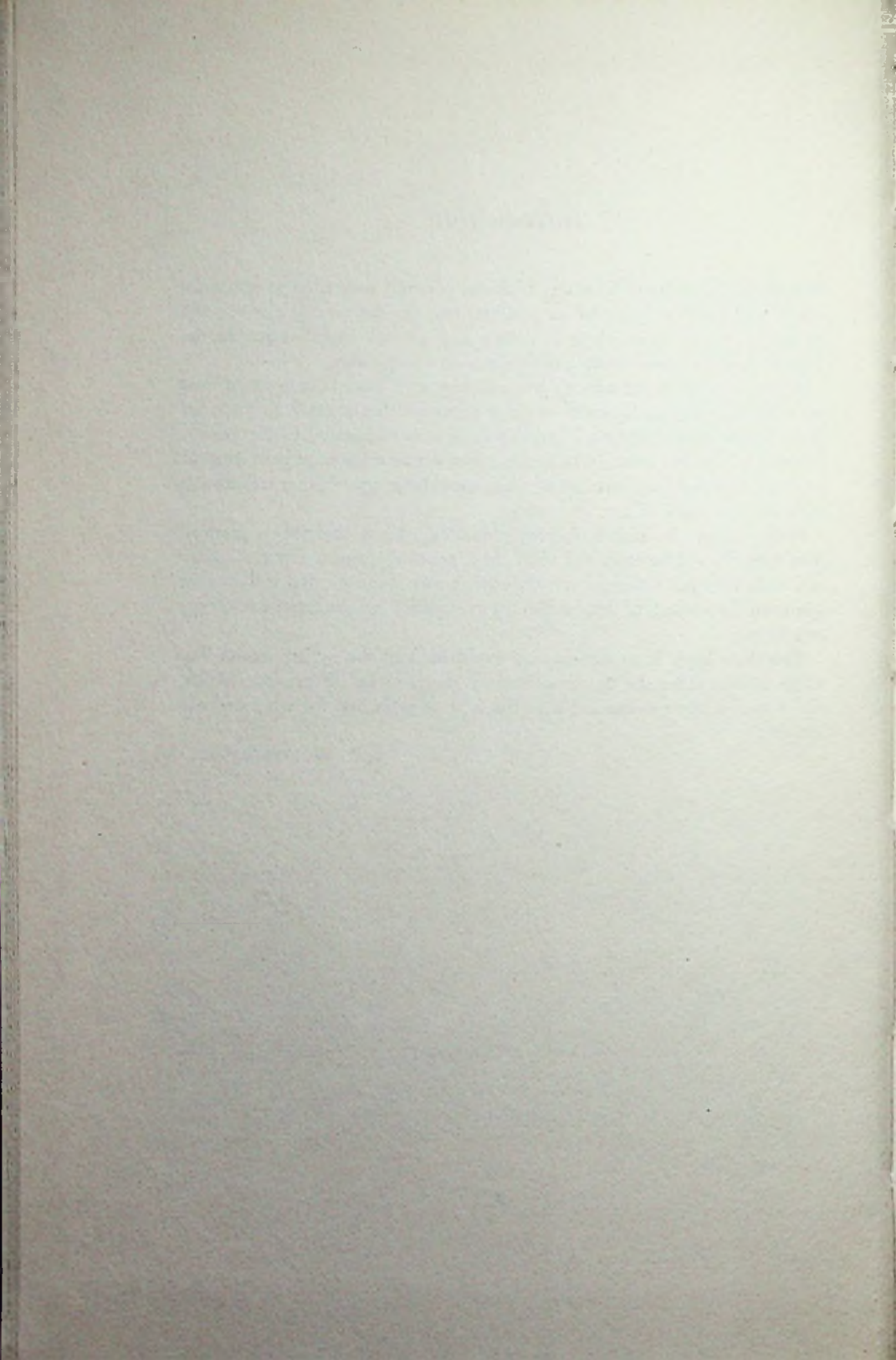
Semiconductor Fundamentals

THE transistor is a comparatively new device (it was invented in 1948 and developed since that time), yet its ancestry is older than that of the valve. Radio receivers and radio broadcasting became popular soon after the end of the first World War. In those days, valves were so new and expensive that the crystal detector persisted alone. This crystal detector (Fig. 1.1) was made of a variety of materials such 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. It had, however, 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 headphones. Headphone reception, though, is a very tiresome affair, and it was not long before the crystal set was superseded by the valve receiver—despite the fact that valves 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 with a fixed contact in place of the " cat's whisker ", was put back into service, but it still performed its old function—that of a detector (Fig. 1.1). It did this job very well and quite efficiently since it 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 to amplify, 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 some 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 compounds of sulphur, such as copper sulphide and lead
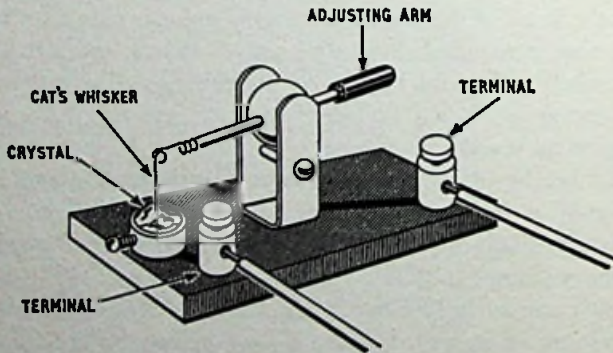

Fig. 1.1—The crystal detector has a long history. The drawing shows a detector that was popular many years ago

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 one in which we are primarily interested is known as germanium. Germanium, which we will discuss in considerable detail, is exactly the same

substance that you already know as a diode in radio and television receivers.

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 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 anode (Fig. 1.2). This is another
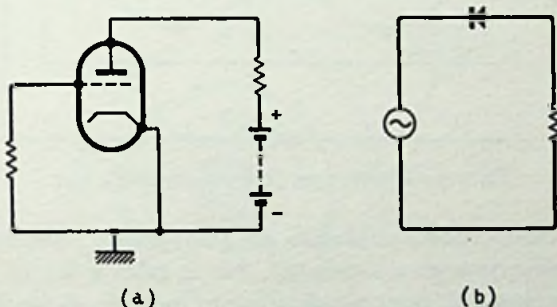

(a)   (b)

*Fig. 1.2—Electrons can move through a vacuum (a).
They can also be made to move through a solid (b)*

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 valve) is somewhat different from the movement of electrons in a solid material. In a valve (apart from 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, but in fact 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, embedded in the stream is a series of flat rocks and so our young adventurer is able to cross 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 similar manner. The electrons move from one atom to the next, ultimately arriving at their destination (Fig. 1.3).

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 plastics. The difference between a conductor and an insulator is not in the way the electrons move but
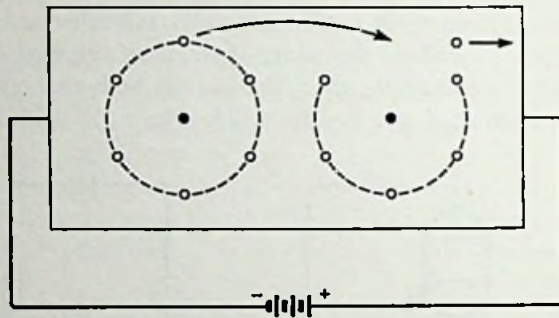

Fig. 1.3—Electrons move from one atom to the next

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 to move in an insulator.

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 television 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 rings of electrons encircling a nucleus.

In Fig. 1.4 we have a drawing of an atom of germanium. Essentially, it consists of a nucleus (or central portion) around which we have rings of electrons. The innermost ring contains 2 electrons; the

second ring 8; the third 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 a strong attraction for all the electrons that revolve around it, and it will not let any go without a struggle. However, of all the electrons shown in Fig. 1.4, the outermost or valence electrons are farthest from "home" (the nucleus) and so these are the ones we are going to manoeuvre 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 elec-
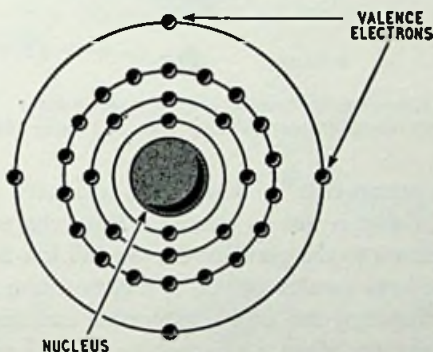

Fig. 1.4—*The germanium atom. The four valence electrons are the ones we are interested in*

trons 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.

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 by just 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 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 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
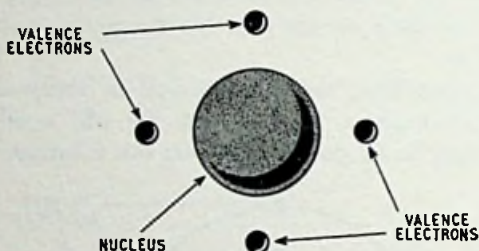

Fig. 1.5—Simplified version of the germanium atom. The valence electrons are the ones that will work for us

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. 1.5 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 sphere in the centre 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 as shown in Fig. 1.5 represents a condition of stability, since the electrons are firmly attached or attracted to their central nucleus.

If, as shown in Fig. 1.6, 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 has one electron more than is really needed.

As far as the antimony atom is concerned, this excess electron has its permission to go wandering off and not return. Now, if you multiply this condition by the millions upon millions of excess electrons donated by the antimony, you will see that we have a very useful 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.

If you think back to the way a valve behaves, you will see that we are working towards an operation that is already familiar. After all, a valve 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 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 happens when another
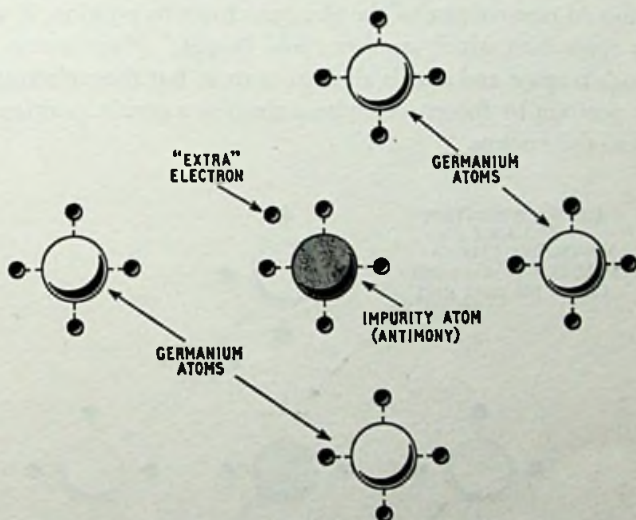

Fig. 1.6—N-type germanium is formed by adding an "impurity" that contains excess electrons

kind of impurity is added to the germanium. This time, though, a material is added that has fewer valence electrons than the germanium.

A substance such as boron or aluminium has only three valence electrons—that is, one fewer than the outer ring of germanium. In Fig. 1.7 we show this atom of boron in company with a number

2

of germanium atoms. Everything appears to be normal except that there is a vacant space that should be occupied by an electron.

In order to understand the importance of this, let us compare it with a boarding house. A boarding house produces no profit unless it has lodgers. If the boarding house has 15 rooms and each of them is occupied, then we have a very good situation. But if one of the rooms is vacant there is a space into which a boarder could 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.

In between the boron atom and the germanium atom we have a "room to let". It is a space into which an electron could conceivably move. We call this space a "hole". Remember, 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 another could be put. Now it may seem that space is space and that is all there is to it, but these electrons are held in position by forces which keep them in a certain position with respect to the nucleus.
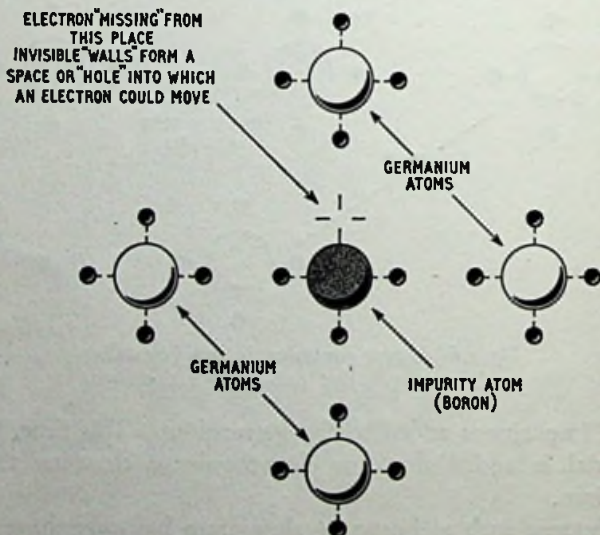

Fig. 1.7—P-type germanium is formed by adding an " impurity " that has a shortage of electrons
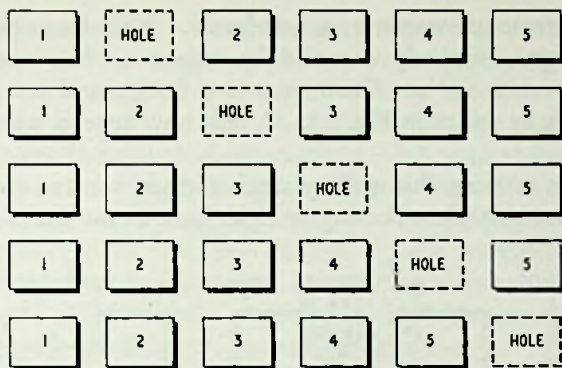
Fig. 1.8—Each block represents a goods wagon. The vacant space or " hole " can be made to move back by changing the positions of the wagons

To make this clearer, imagine that you have a set of toy trains and that these are arranged on a circular track. You stand at the centre and are therefore the nucleus. The set of trains goes round and round as long as power is applied. Let us assume that the train set consists of a locomotive pulling 10 empty wagons. If you were to disengage the last, you could substitute another for it. In other words, the new wagon would take the place of the old one. That is, it would be inserted in the space previously 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 wagons somewhere in the centre you would leave a " hole " into which you could put some other goods wagon.

MOVEMENT OF HOLES

It will be useful for us to continue playing with this goods train. Let us imagine that we can remove any wagon we wish. Let us also imagine that the wagons are all held together by side strips so that, if we do remove any one wagon, the train will continue in motion as shown in Fig. 1.8. All that will happen is that we have a vacant space or hole where our particular goods wagon used to be.

For example, we can have one possible arrangement of a goods train. Behind the engine is a space into which we could put a goods wagon, but which for the moment is empty. The side slats couple the engine to the remainder of the train, so the wagons are pulled along behind this vacant space. Let us call this vacant space a " hole ". In this hole would normally appear goods wagon 1. We have,

however, removed wagon 1, as you know.   Now let us put wagon 2 in the space formerly occupied by wagon 1.   We now have a hole between 2 and 3.   Continue a step further and put wagon 3 into hole 2, as shown in Fig. 1.8.   A hole now appears where 3 used to be.

Without carrying this analogy much further, you can see that we can move a hole from the engine right back to the guard's van, or
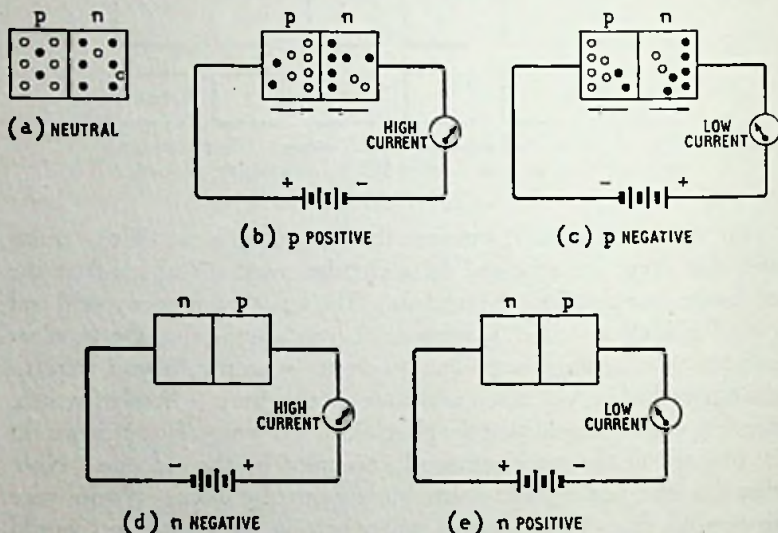

Fig. 1.9—*When the pn diode is properly biased, a " high " current flows*

we can go in the other direction if we wish.   Once again we must remind ourselves that we are not moving just any old " space " but rather a space that is reserved for a particular wagon.

What we have done with a goods train 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 aluminium or boron which has 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 goods wagon than you might imagine.   A goods wagon has substance and so has an electron, and

they both have weight. 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 also when it 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 five shillings in your pocket, represented by two half-crowns, you might consider your financial condition quite sound. If you should spend one of the half-crowns you could represent your condition as " minus half a crown ".

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

Consider now a substance such as boron. Instead of four valence electrons it will have only three electrons and a hole into which a spare electron can be put if one is available. Since one is not available at the moment, the hole will have to be represented by a positive charge. Of course, if this material is mixed with germanium, in effect a tremendous number of positive charges will be added to the germanium. For this reason, when putting an impurity deficient of electrons into germanium, a new sort of semiconductor is created to which we give the name " p-type " (Fig. 1.7). The letter " p ", of course, is an abbreviation for the word " positive ".

THE SEMICONDUCTOR DIODE

As a first step in the manufacture of transistors, let us put together two slices of germanium—p-type and n-type—and for the time being we will call them a sandwich. 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, in addition let us put them across a source of voltage such as that supplied by a battery. This is depicted graphically in the illustrations shown in Fig. 1.9.

As you will probably guess, the electrons, shown as solid black dots, will try to move through the germanium towards the positive side of the battery. And the holes, represented by little circles, will migrate towards 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 reversed. Note the ammeter reading in both these illustrations. In the first instance the ammeter indicates a rather large flow of current; in the second drawing the meter shows either zero or something very close to it.

A NEW KIND OF THINKING

So far all your radio theory and experience—especially in valves and circuits—have emphasized electron flow. Now it will be easier if you can conceive 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 valves was wrong. On the contrary, our knowledge is moving along and growing, so we need to think about current in a new way.

One suggestion may be helpful. Instead of thinking of "electrons" and "holes" as two separate items, group them as a single unit and call them current carriers.

Returning to the p- and n-type germanium—the flow of current carriers is due to the movement of electrons and holes. It is of interest to know which of these two items makes the greater contribution. The answer is quite easy. Take two slices of germanium, one n-type and the other p-type, placed close together, and it would be surprising 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 there are more holes or more electrons.

And what about the current flow that we are interested in? If the n-type germanium is rich in electrons and the p-type germanium has fewer holes, then the current flow will consist mostly of electrons. If the opposite is true, then the current flow will consist mostly of holes. From a practical point of view, this does not matter much since current carriers are being considered—and that covers both electrons and holes.

TRANSISTOR LANGUAGE

There are some special phrases that are used in transistor work.   The voltage that we apply to the transistor " sandwich " is known as a bias voltage.   A bias voltage is a steady d.c. potential and, instead of referring to the transistor as a " sandwich ", let us call it a junction. The reader will recognize that what we have so far is a diode, not a transistor, and he will already know that when a bias voltage is applied to our junction diode in one direction, a large current flows; if we reverse the battery leads, only a very low current is obtained.

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 two ways of saying the same thing.   Since we will get a large
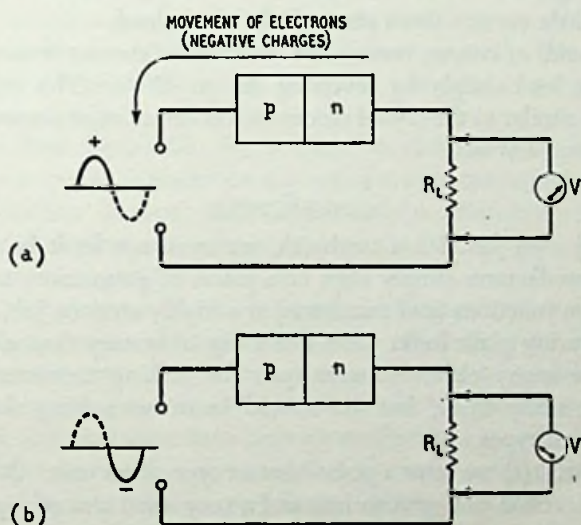

MOVEMENT OF ELECTRONS
(NEGATIVE CHARGES)

(a)

(b)

Fig. 1.10—A pn diode acts as a rectifier for an a.c. voltage

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 connections reversed), we have a condition of very low current and very high resistance.

Now this sort of behaviour is not new.   It is exactly the same as the way in which a germanium diode performs when used as a detector in a television set.   Such a diode permits current to flow much more

readily in one direction than in the other. It may seem to you that we are back where we started, but actually we are now only one step away from converting the diode into a triode amplifier.

Instead of biasing the diode, we can apply an a.c. voltage as shown in Fig. 1.10. Here there is a pn diode connected to a source of a.c. In series with the diode is a load resistor, R_L. To see if current will flow through the resistor, there is a voltmeter placed across it. In Fig. 1.10(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. 1.10(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.
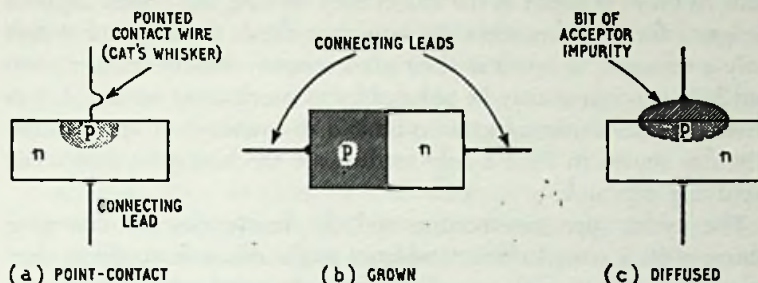
We could, of course, reverse the direction of current flow through the diode load simply by reversing the pn diode. This behaviour is exactly similar to the crystal diodes used as detectors or demodulators in radio and TV sets.

MANUFACTURE

In calling a pn junction a sandwich, we must not let it be thought that a manufacturer simply slaps two pieces of germanium together. Making pn junctions (and transistors) is a highly accurate 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. 1.11(a) we have a point-contact type of pn 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 cat's whisker. Older readers will recall that crystal receivers in the early 1920's also used a cat's whisker on the crystal. The idea is the same. The point-contact type is considered obsolete—but you can never tell. It has several unique qualities and some day it may be popular again. However, it is not found in any modern transistor receiver.

In Fig. 1.11(b) is shown 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. 1.11(b) is a highly simpli-

POINTED
CONTACT WIRE
(CAT'S WHISKER)   CONNECTING LEADS

BIT OF
ACCEPTOR
IMPURITY

n   p

CONNECTING
LEAD

(a) POINT-CONTACT   (b) GROWN   (c) DIFFUSED

*Fig. 1.11—The pn " sandwich " can be made in many
ways. The point-contact type is practically obsolete*

fied illustration and may give you the idea that there are two separate
and distinct blocks of germanium, which there are not. The structure
of the grown pn unit is fairly complex, but for our purposes the
illustration of Fig. 1.11(b) will serve.

In the third illustration, Fig. 1.11(c), we show a diffused pn unit.
Here the impurity is placed on a piece of n-type germanium. With
the application of heat, part of the n-type germanium becomes
p-type and diffuses into the n-type germanium—hence the name
applied to this type of structure.

Plate 1 illustrates some of the semiconductor power rectifiers that
have been popular. We have included a selenium type along with
the silicon rectifiers for size comparison only. Such rectifiers have
been used quite extensively in both radio and television transformerless
receivers, although some 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 are
made to operate from the mains, as some transistor hi-fi amplifiers and
pre-amplifiers might be. For ordinary use batteries are still less
expensive, and bothersome wires are not needed.

The new, more efficient batteries, and those which are rechargeable,
offer advantages which will keep the semiconductor power supply
for transistor radios from becoming popular rapidly.

Silicon power rectifiers are also designed to replace mains rectifying
valves. These need no filament current as do valve rectifiers used in
car radio and a.c. mains powered equipment. They may cost more

than 10 times as much as the valves they replace, but power supplies designed for these rectifiers are only two-thirds the size and weigh only a sixteenth as much as their predecessors. Power consumption and heat generation may be reduced by as much as 25 watts. Let us never consider semiconductors as limited to low-current applications. The fins shown in Plate 1 help to dissipate the heat generated while rectifying 750 mA.

The eyelet type construction and the heat-exchanger fins give silicon units a remarkable resemblance to the selenium rectifiers they were designed to replace. This type of construction allows the original mounting holes to be utilized without resorting to conversion kits or drilling new holes.

A semiconductor unit, however, could contain a voltage-regulating semiconductor called a Zener diode. Although 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 used to obtain 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 their entertainment uses. Silicon rectifiers are made that exceed the capabilities of the seemingly monster-size 250-ampere rectifier which would dwarf a normal domestic rectifier. These units might be found in a heavy-duty battery charger of the quick-charge type used by some garages. Semiconductor diodes and transistors are by no means limited to the portable radio field, and these heavy-current units have been included to emphasize the vastness of the semiconductor field, but they will not be discussed further in this book.

SIZE

Radio components, 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 Plate 2 with the valve. As far as size is concerned, the valve takes up very little space. Compared to the transistor, though, it is a giant.

Other components (Plate 3) 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 small physical size but seemingly large values, made necessary by the inherently low impedance characteristics of transistor circuitry.

Capacitors using an electrolyte of tantalum oxide are now manufactured with capacitances that once would have been remarkable in a unit of india-rubber size. Some variable capacitors utilize thin plastics insulators between their plates, not only to take advantage of the increase in dielectric constant, but to provide an insulation medium that is comparatively free from short-circuits. Loudspeakers are as small as headphone earpieces. Transformers for both audio and r.f. are only a shadow of their former selves. Jacks, plugs and other connectors are shrinking rapidly to keep in proportion with the diminutiveness of the other components, all redesigned to make connection to printed-circuit assemblies easier.

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 sub-assembly is formed. An entire instrument may be no larger than a single i.f. transformer once was. The electrical characteristics of transistor components are dealt with in the chapters on servicing.

The size of the components shown in Plate 3 can be gauged from a comparison with the ruler that is included with them.

CHAPTER 2

How Transistors Work

WHEN first studying valves it is usual to begin 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 as a valve, and nothing could be less mysterious. That is why, in our first chapter, we started with pn diode units.

We are now ready to go a step further and we can begin by looking at Fig. 2.1. Here we have a pn diode which we have connected to a bias battery. Let's see what we've got. There is single bias cell connected to a p unit which we call the emitter. Our slab of n-type
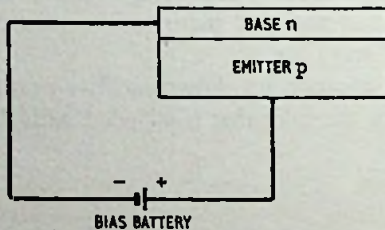
*Fig. 2.1—The emitter injects current
carriers (holes) into the base*

germanium, connected to the negative terminal of the cell, is called the base.

There are a few more facts to be learnt from Fig. 2.1. 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. 2.1, the current carriers

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HOW TRANSISTORS WORK 19

are holes or positive charges. Because of the flow of current carriers, the resistance of this forward-biased diode is low. Note also that the size of the base is small compared with the emitter.

THE TRANSISTOR

To arrive at the transistor, one final step must be taken, as shown in Fig. 2.2. Note what has happened. A slice of p-type germanium has been added to the diode of Fig. 2.1, and to complete the circuit another bias battery has been added. But, before we go any further, make a note of 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. These two, and the base, constitute a transistor.

The arrangement we have shown in Fig. 2.2 really consists of a pair of diodes, back to back. The emitter and base form one of the
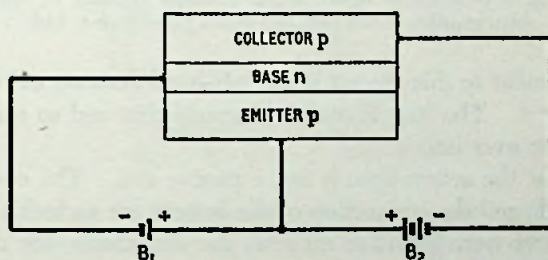
Fig. 2.2—The transistor consists of an emitter, base and collector

diodes, and the collector and the base form the second diode (Fig. 2.3). Note also that the collector (Fig. 2.2) is connected to the negative terminal of a bias battery.

HOW DOES THIS SET-UP WORK?

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, since they are pulled in two different directions. They are attracted by the negative terminal of battery 1, and also by that of battery 2. If both batteries were of equal strength, there might be an equal division of charges.

But suppose that we make battery 2 much stronger than battery 1.

Those positive charges will not then be side-tracked by battery 1 but will go on over to battery 2.

HOLE MOVEMENT IN A PNP UNIT

Let us see what happens in the pnp transistor. First, consider the forward-biased diode made up of the emitter and the base. The
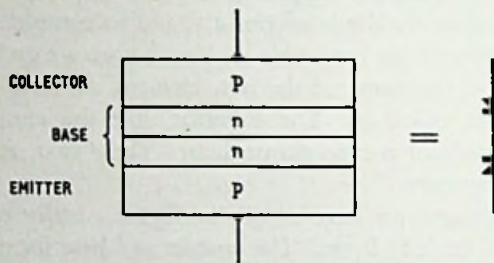

Fig. 2.3—*If the n region of the transistor is sliced in half (theoretically), it will form two diodes placed back to back*

action is similar to that shown in the left-hand drawing of Fig. 1.9 (b) in Chapter 1. The base is made extremely thin and so some of the holes diffuse over into it.

Note that the action here is not a passive one. The construction of the diode and the connection of the battery are such that the holes in the emitter were bound to move in that direction. For this reason it is quite correct for us to say that positive charges are injected by
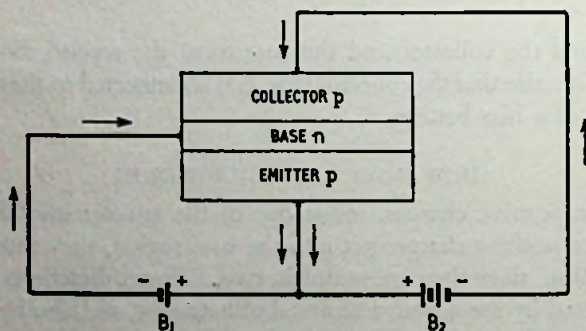

Fig. 2.4—*Most of the carriers (holes) go to the collector and form the collector current. A few of them flow in the base-emitter circuit. The arrows indicate electron movement external to the transistor*

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, it is estimated that about 95 per cent. of the positive charges will go to the collector and about 5 per cent. (the remainder) will be side-tracked and stay in the base. This is shown in Fig. 2.4.

Keep in mind that there is 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
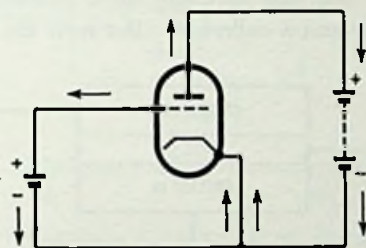
Fig. 2.5—*The triode transistor can be compared to a triode valve. Arrows show paths of electron flow*

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 an electron 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) towards the battery.

If you feel still puzzled, look at Fig. 2.5. Here we have a triode valve with a cathode (emitter), control grid (base) and anode (collector). There is a positive voltage on the control grid but this 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 they waste their time meandering through the grid-cathode circuit. But the great majority of the electrons moves over to the anode, which has a large positive charge on it.

Now what is the difference between what is going on in Fig. 2.4 and the events taking place in Fig. 2.5? 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 negative charges (electrons). In the case of the valve, not all of the electrons get over to the anode and, in the case of the transistor, not all of the holes get over to the collector.

THE NPN TRANSISTOR

We can arrange our pn germanium diodes so that they look like Fig. 2.6. Compare Fig. 2.6 with Fig. 2.2. Although at first glance the two will seem alike, 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
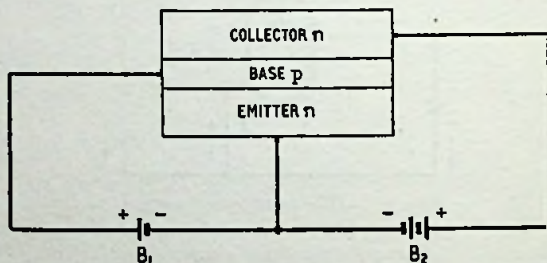
Fig. 2.6—In the npn transistor, the negative terminal of bias battery B_1 is connected to the emitter

germanium, the base is p-type germanium and the collector is n-type. Now examine the bias batteries, B_1 and B_2. The batteries seem to be in the same position as those shown in Fig. 2.2, but observe that their polarity has been reversed.

Electron movement in the npn transistor

When we studied the pnp unit of Fig. 2.2, we learned that the current carriers were holes. In the npn transistor, however, we may regard the electrons as the current carriers. 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 voltages of B_1 and of B_2. Most of the electrons are attracted to the collector, but some travel from the base, through B_1, 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 valve.   The cathode is necessary because we need a device that will, somehow, start the electron ball rolling.   There is no cathode in the transistor, but through the use of positive charges or holes the electrons are stirred out of their lethargy.
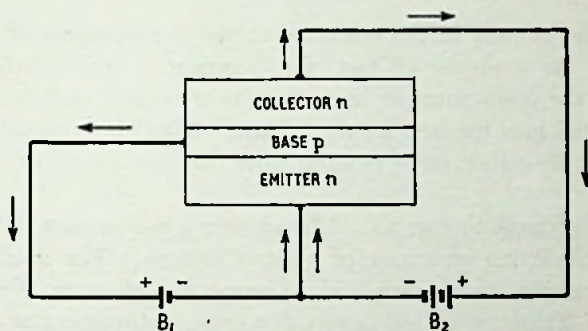

Fig. 2.7—*Electron flow in the npn transistor circuit*

Hole movement and electron movement in a transistor are always in opposite directions.   In Fig. 2.4 the electron current in the external circuit of a pnp transistor is shown.

At this point the convenience of thinking of current carriers instead of holes and electrons becomes apparent.   If we just talk about current carriers, then there is really no difference between the pnp and the npn types apart from the polarity.

In Fig. 2.7, we show the flow of electrons in an npn circuit.   Compare this with Fig. 2.4.   In the npn transistor, the direction of current flow (as shown in Fig. 2.7) is similar to that of a triode valve.   In the pnp transistor (as shown in Fig. 2.4) current flow is exactly opposite to that of the valve.   While the end result is the same from both types, most transistor radios (and practically all British ones) use pnp transistors.   And so, when measuring voltages, when considering polarity, and when replacing electrolytic capacitors, you must be careful to make the connections the right way round.

CURRENT-CARRIER INJECTION AND CATHODE EMISSION

The fundamental idea in either a transistor or a valve is to produce a current and then to obtain complete control over that current.   In a

3

valve the current is obtained by force. A cathode coated with an electron-rich material is heated and electrons are literally boiled off through the application of the intense heat. This method works —as any valve shows—but it is comparatively inefficient. Heating a filament or cathode requires a lot of watts and represents a large percentage of the power that must be supplied to 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 without the application of heat. In the transistor, current carriers are injected into the base by the emitter. This has been mentioned briefly a little earlier, but it requires more than just a word of explanation.

Let us go back to Fig. 2.1. 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. 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
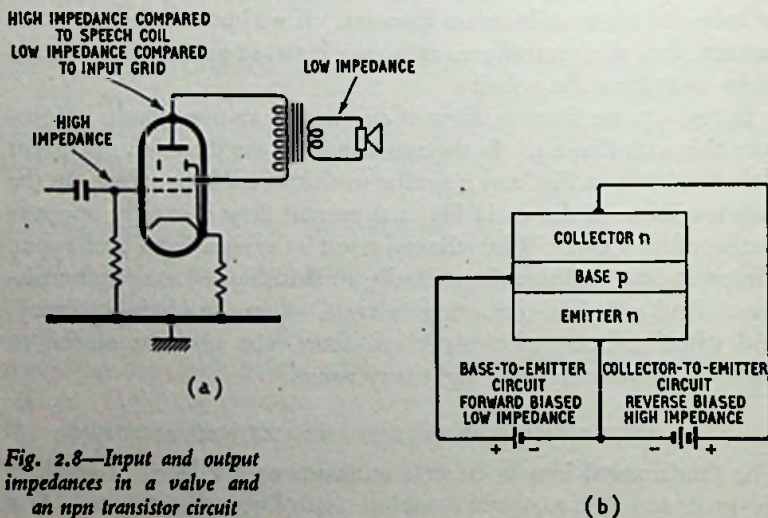

Fig. 2.8—Input and output impedances in a valve and an npn transistor circuit

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.

Of course, Fig. 2.1 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 npn transistor is exactly the same except that the current carriers injected into the base are negative charges (electrons).

HIGH AND LOW IMPEDANCE

High impedance and low impedance are terms quite commonly used by service technicians but perhaps some explanation of them is required. 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 valve is considered a high-impedance point, while the anode of that valve, passing a comparatively large current, is low-impedance when compared with the control grid of that same valve. But suppose we are talking of an audio output valve, transformer-coupled to a loudspeaker as shown in Fig. 2.8(a). The anode of an audio output valve could be regarded as a low-impedance point, from the viewpoint of the control grid of that valve. But the loudspeaker to which the anode is coupled is far lower. The loudspeaker might be 3 ohms, the anode of the valve might be 10,000 ohms and the grid might be of the order of several 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. 2.8(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 valves, so we have them also for transistors. The two basic transistor symbols are shown in Fig. 2.9. The letters b, c and e represent base, collector and

emitter, respectively.   The symbols for the emitter elements are the arrows—otherwise the pnp and npn transistor symbols are identical. The arrow representing the emitter points inwards in the pnp unit, and in the npn it points outwards.   In other words, it points in the direction of conventional current, which is opposite to that of electron flow.

These symbols are for three-element transistors—that is, transistor triodes.   There are other forms, such as transistor tetrodes, but we are not as yet concerned with them.   The symbols shown in Fig. 2.9 may be drawn in any convenient position, and letters identifying the electrodes can be omitted if desired.

THE INPUT SIGNAL

In valve 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. 2.10 is shown one way in which the input voltage
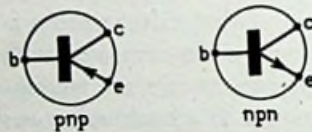
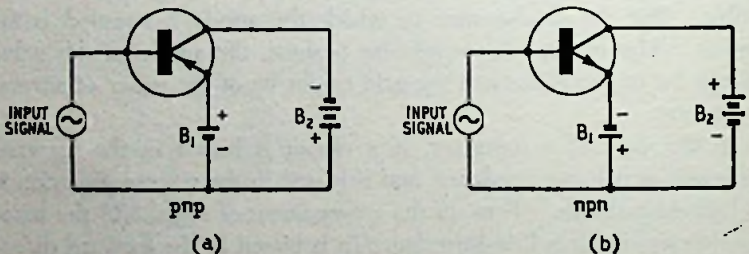*Fig. 2.9—Electronics symbols for pnp and npn transistors*

Fig. 2.10—The input can be a radio signal or the output of a generator

can be applied to the transistor.   In this circuit, the base behaves in a manner similar to the control grid of a valve.   The emitter is equivalent to the cathode and the collector represents the anode.

The emitter is biased by battery B_1.   As long as B_1 and B_2 are not changed, a small but steady current flows in the collector circuit. The input signal is in series with battery B_1.   The base-to-emitter
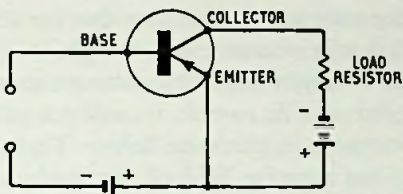
Fig. 2.11—Method of connecting
the load resistor to the transistor

circuit now consists of the base, the input signal voltage, battery B_1
and the emitter.

Because the input signal voltage is a.c. it alternately adds to and
subtracts from battery voltage B_1. 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 number
of current carriers reaching the collector. In this way, the collector
current is a replica of the signal voltage.

The circuit in Fig. 2.10(a) is for a pnp unit while that in Fig. 2.10(b)
is for an npn unit. It is important to note the difference in battery
connections.

In identifying a transistor, we refer to it as an npn- or pnp-type.
The first letter refers to the emitter, the second to the base and the
third to the collector. Thus, an npn transistor has n-type germanium
for the emitter, p-type for the base and n-type for the collector.
This 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 valve 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 loudspeaker or a relay.

In Fig. 2.11, we have a pnp 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 the signal source is not
connected, we can consider the input circuit as being open. However,
the output circuit is closed by the load resistor, and so we get a small

amount of collector current. 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 number of electrons will flow from the negative terminal of the battery through the load resistor, through the collector, back to the emitter and the positive 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 amplifies.

THE AMPLIFYING TRANSISTOR

Before we get down to learning how amplification is obtained from a transistor, let us consider the input and output resistances of a typical transistor circuit. Suppose that the input resistance is 100 ohms and 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 and suppose that there is 1 mA of current flowing in the input circuit. Since our input resistance is 100 ohms, 1 mA (0·001 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.

Not all of this current will reach the collector, but to make our arithmetic easier, let us imagine that it does. This means that there will be 1 mA of current flowing in the output circuit. This 1 mA (0·001 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

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 per cent. and 99 per cent. of the emitter current. The ratio of collector current

to emitter current is known as *alpha* or α. Since collector current is less than emitter current, it is less than 1, and therefore 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 is 9 divided by 10 which equals 0·9, or 90 per cent.

VOLTAGE GAIN

To determine the voltage gain of a transistor circuit, divide the output resistance by the input resistance and, having obtained this value, multiply it by the current gain α. In the example above the output resistance was 10,000 ohms and the input resistance 100 ohms. Dividing these two, we get 100 as the ratio of the two resistances. If the α of a particular circuit is 0·97, 0·97 times 100 equals 97, which is the voltage gain of that particular circuit.

So far it can be seen that if a very large gain is required from a transistor circuit, the output resistance should be made as high as possible, the input resistance as low as possible and α as high as possible.

BASIC AMPLIFIER CIRCUITS

Transistor amplifiers can be arranged in three ways: one of the " electrodes " is generally directly earthed or earthed through a resistor, and the type of amplifier is named by the earthed electrode. Thus, when the base is earthed, the circuit is referred to as an earthed-base amplifier, and one of this type is seen at (a) in Fig. 2.12. Similarly, if the emitter is earthed, as in Fig. 2.13, it is termed an earthed-emitter amplifier; and finally, if the collector is earthed (Fig. 2.14), we have an earthed-collector amplifier. In each figure the comparative valve circuit is shown at (b).
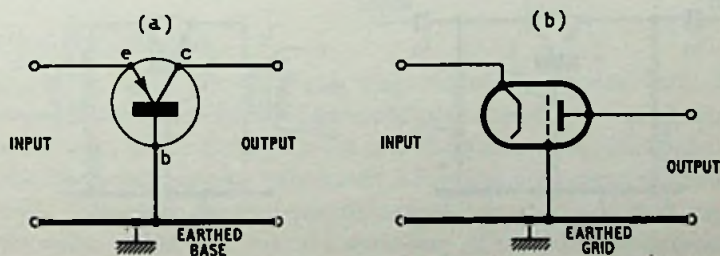

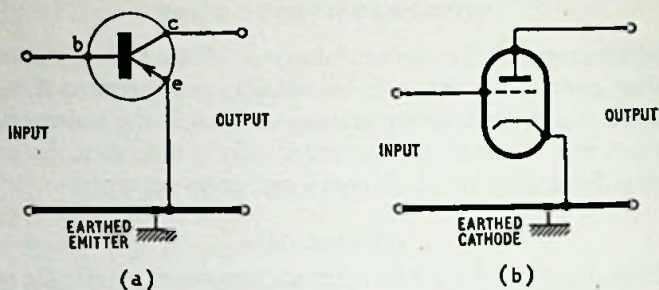Fig. 2.12—Circuit of the earthed-base transistor and its counterpart, the earthed-grid valve amplifier

Fig. 2.13—The earthed-emitter transistor ampli-fier is similar to the earthed-cathode circuit
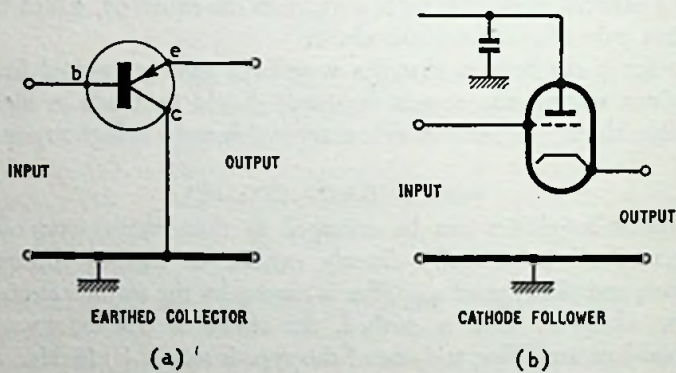

Fig. 2.14—The earthed-collector has charac-teristics similar to those of the cathode follower
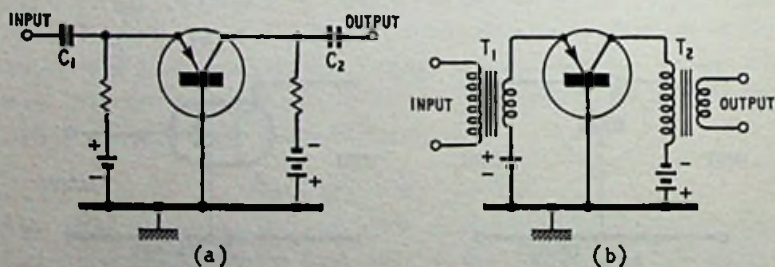

Fig. 2.15—Resistance-coupled and transformer-coupled earthed-base amplifiers

Both the earthed-base and earthed-emitter amplifiers have very low input impedances, as a general rule lower than 1,000 ohms. The output impedance is high—for the earthed-base usually several hundred thousand ohms, and for the earthed-emitter generally less than 50,000 ohms.

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

Phase inversion

In nearly all radio and television valve circuits the cathode is earthed, and the signal voltage on the output or anode side of a valve is out of phase with the signal at the input. This means that the output signal becomes more positive when the input signal becomes more negative, and vice versa.

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

There are certain valve circuits in which there is no phase reversal of the input signal. For example, there is no phase reversal in a cathode follower. Similarly, in the earthed-collector transistor amplifier there is also no phase reversal. If there is no phase reversal, it 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 is expected from it.

Earthed-base amplifier

In Fig. 2.15, are shown circuit diagrams of two typical earthed-base single-stage amplifiers. The one at (a) is a resistance–capacitance-coupled unit, while the one at (b) is a transformer-coupled unit.

The input resistance (or impedance) is low and the output resistance is high. Therefore the two transformers shown at (b) are both step-down units. That is to say, the secondary of the input transformer T_1 is low-impedance to match the input resistance of the emitter circuit, while the primary of the output transformer T_2 is

high-impedance 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 that of the input.   Remember—this circuit does not give phase reversal of the signal, which means that if at any instant the input signal is positive, so is the output signal.

In Fig. 2.15, two new components, C_1 and C_2, have been added. These work as coupling and d.c. blocking units, just as they do in valve circuits.

Earthed-emitter amplifier

In Fig. 2.16, are two circuits of the earthed-emitter amplifier.   One of these (a) is a typical resistance-coupled stage while the other (b) is a transformer-coupled stage.   Although in (a) bias battery B_1 is
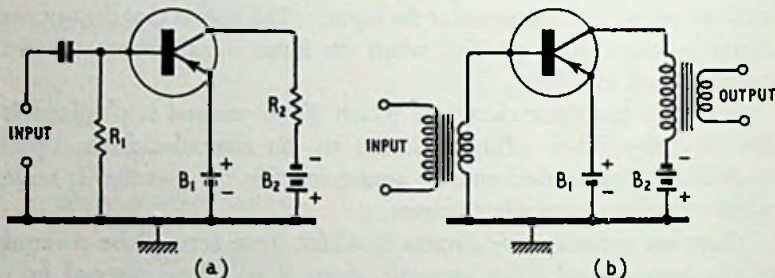
Fig. 2.16—Resistance-coupled and transformer-coupled earthed-emitter amplifiers

connected between emitter and earth, the emitter is effectively earthed through this component.   Also note the inclusion of resistor R_1 in the resistance-coupled stage.   The input signal is developed across this resistor, as it was also in Fig. 2.15(a).

In the transformer-coupled stage at (b) we once again have step-down 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 output is high-impedance, so the primary of the output transformer is high-impedance to match it.

Earthed-collector amplifier

Fig. 2.17 shows two circuits of earthed-collector stages.   Once more resistance- (a) and transformer- (b) coupled units are used as

examples. It is essential to remember that the earthed-collector is quite different from the other two amplifier types we have just described. In the earthed-collector circuit, the input impedance is much higher than the output impedance, which can be remembered by comparison with the cathode follower valve circuit.

In the circuits of Figs. 2.15, 2.16 and 2.17, only pnp transistors are shown, but we could have used npn units. The only change to be made in the circuit would have been to transpose both emitter and
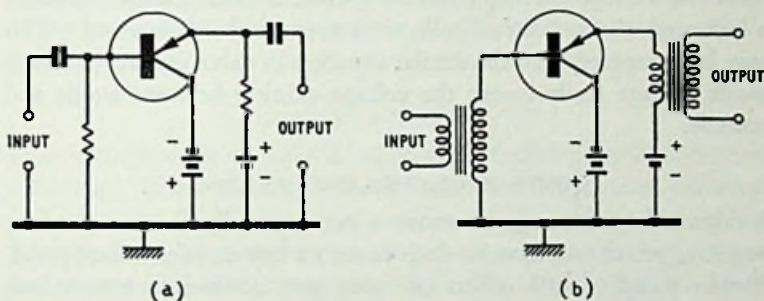

Fig. 2.17—*Resistance-coupled and transformer-coupled earthed-collector amplifiers*

collector bias battery polarities and reverse the direction of the arrows in the emitter symbol. Failure to reverse the batteries could 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, and we saw examples of miniature components in Plate 3. In the transistor receiver you will find parts such as audio transformers whose maximum dimensions are less than 1 inch, and miniature penlight or mercury cells are often used as batteries. There is further discussion of the parts in transistor receivers in the chapters on servicing. You will also find that transistor receivers make extensive use of printed-circuit boards, which 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 can be expected. Remember, however, that the figures given here do not cover all transistors.

One of the values of interest is collector current, which corresponds to the anode current of the valve. For many audio transistors the collector current will have a minimum value of 2–3 mA, with a maximum in the order of 20–25 mA. A d.c. milliammeter lends itself 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 (between collector and emitter) is increased, the amount of collector current will also increase. This may be compared with the similar situation in valve circuits in which anode voltage really means the voltage existing between anode 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. Similarly, the control grid of a valve controls the power supply. All the control grid needs is a small signal voltage and a power supply starts delivering.

Transistor control element

There is a control element in the transistor also. In practically all transistor radios this is the base. The movement of current carriers in the transistor is determined by what we do to the base. First, let us consider a pnp transistor. When a negative voltage is applied to the base of a pnp unit, the flow of current carriers is increased. And if we do the opposite—that is, put a positive voltage on the base —we can decrease or even stop the flow of current carriers. But by themselves, positive and negative are meaningless—when we say the base is negative, we mean it is negative with respect to the emitter (just as in a valve a grid is nearly always negative with respect to the cathode).

POSITIVE AND NEGATIVE

Now that we have this information, let us see what use it will be. First of all, if a receiver uses pnp 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, in a circuit diagram a pnp transistor could have 3·8 volts marked next to the emitter. But is this plus or is it minus? If you look at the base, it might be marked 3·6 volts. In fact, if you look at the battery, both of these are positive voltages, because they are at the positive end, but since the emitter has the higher (positive) voltage, it is more positive than the base. The actual emitter bias, of course, is its potential difference, or voltage difference, with respect to the base; the base bias is its potential difference with respect to the emitter.

POLARITY ON NPN TYPES

In an npn transistor we have the same state of affairs, but with reversed polarities. When the base is made positive current carriers will flow, and when it is negative current carriers will decrease or stop. Thus the base bias in an npn transistor is the same way round as the grid bias in a valve, whose control grid (if it is biased at all) is biased negatively with respect to its cathode. In a transistor radio, however, irrespective of whether it is npn or pnp, the bias (d.c. voltage between base and emitter) is " forward " (which is opposite to that in a valve) so as to ensure that current carriers flow.

This might seem a little confusing since we have just discussed an example in which a pnp transistor had positive voltages on both base and emitter. However, it is perfectly correct. If the base is more negative than the emitter, it is the same thing as saying that the emitter is more positive than the base.

Actually the same condition exists with valves. Consider a triode valve with a cathode and an anode. The anode is positive, usually by several hundred volts. The cathode is also positive, usually by a few volts only. The anode is positive with respect to the cathode (it has more positive volts than the cathode). But the cathode is negative with respect to the anode.

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

is positive with respect to the negative terminal of the battery, and negative with respect to the positive terminal of the battery.

CURRENT GAIN: BETA

When the collector current is compared with the emitter current, we find that the collector current (except in point-contact transistors) is always less than the emitter current. Earlier in this chapter we
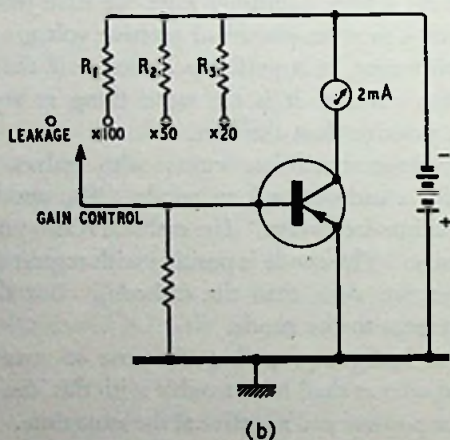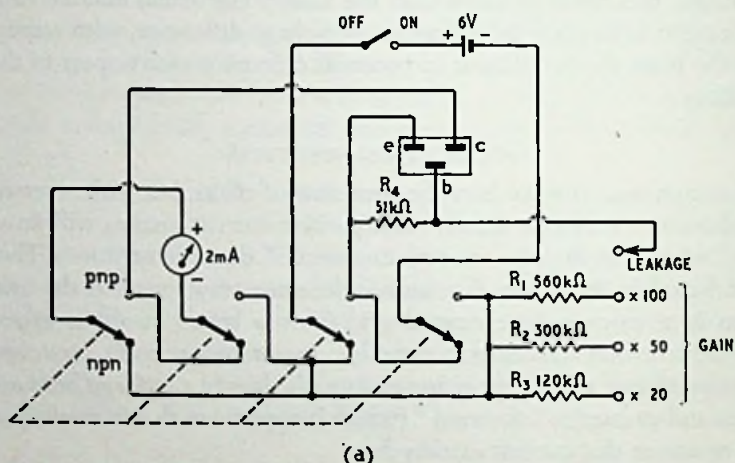

(a)

(b)

Fig. 2.18—Transistor test circuit. A meter, four switches, four resistors, a battery and a socket for the transistors are all housed in a neat pre-finished cabinet. The basic circuit from which (a) is described is shown at (b)

learned that the ratio of these two currents is known as *alpha* or α, and because collector current is always the smaller amount, α 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 α, and in this case equals 0·96 approximately.

We can also compare collector current with base current. When we do, we find that base current is usually very small in comparison with collector current.   This ratio is known as *beta* or β, which is also called the base-current amplification factor. β is the ratio of a change in collector current to a change in base current.

TRANSISTOR TESTERS

The measurement of α and β is a good way of testing a transistor. The methods are similar to the emission and mutual conductance tests performed on valves.

Transistors are comparatively simple devices; the testers required are equally simple.   Only the switching circuits used to give maximum testing conditions with the minimum number of components make the complete tester complex.   The circuit of a representative tester is shown in Fig. 2.18(a).

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

Since the characteristics of all transistor types are not the same (that is why they have different identifying numbers), it is 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 would control the base current.

In the circuit of the transistor tester Fig. 2.18(a) a switch is used instead in the base circuit.   The three resistors R_1, R_2, R_3 are selected in turn, and they form a voltage divider with the fourth resistor R_4 connected from the base-to-emitter terminals of the transistor socket. This has the advantage of giving three permanently reproducible 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 ageing of the resistors, and they will not be large. When the emitter–collector leakage is measured the base is connected to the emitter through the 51,000 ohm resistor R_4.

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 npn and pnp 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 as important as the α and β tests and they correspond to short-circuit and leakage tests in valves.

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

In some cases transistors can be tested while they are connected in their circuits. This is an advantage, since in practically all transistor receivers the transistors are soldered into circuit.

There are other ways to test transistors, using the regular equipment found on the average service bench. Audio and r.f. signal generators may be used as signal input circuits, and the signal tracer and oscilloscope can replace the normal output circuits. This is practically the same signal-injection and signal-tracing technique as is used in servicing valve receivers.

Fig. 2.19 shows the 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 are explained more fully later on.

Another type of 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 step-up output transformer.

All these tests have their merits. Some transistors may pass some of these tests and fail others. As with valves, they may seem to operate satisfactorily even without passing all tests by a large margin, but since many transistors are soldered into their circuits, it is unlikely that many transistors actually used will ever be tested.

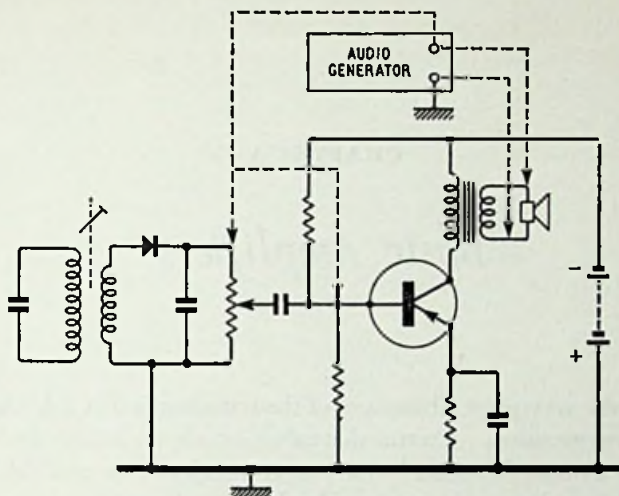If an inoperative circuit has a transistor that fails in any one of many

Fig. 2.19—There is 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

possible tests, it is best to replace it.   Like a valve, a transistor may work in one circuit configuration and not in another; that is, it may work well as an audio amplifier or i.f. amplifier, and not as an r.f. amplifier.   Some rather critical 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 practicable.   Many new developments in the semiconductor field have produced strange new devices, and such a " universal" tester might well 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 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 might seem as bulky and crude as the diodes and triodes of the early part of this century do when compared with present-day valves.

4

Basic Amplifiers

ONE of the very great advantages of the transistor is that it lends itself to battery operation. It is true that valves can also be battery-operated, but the transistor's much lower power requirements and the small physical space it occupies are considerably in its favour.

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 receivers have their own servicing hazards.

VOLTAGE LIMITATIONS

In a valve receiver, the voltages that can be applied to the anode and screen-grid can generally be varied within fairly wide limits. The bias voltage on the control grid is, of course, much more critical, but as this is usually derived from a cathode resistor, the service technician simply measures the cathode–chassis voltage across it as a quick check on valve operation.

A transistor, however, is quite another story. It must be remembered that the transistor is a tiny device and that the volume of " active " material in it 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 can heat up rapidly. In addition, the junction is temperature-sensitive, so that damage can easily be done. The collector voltage, which should never exceed that specified by the manufacturer, 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 earthed-base, earthed-emitter and earthed-collector circuits. These three fundamental circuits are shown in Fig. 3.1. Instead of referring to them as earthed-base, earthed-emitter etc. let us call them common-base, common-emitter, etc.

Consider, for example, the simple triode valve shown in Fig. 3.1(a). The input circuit consists of grid and cathode, while the output consists of anode and cathode. The cathode is used by both circuits, hence, this could be called a common-cathode circuit—that is, the cathode is common to (is used by) both input (grid) and output (anode) circuits.

Figs. 3.1(b), (c) and (d) show common-base, common-emitter and common-collector circuits respectively for pnp transistors. In each

(a) CATHODE IS COMMON ELECTRODE

(b) BASE IS COMMON ELECTRODE

(c) EMITTER IS COMMON ELECTRODE

(d) COLLECTOR IS COMMON ELECTRODE
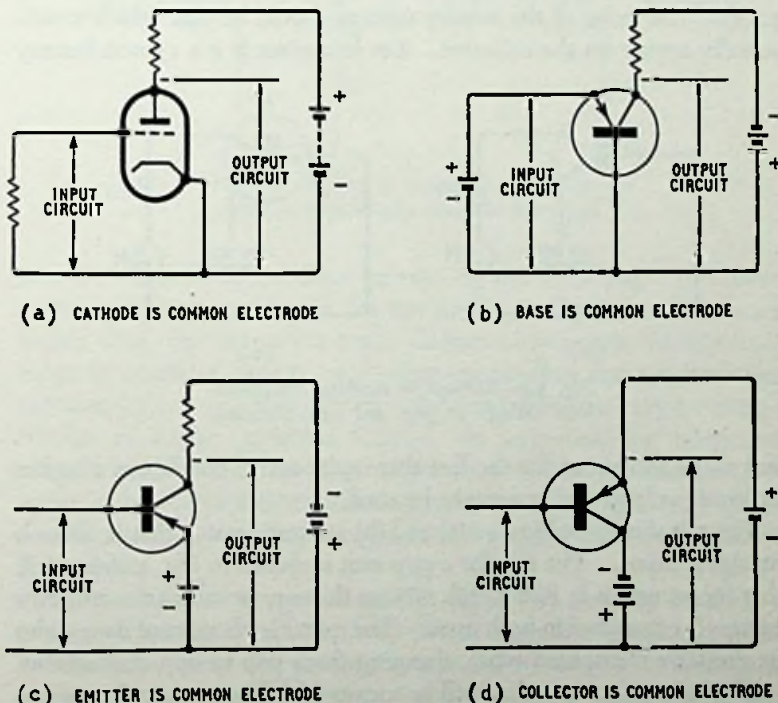
Fig. 3.1—Like the thermionic valve, the transistor uses one electrode common to the input and output circuits

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 valve, you can apply a sufficiently negative voltage to the control grid to drive the valve into cut-off—a condition in which no anode current flows. In a transistor, on the other hand, some collector current is always present even though the emitter current at the moment may be zero. This is called leakage current.

The leakage current of a transistor exists between collector and emitter, and also between collector and base. These currents 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 pnp unit can be checked as shown in Fig. 3.2(a). The value of the battery voltage should be that which would actually appear on the collector. Let us assume it is a 15-volt battery
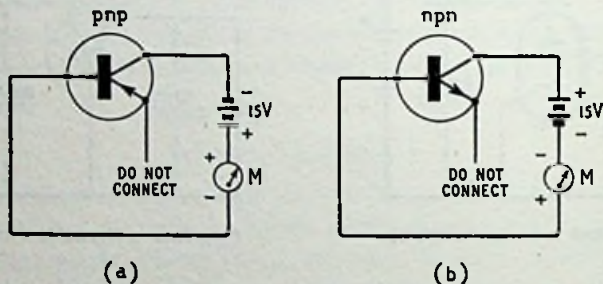
Fig. 3.2—Method for checking collector-to-base leakage in pnp and npn transistors

and make allowance for the fact that under actual conditions a higher or lower voltage battery might be used.

The test shown in Figs. 3.2(a) and (b) are static tests—that is, there is no signal input. The test for a pnp unit is shown in Fig. 3.2(a), while that for an npn is in Fig. 3.2(b). Note the way in which the collector battery is connected in both cases. The meter leads must of course also be similarly transposed when changing from pnp to npn connections.

The leakage current that will be measured is known as collector-to-base leakage and will be very small, generally less than $25\mu A$. The meter needle should remain steady during this test and should approx-

imate to the value specified by the manufacturer for the particular
transistor being checked.   The transistor is defective if the reading is
eratic or if the collector-to-base current is much in excess of the
manufacturer's published value.

Collector-to-base leakage has a number of names.   It may simply
be called leakage current, or collector leakage, and sometimes it is
termed collector saturation current, or collector cut-off current.
However, there is no such thing as cut-off—there is always some
collector-to-base leakage, however small.

Another leakage current that exists is between collector and emitter.
The connections for this test which are very much the same as those
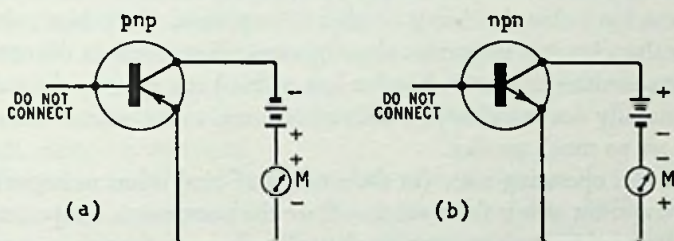
Fig. 3.3—Method of measuring collector-to-
emitter leakage in pnp and npn transistors

described for collector-to-base leakage are shown in Fig. 3.3.   How-
ever, the leakage current for the test shown in Fig. 3.3 will be much
higher than for the earlier test.   Collector-to-emitter leakage may
range in excess of $100\mu A$.   Compare the reading you get with that
specified by the manufacturer, remembering that you may be using a
smaller or higher collector voltage.   In any case, the maximum
voltage specified by the manufacturer must not be exceeded.   Once
again, if the collector-to-emitter leakage current is excessively high, or
unstable (that is, the meter needle fluctuates), the transistor is said to
be defective.

The amount of leakage current will depend on how the transistor 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
$250 \mu A$ d.c. maximum, it is quite possible that the meter needle may
not move appreciably, or that it will move so little that no reading can
be taken.   This is an indication of extremely small value of the 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 of junction temperature, leakage current and total collector current will continue to increase. This raises the temperature of the transistor still further, resulting in a " runaway " condition that will ruin the transistor.

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

The d.c. operating point (or the amount of bias) is just as important for a transistor as it is for a valve. 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 valve (Fig. 3.4), anode-current runaway is prevented through the use of the cathode resistor. A separate power

SEPARATE
BIAS SUPPLY

AUTOMATIC OR "SELF BIAS"
PROTECTS VALVE
AGAINST CURRENT "RUNAWAY"
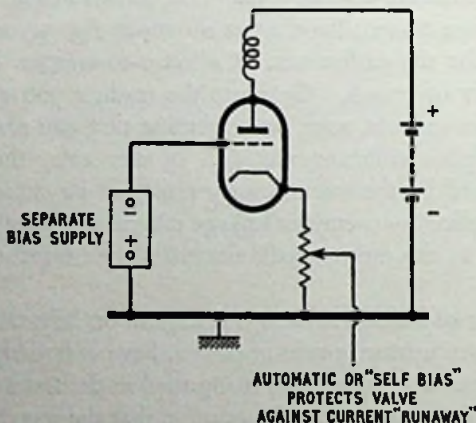
Fig. 3.4—The cathode resistor helps to keep the anode current within reasonable limits
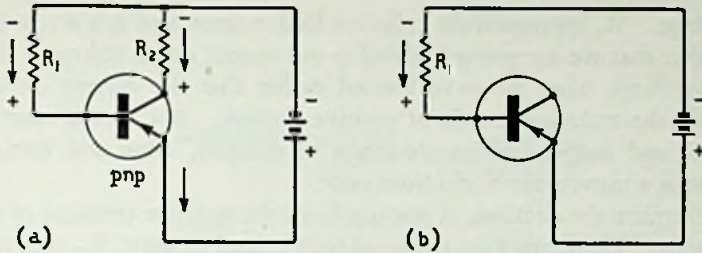
Fig. 3.5—*Electrons move into the transistor through the collector, return via the base and emitter in the pnp transistor*

supply is used for bias, which 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 d.c. bias supply. If the anode current should try to increase, the voltage across the cathode resistor increases. This raises the total bias on the valve and, as a result, the anode current is decreased.

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

All this indicates how to stabilize a transistor so that the collector current stays within limits. We must set up a circuit so that an increase in collector current results in a change in input-circuit bias current that opposes the collector-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 small differences in characteristics. It also makes 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 *forward* bias current.

In Fig. 3.5 a single battery is used for both emitter and collector

voltage. R_2 represents the collector load resistor, and it is across this 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 input and output circuits consisting of resistors, wires and battery, there is a movement of electrons only.

Consider the electrons as starting from the negative terminal of the battery.   There are two paths—through load resistor R_2 and also through resistor R_1, but for every electron that leaves the battery, an
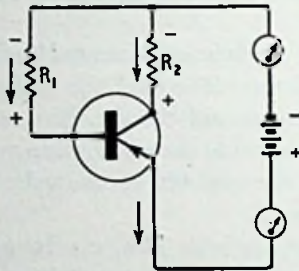
Fig. 3.6—The electron flow out of the battery is identical to the electron flow into the battery

electron must return.   In other words, if we were to insert a d.c. milliammeter at the negative terminal of the battery and an identical meter at the positive terminal of the same battery as in Fig. 3.6, 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 electron currents flowing in the base and collector circuits through R_1 and R_2 must equal the current flowing through the emitter.

Whenever a current flows through a resistor it produces a voltage drop across it.   The arrows in Figs. 3.5 and 3.6 show the direction of electron flow and also the polarity of the voltage across R_1.   The voltage produced across R_1 has a polarity at the base that is opposite to that of the collector battery.   It is, however, negative with respect to the emitter, which is connected to the positive terminal of the battery.

In Fig. 3.5(b), is shown a simplified version of the circuit in 3.5(a). R_1 helps to complete the input circuit and at the same time allows the use of a single battery for both output (collector) and input bias.   This type of input bias is called fixed bias.   This is not a very satisfactory
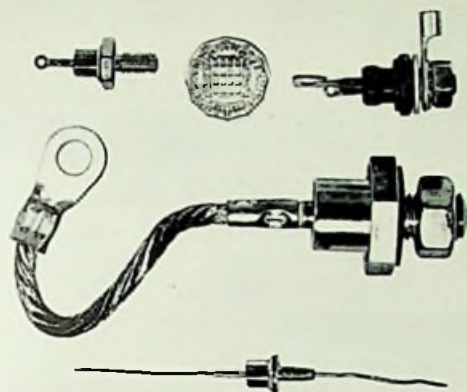
Plate 1 (above) *A group of Mullard silicon rectifiers compared in size with a threepenny piece. The large one can handle 20A at 200V. The small ones will supply H.T. current for a television receiver; (below) Several types of S.T.C. silicon rectifiers shown with a selenium stack for size comparison*
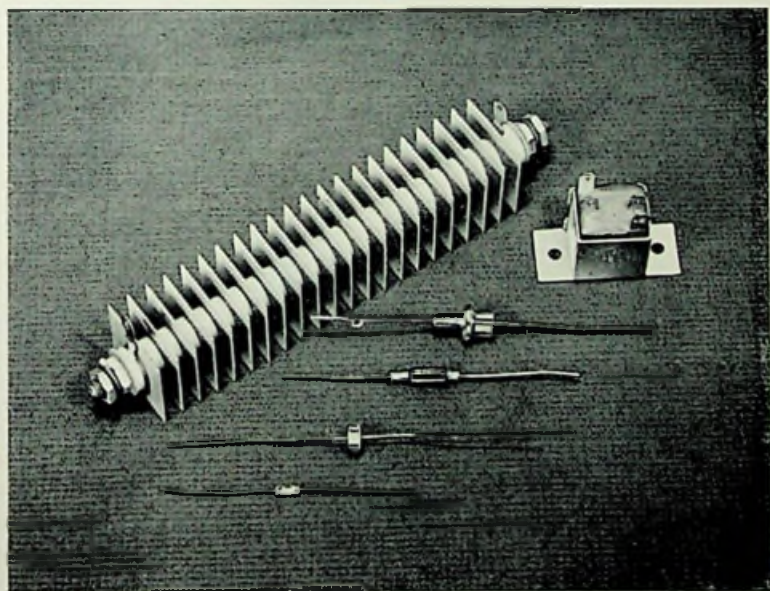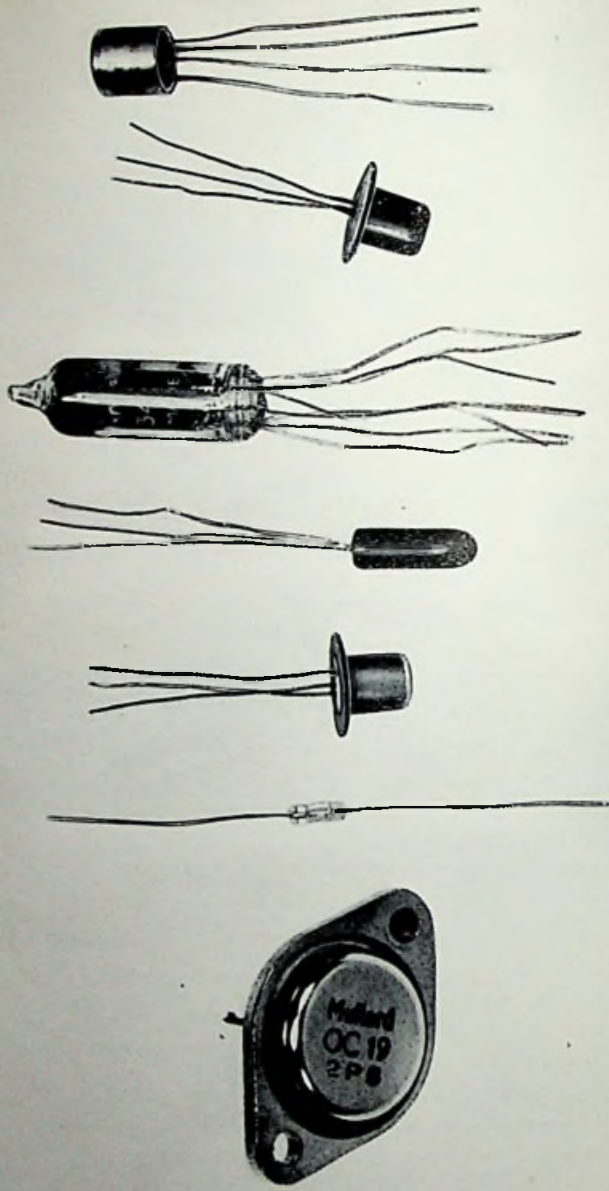
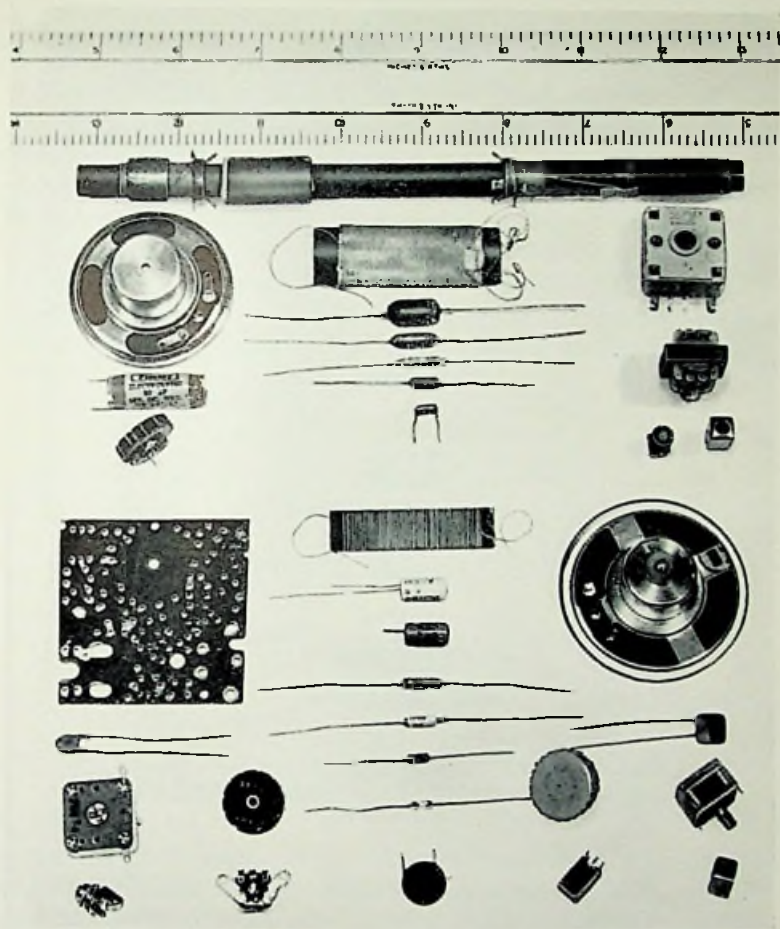*Plate 2. Compared with a sub-miniature valve, transistors still look small*

Plate 3. Examples of transistor receiver components, with an inch scale at the top to indicate their dimensions. The upper group are of Plessey manufacture and the lower group are used in G.E.C. receivers. They include aerials, loudspeakers, ganged tuning capacitors, volume controls housed within their knobs, i.f. transformers and audio transformers, electrolytic capacitors and several electrolytic and paper-insulated capacitors, and at the left on the lowest row an earphone plug socket and an extremely small volume control with on/off switch
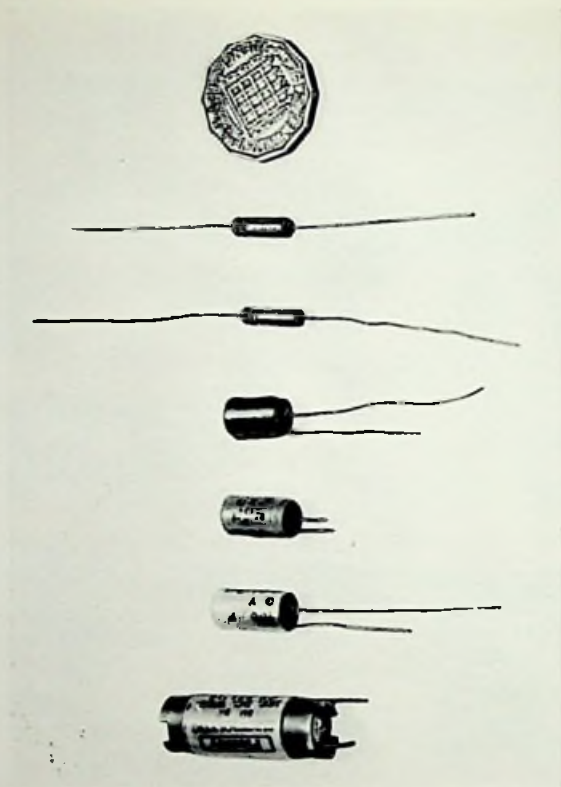
Plate 4. Typical electrolytic capacitors used in transistor receivers. These are very small compared with those which are found in valve receivers
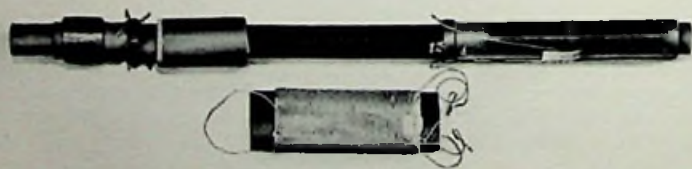
Plate 5. Ferrite aerial coils may be as long as seven inches (above) or as short as two inches (below)

arrangement since R_1 would have to be adjusted for each individual transistor—and there is still nothing to prevent collector-current runaway.

The circuit in Fig. 3.7(a) looks exactly like that in Fig. 3.6 except that we have added another resistor, an emitter resistor R_3. Unlike resistor R_1, which passes only a small amount of current (usually less than 5 per cent. of the total), R_3 carries not only the base current but the collector current as well, and it helps to stabilize the circuit.

Let us suppose that for some reason the collector current increases substantially. This current, flowing through R_3, will increase the voltage drop across it. But this voltage has a polarity that opposes the current in the base-emitter circuit. When the current in the base-

(a)   (b)
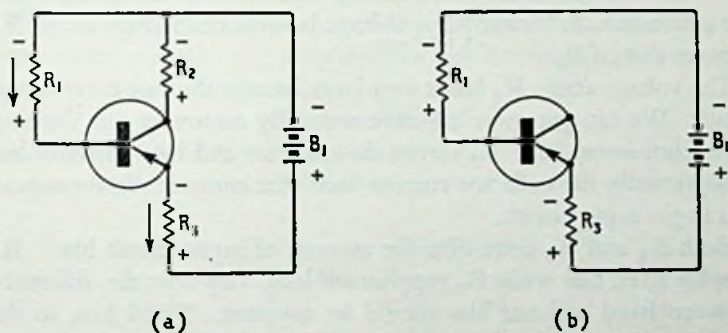
Fig. 3.7—The voltage across R_1 supplies fixed bias. This bias remains fairly constant. The voltage across R_3 supplies self bias. The value of self bias depends primarily upon the amount of collector current

emitter circuit decreases, so does the collector current. A reduction in collector current, though, will lower the voltage across R_3, permitting the current in emitter-base circuit to rise to normal once again.

The circuit in Fig. 3.7(b) is a simplified version of Fig. 3.7(a). Note that the polarity of the voltage across R_3 is such that it opposes the battery voltage. Suppose, as an example, resistors R_1 and R_3 were shorted with a piece of wire. The forward bias on the transistor would be the entire voltage of battery B_1. This battery, of course, is properly polarized for base current bias—that is, the positive terminal of the battery is connected to the emitter and the negative terminal to the base. Consequently a very heavy emitter current would flow since the emitter-base portion of the transistor is biased in the forward
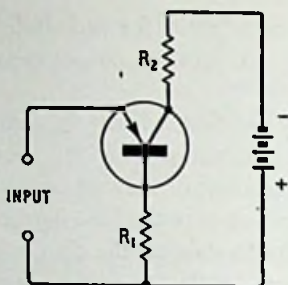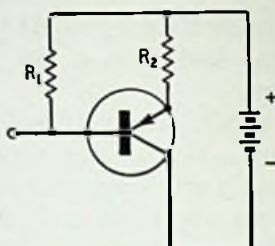
*Fig. 3.9—Common-collector
circuit using fixed bias
supplied by the voltage drop
across R_1*

*Fig. 3.8—Common-base pnp
arrangement using self bias*

direction.   If we removed the shorting wire from across R_1, we would get a reduction in forward-bias voltage because the voltage across R_1 opposes that of B_1.

The voltage across R_1 is not very large because the base current is so small.   We can get more effective action by removing our shorting wire from across R_3. R_3 carries the collector and base currents, but it is primarily the collector current itself that controls the amount or bias in the input circuit.

Both R_1 and R_3 determine the amount of input circuit bias. R_1 supplies fixed bias while R_3 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 d.c. voltage on the input (base and emitter) so that the transistor works at its correct operating point.

As we shall see very shortly, however, the stability of the bias circuit can be increased still further.   Very small changes of base-emitter bias voltage, as we have already seen, can produce very large changes in collector current, and the use of R_1 as shown still permits small changes of voltage drop to occur across it.   This can be prevented by connecting another resistor between the base and the positive terminal of the battery, forming a potential divider, or voltage divider, across the battery.   The current through the potential divider is greater than it was originally through R_1 alone, and changes in base current through R_1 have comparatively little effect on the voltage drop along it.

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 bias are identical.

The common-base circuit shown in Fig. 3.8 uses R_1 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 a separate battery would then be required for base-emitter bias. If resistance-capacitance coupling is used, the amount of fixed bias will depend upon the value of the resistor connected across the input terminals.

The common-collector circuit of Fig. 3.9 follows the same pattern as the earlier circuits. R_1 supplies fixed bias for the input circuit.

VOLTAGE DIVIDER

Resistors are frequently used to enable various voltages to be obtained from a single source and for this reason are often called voltage
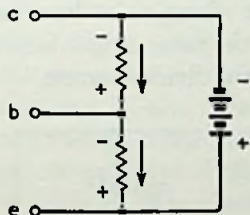
Fig. 3.10—Simple voltage-divider action
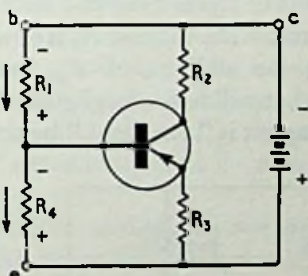
Fig. 3.11—R_1 and R_2 act as a voltage divider across the battery

dividers. Voltage dividers are not economical from the viewpoint of battery power but they do represent a simple way of stabilizing the required voltages.

To see how this is done, let us look at Fig. 3.10. Here two series resistors are connected across the battery. Current will flow through the two resistors and there will be a voltage drop across them. The arrows show the direction of electron flow and the polarity of the voltages. The centre or common connection of the resistors is

marked b, while the outer terminals are identified by the letters e and c; c is the most negative point while e is the most positive. b is negative with respect to e, but positive with respect to c, and can be used as a positive or a negative point, depending upon whether e or c is the reference.

We can put the voltage divider to work as shown in Fig. 3.11. Here we have two resistors R_1 and R_4 connected in series. Looking at the circuit, it can be seen that the battery and the resistors R_1 and R_4 form the same circuit as shown in Fig. 3.10, while R_1, R_2 and R_3 are the same as they were in Fig. 3.7.

Current leaves the negative terminal of the battery, flows through R_1 (producing a voltage drop), through R_4 and then back to the positive terminal of the battery. But what about point b, corresponding to point b in Fig. 3.10? This point (connected to the base) is negative with respect to point e. In other words, point e (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 R_1 and R_4 and upon the amount of battery voltage. This sort of bias is fixed bias since it is completely independent of the transistor. The value of R_1 is now much lower than it was in Fig. 3.7, before the addition of R_4, and slight changes in base current through it will have a negligible effect on the value of base bias. The base current is "swamped" by the potential divider current.
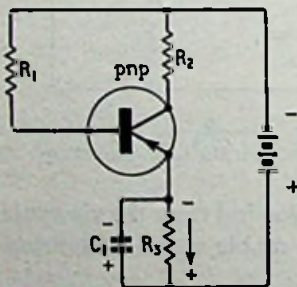

Fig. 3.12—The emitter resistor R_3 is by-passed by capacitor C_1. If C_1 is an electrolytic, its polarity must be the same as that of the emitter resistor
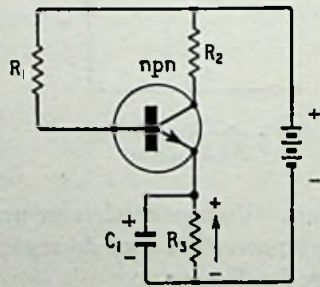
Fig. 3.13—When using an npn unit in place of a pnp, the battery leads must be transposed, and an electrolytic emitter by-pass must therefore also have its leads changed

NEUTRALIZATION AND FEEDBACK

These two terms, neutralization and feedback, have been carried over from valve 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, and it 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. It is often found in connection with transmitting r.f. amplifier triodes and is also associated with the triode r.f. amplifier in television tuners.

DEGENERATIVE FEEDBACK

In a valve receiver, degenerative feedback is easily obtained by omitting the by-pass capacitor shunted across the cathode resistor. In a transistor amplifier, the same technique is followed. This capacitor is normally connected across the emitter resistor in a common-emitter amplifier. Fig. 3.12 shows a pnp circuit with the emitter by-pass capacitor in place. For an npn arrangement (Fig. 3.13), the polarity of the emitter by-pass capacitor (if electrolytic) must be transposed, but otherwise the circuit is the same.

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

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.

The value of the emitter by-pass capacitor in an audio circuit 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 pnp units, the negative terminal of the capacitor connects to the emitter. For npn transistors, the positive end of the capacitor connects to the emitter.

Electrolytic capacitors used in transistor receivers are small compared with the types you will find in valve receivers and their d.c. working voltage is generally less than 20. Both aluminium and tantalum electrolytics are used. Their appearance is shown in Plate 4.

MULTIPLE STAGES

Coupling of transistor stages follows the same general technique used in valve receivers. Both transformer and resistance-capacitance coupling are quite common. Direct coupling of one stage to the next is also used.

TRANSFORMER COUPLING

A transformer-coupled transistor audio amplifier circuit is shown in Fig. 3.14 which demonstrates some of the principles we have been discussing. Both of the transistors are pnp-types and are used as common- (or earthed-) emitter amplifiers. A single battery supplies collector current for both stages. Fixed bias for the first stage is furnished by R_1 and fixed bias for the second stage by R_2. Capacitors C_1 and C_2 are used to prevent shorting the d.c. voltage developed
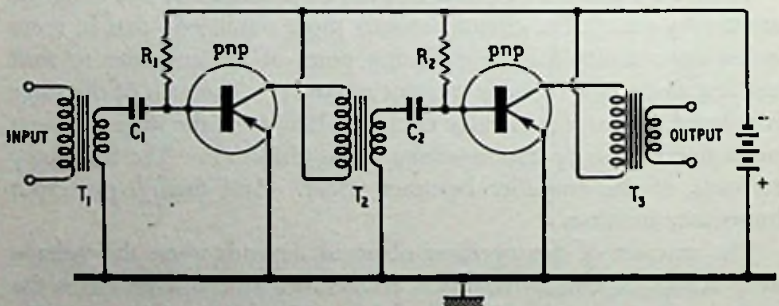
Fig. 3.14—*Two-stage transformer-coupled audio amplifier using pnp units. A single battery supplies collector and base bias. Resistors R_1 and R_2 provide fixed bias for the base-to-emitter input circuits*

TABLE 3.1. *Typical characteristics of input, inter-stage and output transformers used in transistor receivers.*

Application	Turns ratio, pri. to sec.	Impedance in ohms		D.C. resistance in ohms	
		Pri.	Sec.	Pri.	Sec.
Input	1·00:45·5	30 C.T.	50,000	14·7	4,060
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	5,135
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	1,860
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	1,100
Interstage	1·00:4	5,000 C.T.	80,000 C.T.	573	5,740
Output	24·6:1	10,000 C.T.	4, 8, 16	1,174	2·6
Interstage	14·0:1	10,000	200 C.T.	1,200	33·4
Interstage	2·24:1	10,000	2,000 C.T.	1,200	257
Interstage	1·83:1	10,000	3,000 C.T.	1,200	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

across R_1 and R_2. Without the capacitors, resistors R_1 and R_2 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 common-emitter amplifier. Transformers T_1, T_2 and T_3 are audio transformers. The chart shown as Table 3.1 will give you some idea of the turns ratio, the primary and secondary impedances and the d.c. resistances of the primary and the secondary windings of typical transformers.

Two transformer-coupled stages as shown in Fig. 3.14 would not be found in a British transistor portable, however. Transformer coupling is usually employed only in the output stage, and in most cases it then drives a pair of output transistors in push-pull. A hypothetical transformer-coupled circuit to a single-ended output stage is shown in Fig. 3.16, where the circuit features are typical of those found in British receivers except for the inclusion of R_1 and C_4, which would be unusual. If they were used, their values would probably be 1,000 ohms and 100–200 μF.

RESISTANCE-CAPACITANCE COUPLING

A representative resistance-capacitance coupled stage is shown in Fig. 3.16 which might easily be used in front of the transformer-coupled stage of Fig. 3.15 in a receiver where two stages of audio amplifier preceded the output stage. This is frequently done where the output stage comprises a fairly powerful push-pull circuit. The audio coupling capacitor C_1 is electrolytic and its value may be as high as several microfarads. The emitter by-pass capacitors C_2 and C_3 might be 100 μF, but their working voltage is very low, and they are quite small physically. This small size is made possible by the new manufacturing techniques and the very low voltages involved.

Large values of capacitance are needed for coupling in audio transistor stages since the input impedance of such stages is very low
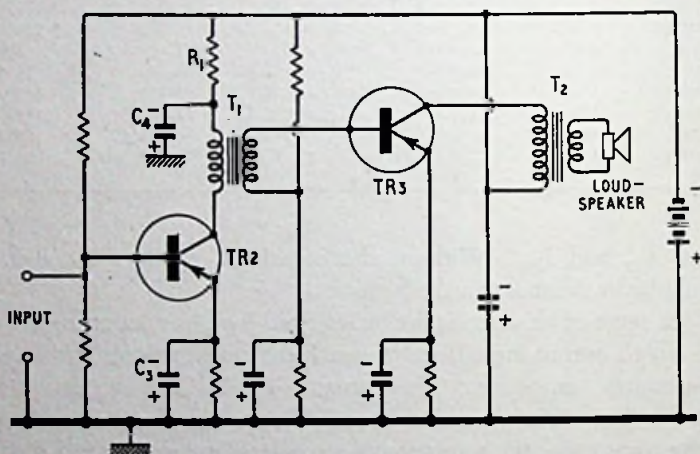
Fig. 3.15—Transformer-coupled transistor amplifier using pnp units.
Fixed bias is used throughout

compared with valve circuits. Electrolytics can be used as coupling units, but then the polarity must be carefully watched. Since, for pnp 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 of the following stage. Problems raised by defective components such as capacitors and transformers are covered later in the chapter on servicing.

DIRECT-COUPLED AMPLIFIERS

There are a number of possible arrangements of direct-coupled amplifiers, one of which is shown in Fig. 3.17, where the first transistor is connected in the common-collector mode. This circuit is unique in that a number of biasing arrangements are used. We can immediately recognize R_1 and R_2 as the type of voltage divider that we studied earlier in this chapter. R_2 supplies fixed bias. In the first stage, R_3 forms part of the base-to-emitter bias network but,
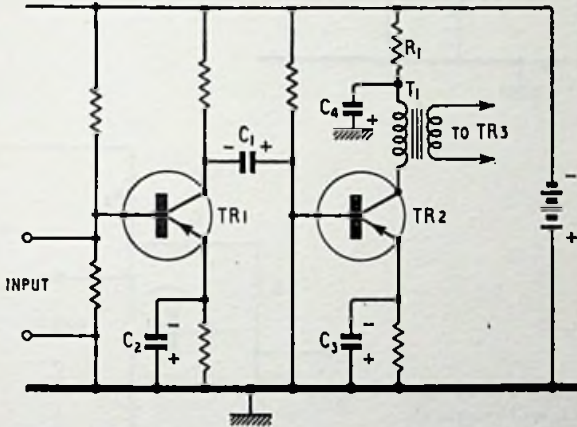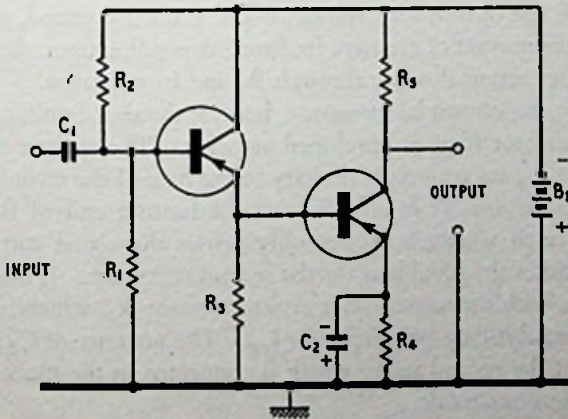

Fig. 3.16 (above)—R–C-coupled transistor amplifier using pnp units. Fixed bias is used throughout. The coupling capacitor can be a 2-μF tantalum electrolytic

Fig. 3.17 (below)—Direct-coupled earthed-collector transistor amplifier

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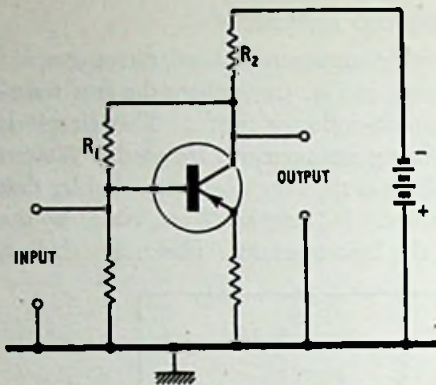
Fig. 3.19 (right)—The insertion
of capacitor C₁ will prevent the
feedback resistor R₁ from affecting
the bias
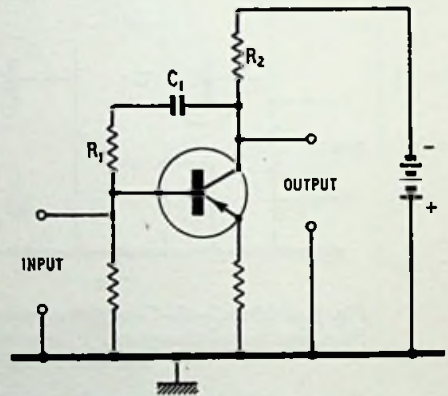
since R_3 is the output load resistance and is not by-passed, this stage
has a certain amount of negative feedback, depending upon the amount
of collector current flowing through R_3 and its resistance.

Actually, R_3 cannot be by-passed, because the signal voltage for the
second transistor stage is developed across it.   The emitter itself and
one side of R_3 are connected directly to the base of the second transis-
tor, while the emitter is returned via the bottom end of R_3 to the
common earth wiring. R_3 not only carries the signal currents but
also establishes the fixed bias for the second transistor.   It does this in
association with the second-stage emitter resistor R_4, which is shunted
by the electrolytic by-pass capacitor C_2.   The presence of C_2 increases
the gain of the second stage, which is connected in the more familiar
common-emitter mode.

COMBINED NEGATIVE FEEDBACK AND SELF BIAS

Components in transistor radios can be made to perform a double job. Resistor R_3 in Fig. 3.17 is a typical example of this, as we saw in Fig. 3.12. We can also return in Fig. 3.18 to a circuit that we studied earlier in Fig. 3.5. When we examined this circuit, we learned that R_1 was used to provide a source of fixed bias for the pnp transistor. In an earthed-emitter circuit, however, as we saw earlier under " Phase inversion ", the output signal voltage is 180° out of phase with the input signal. The output signal voltage in Fig. 3.18 is developed across R_2, with the bottom end of R_2 representing the high potential, or " live " end of the resistor.

But one end of R_1 is connected to this point. This means that some of the output signal is being fed back to the input, and furthermore,
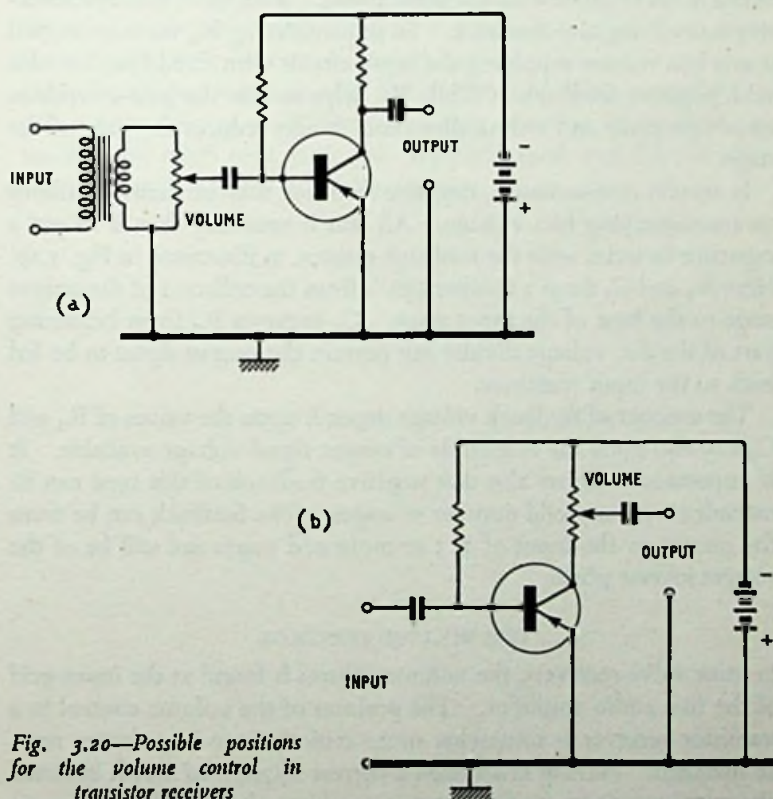
Fig. 3.20—Possible positions for the volume control in transistor receivers

Fig. 3.21—Part of a typical transistor - portable circuit showing the volume control
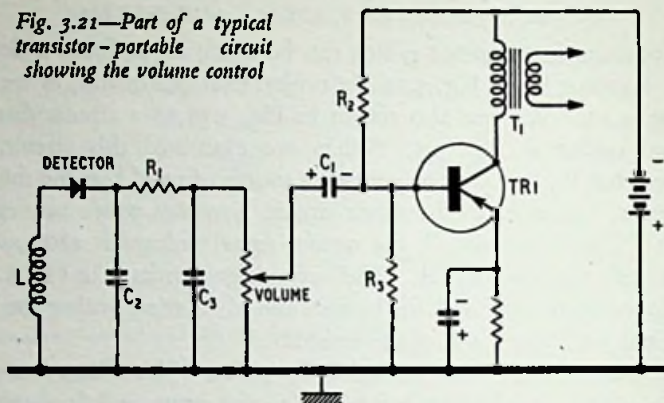
that it is out of phase with the input signal.   This, then, is a representative case of negative feedback.   So in considering R_1 we must regard it as a bias resistor supplying the input circuit with fixed bias, but also with negative feedback.   While R_1 helps to bias the base-to-emitter circuit properly and reduce distortion, it also reduces the gain of the stage.

In certain circumstances, negative feedback may be desired without an accompanying bias voltage.   All that is necessary then is to put a capacitor in series with the feedback resistor, as illustrated in Fig. 3.19.   Here R_1 and C_1 form a feedback path from the collector of the output stage to the base of the input stage. C_1 prevents R_1 from becoming part of the d.c. 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 R_1 and C_1 and also upon the amplitude of output signal voltage available.   It is important to know also that negative feedback of this type can be extended over any odd number of stages.   The feedback can be from the output to the input of 1, 3 or more odd stages and still be of the correct inverse phase.

THE VOLUME CONTROL

In most valve receivers, the volume control is found at the input grid of the first audio amplifier.   The position of the volume control in a transistor receiver is somewhat more critical, since impedances must be matched.   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 in Figs. 3.20(a) and (b) show how the volume control can be connected either in the input or the output circuit of a transistor. Usually, however, in a transistor portable it forms the load resistance of the crystal diode detector. A typical circuit is shown in Fig. 3.21, where L is the secondary of the last i.f. transformer and R_1, with C_2 and C_3, forms a filter circuit preceding the volume control to remove residual i.f. voltages. C_1, T_1 and TR1 perform the same functions as they did in Figs. 3.15 and 3.16.

WHAT COMES NEXT?

In this chapter we have spent quite some time on fundamental types of transistor amplifier. We have not covered every aspect completely, since we have not as yet touched upon push-pull amplifiers, the various classes of operation, tone controls, r.f. amplifiers, etc. These operations, and many others, are described later.

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

R.F. and I.F. Stages

In Chapter 3 we covered the operation of the transistor in a general way. This was done to give an overall idea of the behaviour expected from a transistor. But while such a description was necessary to give a good basic background, the exact working of transistors in actual circuits and how to repair these circuits when they become defective must be learnt.

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 t.r.f. (tuned radio-frequency) receivers, regenerative and reflex receivers. These range in size from very small units to moderately sized portables. Their circuits are very simple, and they do not justify a detailed description. Sufficient is contained in the following pages to cover them generally.

THE SUPERHETERODYNE RECEIVER

The transistor superheterodyne receiver works in exactly the same way as a valve 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 i.f. amplifiers and then into a diode detector. The detected audio signal is amplified and is used to operate a speaker.

Fig. 4.1 shows the block diagrams of typical transistor superheterodynes. The diagram of Fig. 4.1(a) is for a portable and the one shown in Fig. 4.1(b) is for a car radio. Note the difference between Figs. 4.1(a) and 4.1(b). The car radio has an r.f. amplifier stage and may use a d.c.-to-d.c. convertor. Most car radios are hybrid types,

however—that is, they use a combination of transistor and valve circuits, and the d.c.-to-d.c. convertor is not necessary.

The circuit diagram of a typical American 6-transistor portable superheterodyne receiver is shown in Fig. 4.2. The receiver, like others of its type, covers the A.M. broadcast band. The set consists of a frequency changer (mixer-oscillator), two intermediate frequency amplifier stages, an audio detector-driver stage, and push-pull output. The intermediate frequency (in most sets) is the same as that used in valve receivers—455 kc/s (it would usually be 470 kc/s in a British receiver).

The " power supply " consists of seven 1·5 volt torch cells. One of these cells supplies the 1·5 volts of bias required for the base-emitter

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(a)   [FREQUENCY CHANGER]—[I.F.]—[I.F.]—[DETECTOR]—[A.F. OUTPUT]—◁
                                                    
                    [BATTERY]
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(b)   [R.F. AMPLIFIER]—[MIXER]—[I.F.]—[I.F.]—[I.F.]—[DETECTOR]
                    [LOCAL OSCILLATOR]                        [DRIVER]
          [BATTERY]—[D.C.-TO-D.C. CONVERTER]          [PUSH-PULL OUTPUT]—◁
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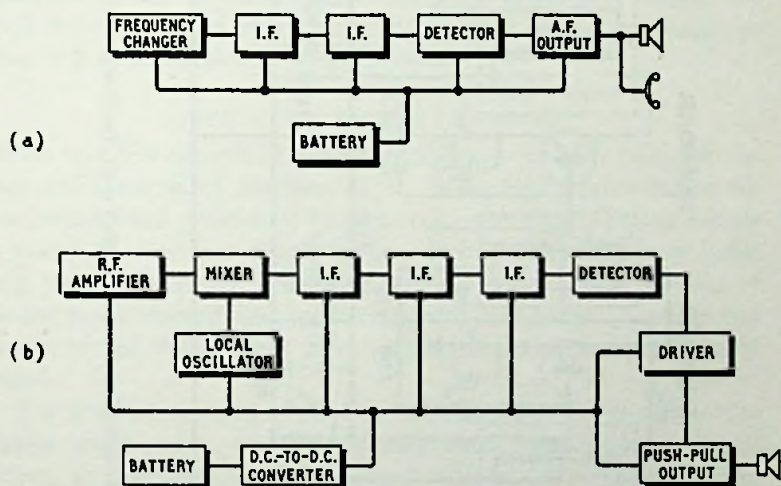
Fig. 4.1—*Block diagram of a portable or home receiver (a) and a diagram of a car radio (b). The latter is the more complicated*

circuits of the transistors and the remaining six form a total of 9 volts for the collector supply.

The circuit of the transistor receiver shown in Fig. 4.2 uses npn transistors. However, as stated in an earlier chapter, the trend in transistor sets is towards the use of pnp's. In receivers using npn transistors the direction of flow of current is similar to that of a valve set.

Transistor receivers use printed-circuit boards extensively. In later
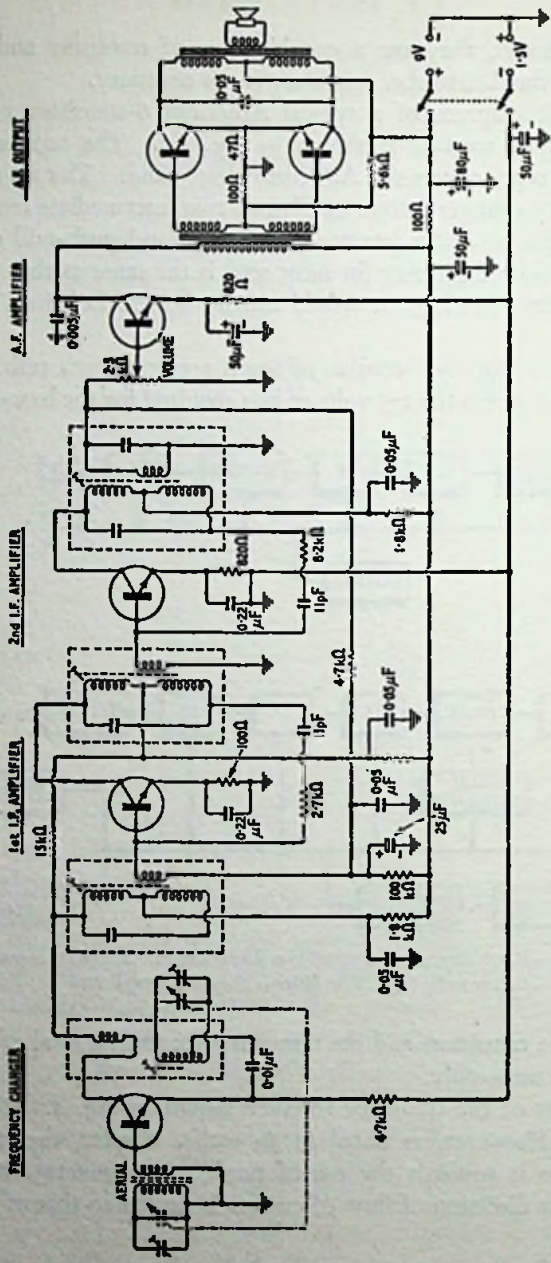
Fig. 4.2—Complete schematic diagram of an American portable transistor receiver

chapters these will be studied more thoroughly. It will be seen why transistors and printed circuits go together so naturally.

In Fig. 4.3 is shown the circuit of a typical British 6-transistor portable receiver, which can be seen to be very different in many respects from the American one, particularly with regard to the way in which the diagram itself is drawn. It uses pnp transistors, a diode detector (X_1), a single battery for collector current and base bias, and covers M.W. and L.W. bands, but otherwise is similar in principle to the American receiver.

CIRCUIT ANALYSIS

Going through a complete transistor radio produces a large amount of information that might be difficult to take in at one go. Instead, we will analyse it section by section, from the front end to the speaker, so you will be ready for any type of receiver.

RADIO-FREQUENCY (R.F.) AMPLIFIER

With very few exceptions, portable and home receivers using transistors do not use an r.f. amplifier stage. In this respect, they follow the long-established practice of a.c./d.c. valve receivers. This is mainly a matter of economics, supported by a lack of need, since most home and portable receivers, both transistor and valve, 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 design of car radios. Car radios work under conditions of high noise levels and low signal inputs, so they are generally equipped with an r.f. amplifier stage in both valve and all-transistor types.

A typical r.f. amplifier stage in an all-transistor receiver is shown in Fig. 4.4(a). The aerial input transformer T_1 can be tuned by means of a variable capacitor or a variable ferrite core; most circuits have both but one is fixed. The transformer is a step-down type to match the low impedance of the base input circuit. The most common arrangement for this circuit is the earthed–emitter amplifier.

Since we are working with a straightforward radio-frequency amplifier, both the input circuit (represented by T_1) and the output circuit (represented by T_2) are tuned to the same frequency. This is an ideal set-up for an oscillator and most nearly resembles a valve
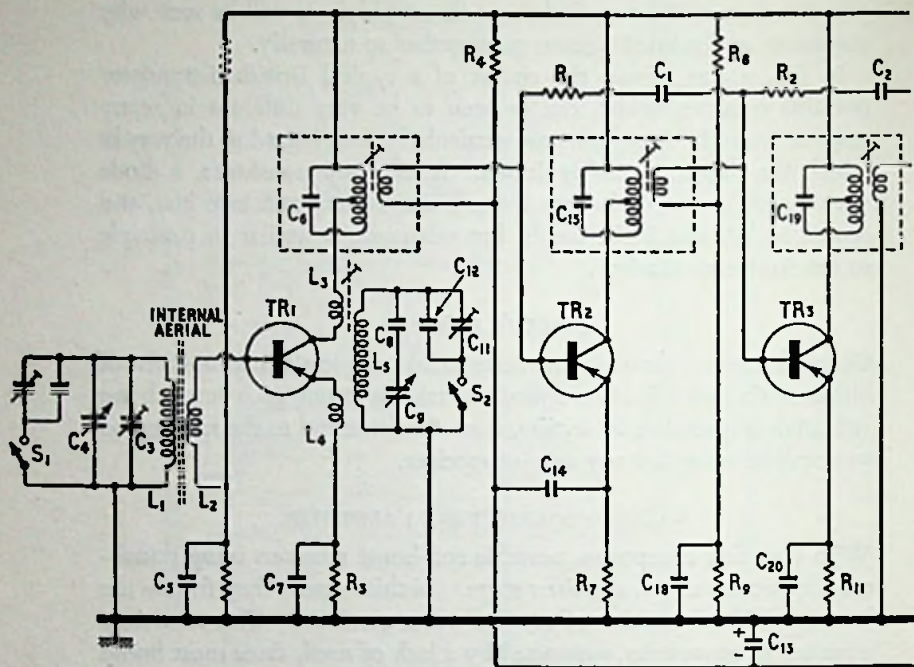
Fig. 4.3—Complete schematic diagram of a British portable transistor receiver

type tuned-grid tuned-anode oscillator. Emitter resistor R_1 is not by-passed, however, and supplies enough negative feedback to over-come 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. 4.4(b).)

The collector load of the transistor is tapped down on transformer T_2 to match the impedance of the collector circuit. The secondary of this transformer can feed the input of a following frequency changer (or mixer) stage.

In a television receiver, automatic gain control (a.g.c.) is used to control picture level or amplitude and to keep it constant. A.G.C. also does a comparable job for the radio receiver. It is introduced at this time because the r.f. stage of Fig. 4.4(a) is a.g.c.-controlled. A.G.C. is discussed at greater length in Chapter 5.

Capacitor C_4 and resistor R_4 represent a decoupling network and,
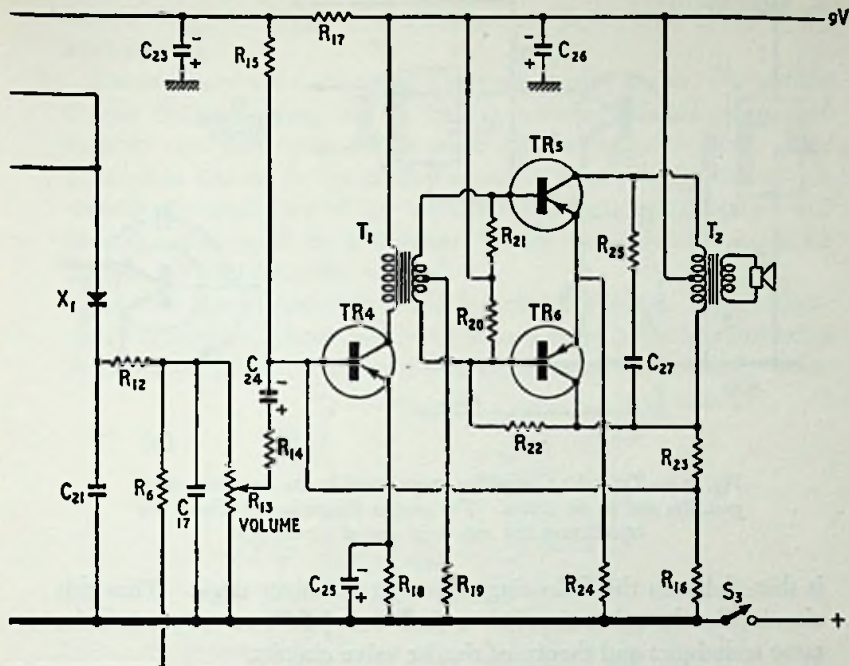
while it may seem strange to have such components in a receiver having a pure d.c. supply (a battery), it must be explained that the battery can act as a coupling device between stages of the receiver. R_4 and C_4 decouple this stage from the others and prevent signal energy from being fed back (via the battery) from other stages in the receiver. Capacitor C_3 is an r.f. by-pass and returns the bottom of the coil to r.f. emitter potential. It also serves as part of the a.g.c. filter.

The incoming signal is picked up by the aerial and is then transferred from the primary of T_1 to the secondary by mutual induction. The signal voltage developed across the secondary of T_1 is actually impressed between the base and emitter since C_3 offers very little opposition to the r.f. signal.

Since the input signal voltage is a.c. (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 T_2, induces a voltage across the secondary which
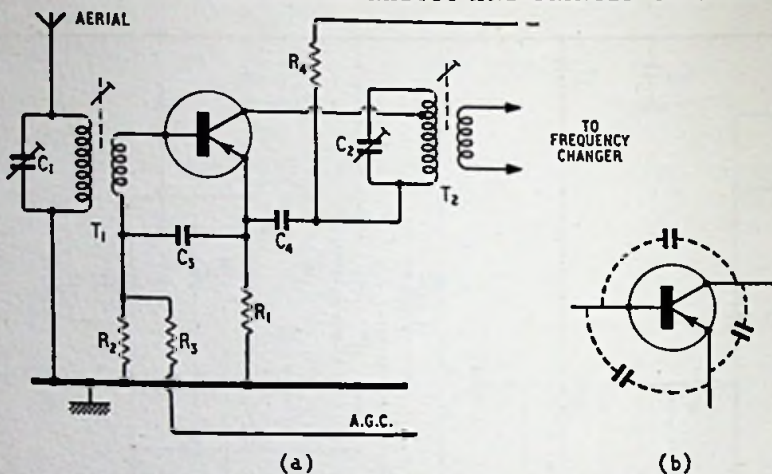
Fig. 4.4—Typical r.f. amplifier stage found in the more expensive portables and in car radios. The smaller illustration (b) shows the capacitances that may exist around a transistor

is then fed into the following converter or mixer stage.   Thus this circuit (like the other circuits we shall study) follows very much the same techniques and theory of similar valve circuits.

It is unusual for a British car radio to use transistors throughout, but if they did the circuit of Fig. 4.4. would be complicated by the need for two wavebands and the switching associated with them. American receivers do not usually include an L.W. band.

THE FREQUENCY CHANGER

The frequency changer, whether in a transistor or valve receiver, performs a double job.   Part of it acts as the local oscillator.   The local oscillator generates a signal and this locally generated signal voltage is fed into the mixer transistor.   At the same time, the modulated r.f. signal received from the broadcast station is injected into the same transistor.   These two voltages mix (or heterodyne, i.e., beat with each other), producing a number of new frequencies.   Of these frequencies, the one selected for the i.f. (intermediate frequency) is the difference frequency—that is, the local oscillator frequency minus the signal frequency.

A typical single-band frequency changer circuit is shown in Fig. 4.5. The incoming signal is tuned in by capacitor C_1 shunted across coil L_1. The r.f. signal is electromagnetically coupled to the base of the tran-

sistor through a step-down r.f. transformer. L_1 is a high-Q coil* with a ferrite core.

The oscillator coil L_2 is tapped to form a Hartley circuit.   Capacitor C_1 (for the r.f. section) and C_2 (for the oscillator section) are ganged variable capacitors—just as they are in a.c./d.c. valve receivers.   The 2,700-ohm resistor in the emitter circuit is 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 from the original.

Another type of converter circuit is shown in Fig. 4.6.   Fundamentally, this circuit works in exactly the same manner as the one illustrated in Fig. 4.5, but there are some interesting circuit differences.   First,
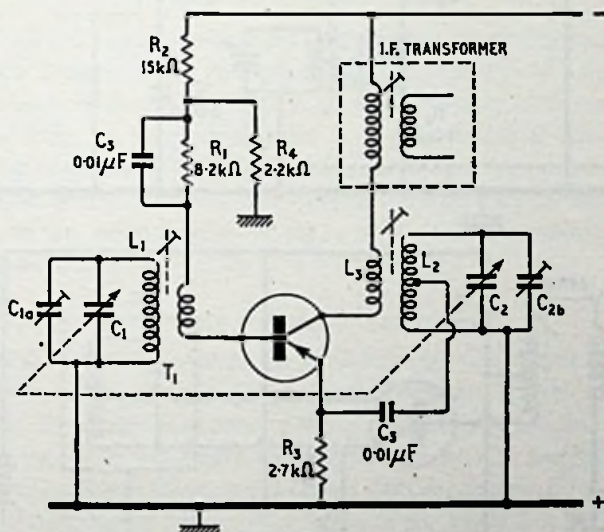
Fig. 4.5—*Typical single-band frequency changer circuit—a Hartley oscillator is used. L_3 is a feedback coil and is in series with the i.f. transformer*

it uses an npn transistor, and the negative terminal of the battery is earthed, whereas in Fig. 4.5 the positive is earthed.   It is essential that this difference is noted well since it demonstrates that the negative end of the battery cannot be assumed to be the earth point.

Now examine the input circuit.   The primary and the secondary of the input transformer are connected at the earth end.   As a result,

* High-Q means low-loss, or high efficiency.

capacitor C_1 must be inserted between the base of the transistor and the aerial 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).
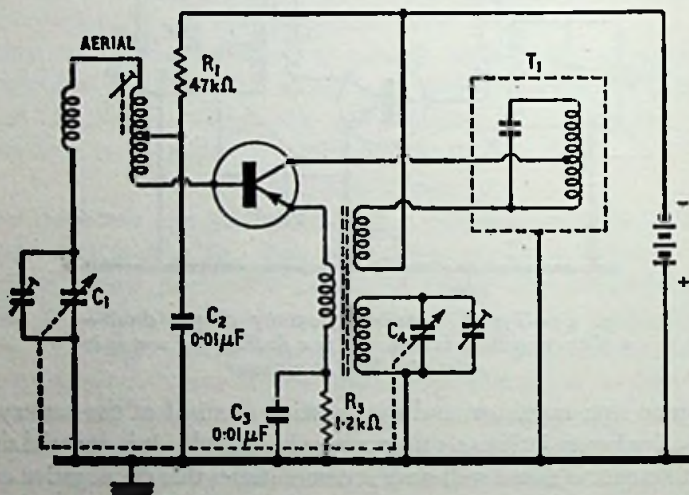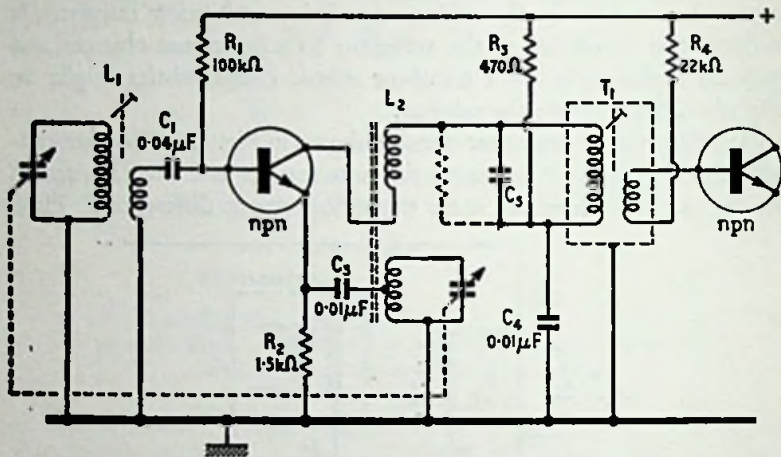
Fig. 4.6 (above)—Converter circuit using an npn transistor.   The input r.f. transformer is connected to the base through a capacitor
Fig. 4.7 (below)—Converter circuit using an auto-transformer type of aerial transformer.   The aerial and C_2 are "tapped" into the coil. The collector is tapped down on the primary of the i.f. transformer
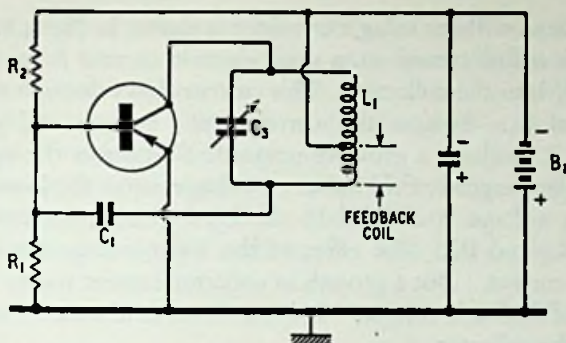
*Fig. 4.8—Hartley oscillator. Oscillator action is the same as in a
valve type*

Not all r.f. input transformers in transistor frequency changer circuits are double-wound units (that is, have a primary and a secondary). Sometimes, as shown in Fig. 4.7, an auto-transformer is used. As a general rule, an auto-transformer 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 wired to the secondary, as in Fig. 4.6, it could be mistaken for an auto-transformer.

THE LOCAL OSCILLATOR

The local oscillator performs the same function whether in a transistor or valve receiver. It generates a signal of its own, and this usually has a higher frequency than that of the r.f. signal delivered by the aerial transformer (and r.f. transformer if there is an r.f. amplifier stage). The local oscillator frequency is higher than the signal r.f. by the value of the intermediate frequency. Thus, if the i.f. is 455 kc/s and the incoming r.f. signal is 1,200 kc/s, then the local oscillator is 1,200 plus 455, or 1,655 kc/s.

The local oscillator can be a completely separate circuit with a valve or transistor of its own, or it can be obtained by making the mixer transistor oscillate, so that it does both jobs. However, whether the local oscillator is a separate transistor or whether it is joined with the r.f. into a combined arrangement, the circuitry of the oscillator is the same. It is exceptional for portable receivers to use a separate local oscillator, but there are a few that do. A separate local oscillator is more commonly used in car radios.

A Hartley oscillator using a transistor is shown in Fig. 4.8. When the circuit is first turned on, a small electron current flows from the battery B_1 into the collector. This current flows through the upper portion of L_1. Because this current starts at zero and gradually increases, it produces a growing magnetic field across the upper part of L_1. The magnetic field induces a voltage across the lower part of L_1. This voltage is coupled to the input (base-to-emitter circuit) through C_1 and R_1. The effect of this input voltage is to increase collector current. But a growth in collector current means a greater amount of feedback voltage. This continues until maximum current flows in the collector.

By this time, the magnetic field around the upper part of L_1 has reached a steady value and therefore no longer induces a voltage across the feedback coil. In the absence of a feedback voltage, the collector current drops rapidly. However, this induces a voltage
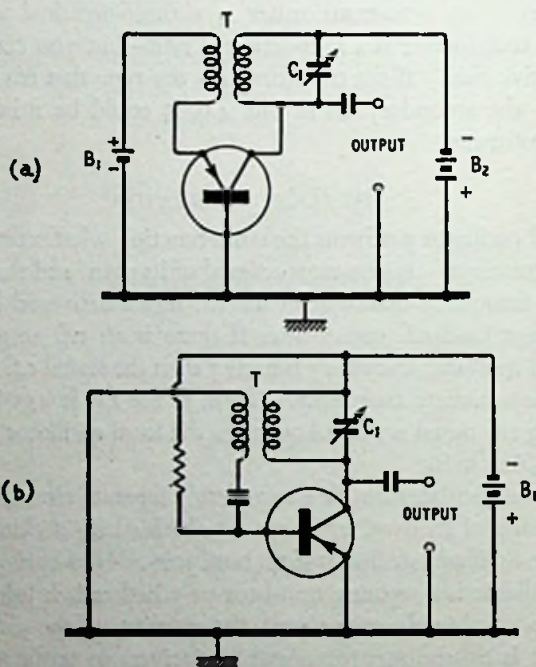
Fig. 4.9—Simplified earthed-base and earthed-emitter oscillator circuits using a transformer for feedback

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 is repeated.

Another type of oscillator is one that uses the feedback arrangement shown in Figs. 4.9(a) and 4.9(b). Actually, this circuit is practically identical with the Hartley oscillator we have just considered. The

Fig. 4.10—The oscillator circuit can be connected to the emitter of the mixer or converter
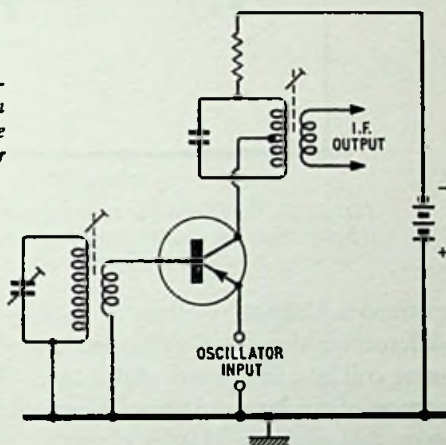
Hartley uses a tapped coil which simply behaves like an auto-transformer. In Fig. 4.9 we have instead of a tapped auto-transformer a coil having separate primary and secondary windings.

The theory of operation, though, is exactly the same. Current flowing from the battery to the collector must pass through the secondary winding of transformer T. This produces an increasing magnetic field which induces a voltage across the primary winding. The 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. Each " reacts " on the other, and at one time this was described as a " reaction " circuit. The rate at which all of these current changes takes place is determined by the secondary coil of transformer T and capacitor C_1 shunted across it.

6
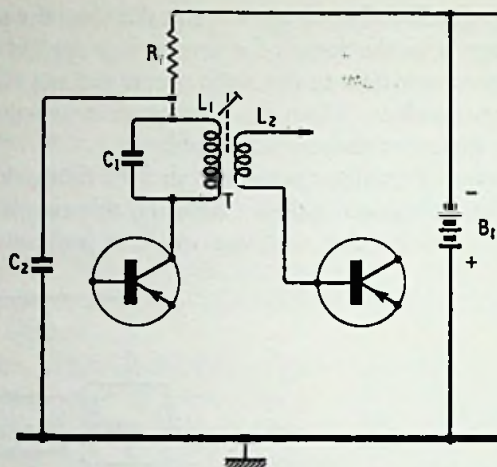
Fig. 4.11—The i.f. transformer is a stepdown type.   The collector circuit has a higher impedance than the base circuit of the following stage

Sometimes a Colpitts oscillator is used in place of Hartley.   The only difference is that the Colpitts uses two capacitors in series across the 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.

Returning to the circuits shown in Figs. 4.9, 4.10 and 4.11, these show 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. 4.5, for example, the feedback coupling coil is L_3 and is connected in series with the following i.f. transformer.   A modification of the circuit is shown in Fig. 4.6.

A different circuit arrangement is used in Fig. 4.7.   Here the collector output goes directly to the i.f. transformer and then to the series feedback coil.   Actually, it makes very little difference whether the feedback coil precedes or follows the i.f. transformer since the collector current must flow through both units.   In Fig. 4.7 it is seen that the oscillator is similar to the arrangement shown in Fig. 4.9.   The circuit of Fig. 4.7 is not a Hartley (that is, it is not an auto-transformer) since the oscillator has a coil with separate primary and secondary windings.

To make things clearer, examine Fig. 4.10. By itself the circuit is
an ordinary r.f. 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
frequency changer or mixer, all we need to do is to inject the signal
produced by a local oscillator.

To do this, we couple the oscillator signal to the emitter of the mixer
and tune the output circuit to the intermediate frequency. And, since
we tune the oscillator at the same time as we tune the incoming signal,
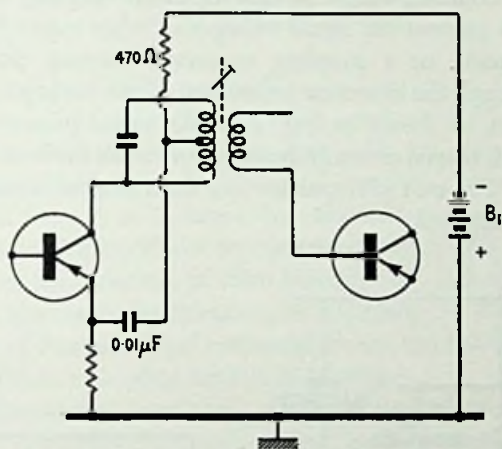
Fig. 4.12—*Tapping down is a widely-used method of obtaining a suitable
impedance match. Because of the presence of the 0·01-μF capacitor the
tap on the primary of the i.f. transformer is at the signal potential of the
emitter, introducing a degree of feedback*

always with the same frequency difference between them, our output
(or intermediate frequency) will be constant no matter what the
position of the r.f. and oscillator tuning capacitors may be.

THE INTERMEDIATE-FREQUENCY STAGE

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

I.F. coupling circuits can be inductive (as in the case of an i.f. trans-
former) or they can be combined inductive-capacitative arrangements.

A typical transformer coupling is shown in Fig. 4.11.   The impedance of L_1 is much greater than that of L_2. L_1 and C_1 form a tuned circuit and at the resonant frequency (the frequency of the i.f. stage) it has its maximum impedance.   If C_1 or L_1 should be detuned, the impedance would decrease and the amount of signal transfer to the secondary L_2 would be reduced.

The impedance of L_2 is small so as to match the input impedance of the base-to-emitter circuit of the following i.f. stage. L_2 is usually an untuned coupling coil. R_1 and C_2 are decoupling units and act as a filter to prevent the signal voltages of other stages from getting into the circuit, or a coupling occurring between this stage and another through the common impedance of the battery.

Sometimes, as shown in Fig. 4.12, the tuned primary of the i.f. transformer is tapped down in the collector circuit for better impedance matching.   The 0·01 μF capacitor and the 470-ohm resistor form the decoupling network.
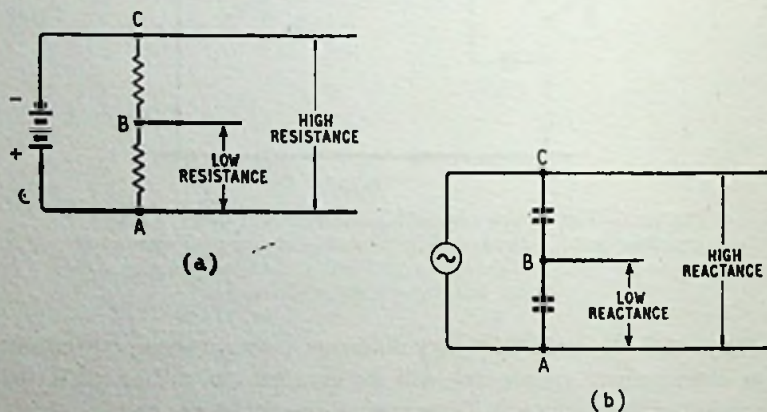
Fig. 4.13—*Resistors and capacitors can be used as voltage dividers*

Another coupling arrangement makes use of the fact that capacitors can be used as voltage dividers or impedance dividers.   In Fig. 4.13(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 "step-down resistance".
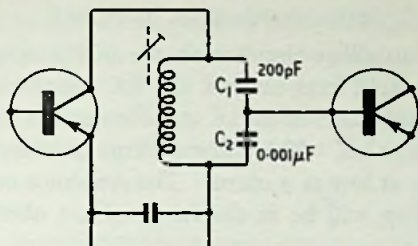
*Fig. 4.14—Method of coupling i.f.stages
through the use of series capacitors*

In Fig. 4.13(b) we have two series capacitors connected across an
a.c. generator. The two capacitors act as a voltage divider, the actual
voltage across each capacitor depending upon the value of capaci-
tance of the individual unit. The total *capacitance* from A to C is
less than that from A to B, hence the capacitative reactance is larger.
(Remember—when capacitors are connected in series the total capaci-
tance is lower than any one of them individually; and the higher the
capacitance, the lower the reactance, or impedance.) But impedance
is made up of reactance (and resistance) so we can use the technique
of Fig. 4.13(b) as a coupling scheme in i.f. stages.

This is illustrated in Fig. 4.14. As far as the collector of the first
transistor is concerned the tuned circuit has high impedance. The
base of the following stage regards the tuned circuit as an "impedance
divider", and the input impedance of the second transistor is matched
into the low impedance the following base circuit requires.

This type of i.f. transformer has a single adjustment—the ferrite core
which tunes the coil. In a typical receiver, C_1 might have a value of
200 pF while C_2 would have a value of 1,000 pF, giving 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. 4.15. In Fig. 4.15(a) the
collector impedance is matched, since it is connected to the tuned
circuit C_1, L_1. The input circuit of the following stage is tapped
down on L_1, so this lower impedance point correctly matches the
base-emitter circuit. In Fig. 4.15(b) both primary and secondary of
the i.f. transformer have taps. The same arrangement appears in
Fig. 4.15(c), except that a single coil is used in conjunction with a coup-
ling capacitor.

THE COMPLETE I.F. AMPLIFIER

A complete i.f. amplifier circuit is shown in Fig. 4.16. The dashed lines represent shield cans around the i.f. transformers. The d.c. resistance of the primaries of the i.f. transformers are in the neighbourhood of 11 ohms or less. This will vary from one receiver to the next, sometimes being as low as 3 ohms. The resistance of the step-down 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 a series resistor, and each of these resistors is by-passed. Note that the by-pass capacitors across the emitter resistors in the i.f. stages are larger in value (about 0·1 μF) compared with the by-pass across the frequency-changer emitter resistor (about 0·01–0·047 μF).
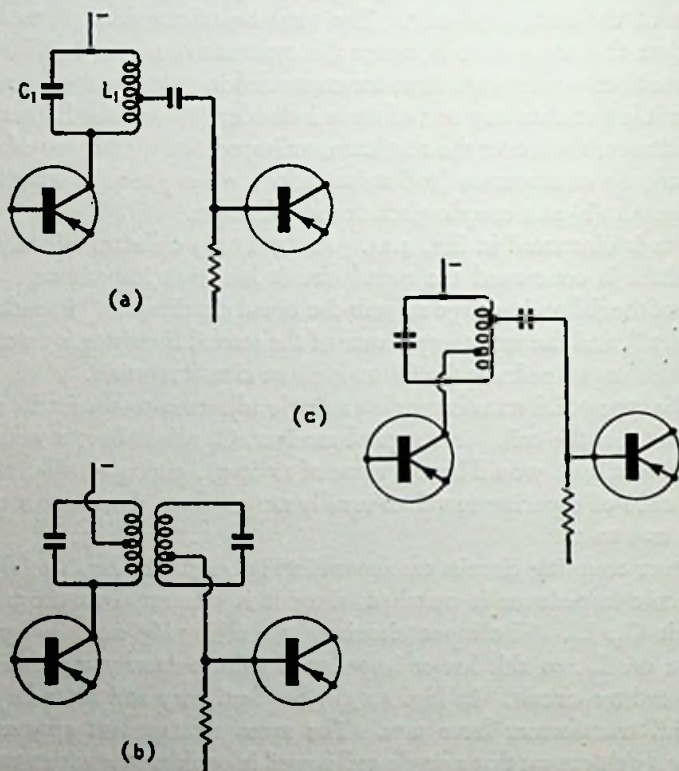
Fig. 4.15—Other methods used in coupling i.f. stages

Typical voltages in various parts of such an amplifier are given in Table 4.1, together with a commonly used set of transistor type numbers. Bearing in mind that the base–emitter bias is the difference between the earth–base voltage and the earth–emitter voltage, it can be seen for instance that the base–emitter bias for TR2 is 0·1 volt.

TABLE 4.1

Transistor		Emitter (V)	Base (V)	Collector (V)
VT1	OC44	1·2	1·2	7·2
VT2	OC45	0·6	0·7	7·2
VT3	OC45	0·9	1·0	7·5
VT4	OC78D	1·3	1·3	8·5
VT5	OC78	—	0·2	8·8
VT6	OC78	—	0·2	8·8

The base voltage is 0·7 and the emitter voltage is 0·6, but these readings when measured from the earth, or chassis line, are negative, and the base is 0·1 volt more negative than the emitter.

On the frequency changer TR1 the readings are both alike, but they change when the transistor oscillates. Conditions in an oscillatory circuit are always different from those in a normal stable circuit.

NEUTRALIZATION

Some types of transistors oscillate readily while others do not. When a transistor in an i.f. stage shows a tendency towards oscillation, neutralization of the stage may be required.

The term neutralization is used in connection with i.f. amplifiers, although it is really a form of negative feedback. In Fig. 4.17, R_1 and C_1, and also R_2 and C_2, represent negative-feedback paths for the two circuits. The signal voltage at the base of 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, necessary because the base of each transistor is at a slightly different d.c. potential.

This is only one method of neutralization. Some receivers omit the by-pass capacitor across the emitter resistor, thus applying negative feedback, as described earlier.
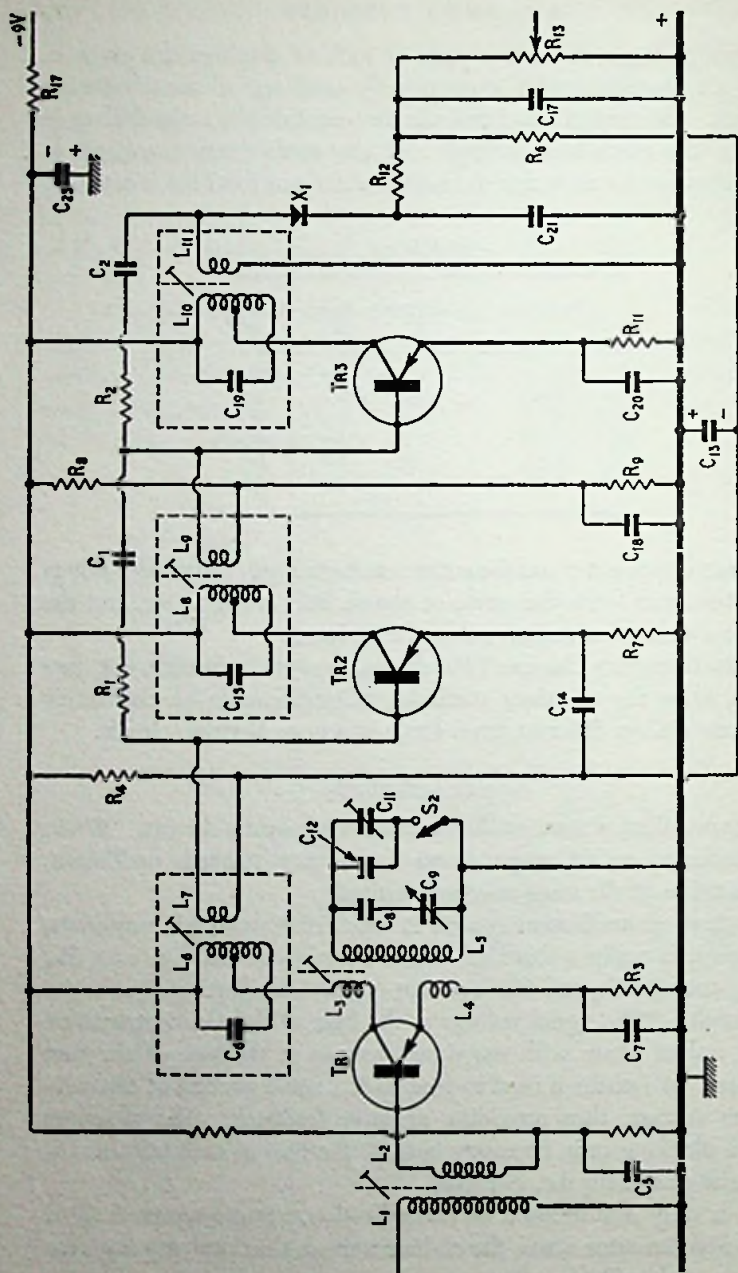
Fig. 4.16—A complete i.f. amplifier circuit. Component values are as follows: R_1 1·2 kΩ, R_2 3·9 kΩ, R_3 3·6 kΩ, R_4 68 kΩ, R_5 8·2 kΩ, R_7 680 Ω, R_8 22 kΩ, R_9 4·7 kΩ, R_{11} 1 kΩ, R_{12} 470 Ω, R_{13} 5 kΩ; C_3 56 pF, C_4 18 pF, C_5 0·04 μF, C_6 250 pF, C_7 0·01 μF, C_8 200 pF, C_9 15 pF (tuning), C_{11} 80 pF (pre-set), C_{12} 150 pF, C_{13} 8 μF (electrolytic), C_{14} 0·04 μF, C_{16} 250 pF, C_{17} 0·04 μF, C_{18} 0·04 μF, C_{19} 250 pF, C_{20} 0·1 μF, C_{21} 0·04 μF, C_{23} 50 μF (electrolytic)

SUMMARY OF FACTS TO REMEMBER

PNP 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. The emitter is made of p-type germanium. The pnp transistor is more commonly used than the npn.

NPN Unit. The collector voltage is positive with respect to the emitter. The base is also positive with respect to the emitter. The emitter is made of n-type germanium.

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

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

Circuit Arrangement. Transistors may be operated with any one of the elements as the common (or earthed) electrode. In transistor receivers the most usual arrangement is with the emitter earthed, or returned to earth through a biasing resistor. The base is the input element, while the collector is the output element. The earthed 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
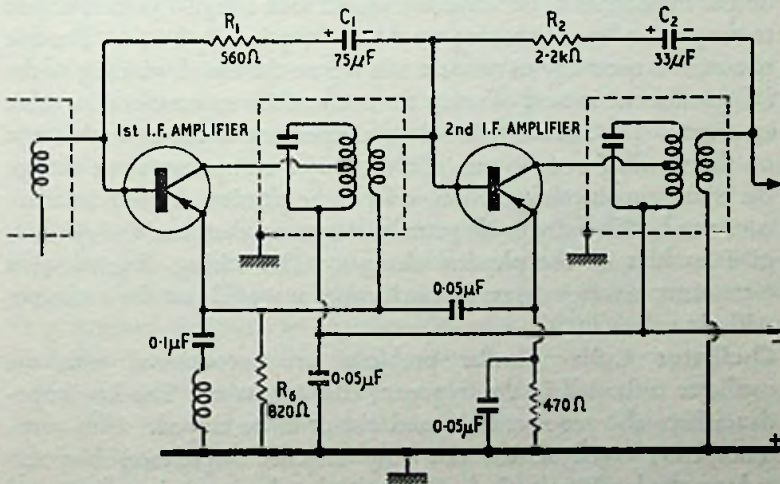
Fig. 4.17—*Illustrating neutralization in an i.f. amplifier stage*

valve circuits).   The earthed-emitter circuit has an output impedance that is high compared with its input impedance.

Transistor Characteristics.   Important measurements for transistors in servicing are: emitter voltage and current, base current, collector voltage and 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.

Current Carriers.   These consist of electrons and holes.   Holes are positive, electrons are negative, so that electrons always move towards a positive region and away from a negative one.   Thus, they will drift towards the positive terminal of a battery terminal.   Hole flow is in the reverse direction and 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 and often as little as 1 mA.   However, some power transistors require a collector current as much as 1·5 amperes.   Current for such transistors is generally supplied by a car battery.   Transistor receivers operate with voltages of less than 15 volts, a common value being 9 volts.

Component Characteristics.   The low-impedance characteristics of the transistor often make tuning of both the primary and the secondary of i.f. transformers impracticable.   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 necessary to connect to a tap on the tuned winding of the i.f. transformer instead of using the connections encountered in valve receivers.   The extremely low input impedance of the base takes taps on the winding even lower.   So the major components can change the whole circuit configuration, as far as the physical characteristics are concerned.   The circuit diagram varies somewhat but the symbols give no hint of the physical changes.   The wiring diagram of a 6-transistor receiver covers as much paper as would that for a receiver with six valves.

Oscillator Coils.   Similar problems are encountered with the oscillator coils used in the frequency changer stage.   The low impedance here also requires the tuned circuit to be tapped.   This auto-transformer 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 connections of these

miniature components are designed for easy insertion into printed-circuit boards, and no other means of securing these lightweight components are needed.

Aerial Coils. Frequency-changer stages have one other important inductor associated with them that forms a tuned circuit, and that is the ferrite rod aerial. 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 Plate 5. This coil, in conjunction with a section of a variable capacitor gang, is tuned to the station to be received. One is seen mounted in a transistor receiver in Plate 6.

Capacitors. Capacitors are also affected by transistor impedances. To act as an efficient by-pass, a capacitor must have a reactance of only a fraction of the impedance or resistance it is to by-pass. Normally, this will be of greater importance in low-frequency circuits such as audio amplifiers and power supply decoupling and filtering circuits.

The extreme compactness of the transistor personal portable has led to changes in the tuning components. The variable capacitors, in some cases, are totally enclosed in plastics boxes (Plate 7) 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 is to separate the plates with a thin sheet of plastics. This has the advantage that the plastics increases the capacitance of the unit, thus requiring fewer plates.

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 is about $\frac{1}{2}''$ long of $\frac{1}{4}''$ diameter. The 25-μF, 25-volt capacitor is a miniature of the type used as cathode by-pass capacitors in valve circuits. The miniature units may cost several times as much as a standard replacement type used in valve circuits, and they are easily lost because of their small construction.

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 quite a difficulty; as special parts, they may have to be ordered specially. While it is sometimes possible to substitute single capacitors, it is usually quite

impracticable to replace dual or multiple units with anything but the original types.

Capacitors of smaller values consist of metallic films plated directly on the surface of paper-thin ceramic wafers and stacked in layers to get the required capacitance. 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 at the circuitry beneath.

Resistors. In pocket transistor portable receivers, it is seldom necessary to resort to high-wattage resistors. For most applications, the familiar $\frac{1}{2}$-watt resistor is more than adequate. In cases where production techniques require extreme compactness, $\frac{1}{4}$-watt and $\frac{1}{8}$-watt resistors are used. 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 car radios, but it is unusual to find the large wirewound units familiar in valve circuits.

Volume Controls. Volume controls are variable resistors. Their wattage and their resistance values are 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 whose resistance falls rapidly as the temperature rises.

Thermistors are inserted into the circuitry to counteract the normal increase of current through the transistor as the temperature increases.

As used in transistor receivers, the thermistor 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 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 over-rated operation. This is necessary when designing such compact units.

Thermistors are often considered a type of semiconductor and have been adapted to many useful applications. Quite apart 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 valve circuits to increase the applied filament voltage slowly, prolonging the life of the valves.

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

The storage battery or accumulator is familiar from its use for many years in cars. 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 torches and electric shavers as well as in transistor receivers. They look like dry cells.

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

More important than the structure of the cell, to the technician, are its electrical characteristics. A common weakness with dry cells is the increasing internal resistance of the cells with age, making the cell a signal-coupling device for all stages and leading to positive feedback. 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 is cured by fitting a new battery but recurs too frequently, and battery life seems short, check the electrolytic filters in the filter or decoupling circuits. They may be weak or open-circuited. Bridge the suspects with another capacitor while using the old battery. If this cures the motorboating, change the filter capacitors for longer battery life.

Detectors and A.G.C.

By now, in the study of transistors and transistor circuits, it must have been realized that not everything connected with transistors is new or strange. All that has been done is to use existing and familiar components—resistors, capacitors and coils—in connection with a new device that acts as a substitute for the valve. This does not mean that, to change from a valve circuit to one using transistors one just substitutes a transistor for the valve. It is not quite so simple. But going from a valve a.c./d.c. receiver to a transistor type is less of a mental jump than going from radio receivers to television.
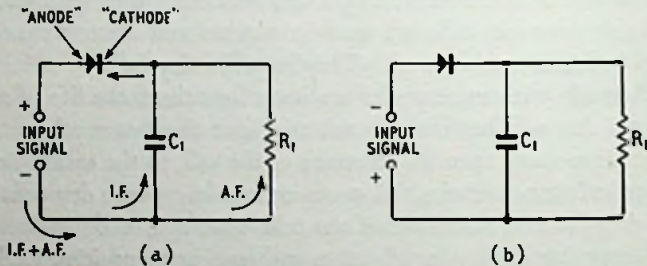
Fig. 5.1—*When the input signal is of the correct polarity, electrons will flow through the diode, as indicated in (a). When the input signal is reversed, practically no current will flow (b)*

In Chapter 4 we stopped just before the detector. The detector seems to be a good division point in a receiver, both from a theoretical and a practical servicing point of view. In servicing, everything that follows the detector is audio (low frequency) and everything that precedes the detector is i.f. or r.f. (a higher frequency). In servicing, you know that a signal injected across the volume control, and

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resulting in sound out of the loudspeaker, means that the audio section is working.

On the other hand, if you put a modulated r.f. signal into the mixer 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 their work.

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, but with the advantage that you don't have to imagine it. It is 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 anode 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.

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. The audio amplifier is quite satisfied to get the audio signal and it does not matter whether it comes from the top of the wave or the bottom—since top and bottom are mirror images of each other.

A diode detector can be arranged as shown in Fig. 5.1. The straight-line portion of the crystal symbol is similar to the cathode of a valve, while the arrow is similar to the anode. Theoretically, electrons 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. 5.1(a) electrons will flow from the negative input terminal, through the resistor, through the crystal diode and towards the positive input terminal.

Now what is this electron flow, and where does it come from? If we imagine the input terminals of Fig. 5.1(a) connected to the

secondary of an i.f. transformer, it is easy to see where we get the input signal from. Current from the i.f. transformer flows through the detector diode during every half-cycle (the positive half when the diode is connected the same way round as in Fig. 5.1(a)) of the inter-mediate-frequency carrier signal.

This i.f. signal is a two-part affair. It consists of the intermediate frequency (or i.f.) and the audio signal. These two currents, i.f. (intermediate frequency) and a.f. (audio frequency), move along the

(a)   (b)
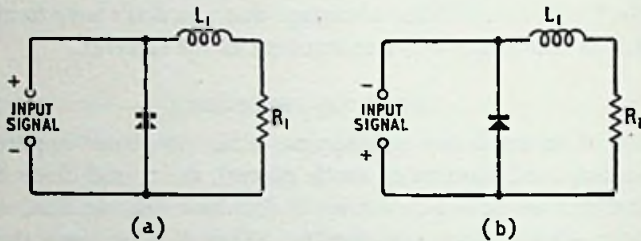
Fig. 5.2—Alternative arrangement of the diode in a crystal detector circuit

bottom conductor when the input signal has the polarity shown in Fig. 5.1(a). These two signals are given a choice—they can go through C_1, through R_1 or through both. The i.f. is about half a megacycle per second (0·5 Mc/s or 500 kc/s); that of the audio can vary from less than 100 c/s to more than 5,000 c/s. It is because of this big difference in frequency that we can separate them.

C_1 has a high reactance (or opposition) to low frequencies, so the audio barely gets through. But there is an easy path for the audio through R_1, which it promptly takes. The much higher i.f. finds it easier to go through C_1, and so it takes this path. R_1 is sometimes called the diode load resistor, or more simply, the diode load. Quite often it is a variable resistor or potentiometer, and is then known as a volume control.

Another type of diode detector is shown in Fig. 5.2. Here the crystal detector is connected in shunt (or in parallel) with the signal source. In Fig. 5.2(a), the signal applies a positive voltage on the cathode side of the diode and a negative voltage on the anode. A diode will not conduct 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 R_1 and through coil L_1. But there really are two currents in one—a low-frequency (or audio) current and a much higher frequency (or intermediate-frequency) current. Coil L_1 obstructs high-frequency current—and the higher the frequency, the greater will be its opposition. As a result, the current flowing through R_1 is mostly audio, with very little i.f.

When the signal polarity reverses, as it does at every half-cycle, we get the condition shown in Fig. 5.2(b). In this state almost all the current—both a.f. and i.f.—flows through the diode. The diode is practically a short-circuit across the coil and resistor. During this
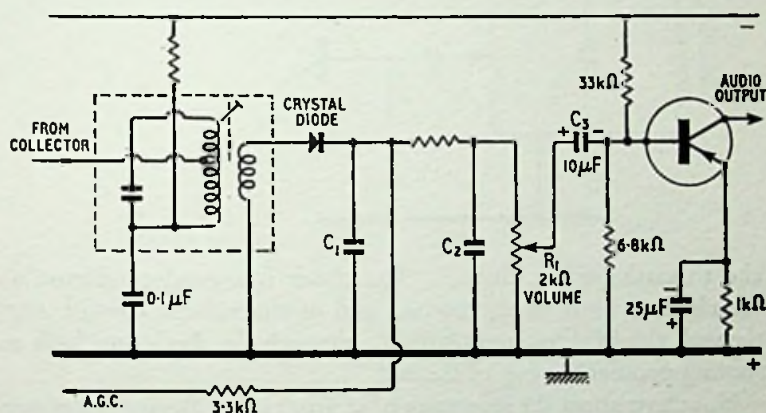
Fig. 5.3—Typical crystal detector circuit. The a.g.c. line is taken from the output of the detector

part of the input cycle, the diode load gets negligible current. This type of detector is not usually encountered in British radio receivers.

PRACTICAL CIRCUITS

The diode circuits we are to study look very much like those shown in Figs. 5.1 and 5.2. In Fig. 5.3, for example, is a circuit that is like Fig. 5.1. The input signal is supplied by the secondary of the i.f. transformer.

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 electron flow is through the coil (from top to bottom)

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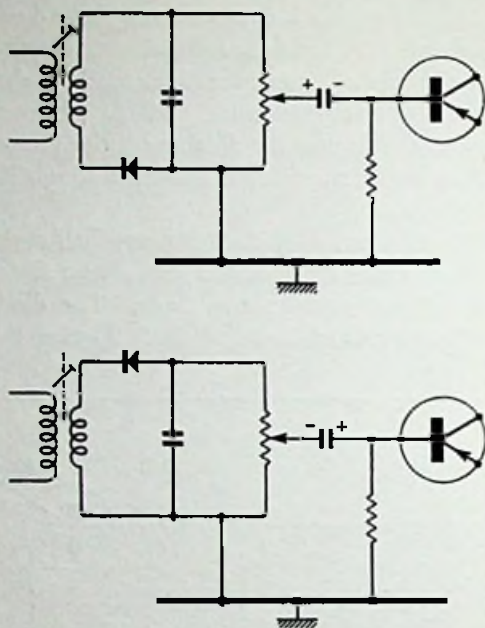
*Fig. 5.4—American cir-
cuit arrangements using
crystal diodes. British
receiver capacitor positive
would be on the chassis side*

and to earth (or the chassis). The chassis is a good conductor, so
the electrons flow to the bottom end of the volume control, then
through the i.f. filter resistance R_2, through the diode and back to
starting point at the top of the coil.

Now how about the separation of i.f. from a.f.? Because transistors
work in low-impedance circuits, capacitor values are considerably
larger than their counterparts in valve circuits, and C_1 and C_2 in
Fig. 5.3 have values between 0·1 and 0·5 μF each, making practically
a short-circuit for the i.f. Some audio is lost through them also,
especially at the high frequency (treble) end, but that is a small price
to pay for a simple and effective filter. In the circuit of Fig. 5.3
the diode load resistor is a 2,000-ohm volume control, and the coupling
capacitor C_3 has a value of 10 μF, which obviously calls for an
electrolytic.

A large value of capacitance is needed here since it couples the input
circuit of the first transistor audio amplifier. Electrolytics are often
used as coupling capacitors in transistor radios, but it must not be
forgotten that electrolytics are polarized. In Fig. 5.3, the positive
terminal of the electrolytic connects to the slider of the volume

control. This is because the volume control goes to chassis, which in a pnp circuit is usually positive. Signal electron flow is upwards through the volume control, which makes the bottom end negative with respect to the top end.

Fig. 5.4 shows some more circuits using diodes. These are similar in principle to those already studied, but they are not used in British receivers. Incidentally, when speaking of crystal diodes, the same language can be used as with transistors. When the polarity of the voltage is favourable, the crystal is biased in the forward direction and behaves as though it were a low resistance. When the signal polarity is reversed the crystal is biased in the reverse direction.

Under these conditions, the crystal behaves as a very high resistance and passes very little current. A crystal diode does not quite cut off, but the amount of current that flows through the crystal when it is reverse-biased is extremely small compared with that in the forward direction.

THE TRANSISTOR DETECTOR

The crystal diode is the ancestor of the transistor, and if the offspring is much younger, it is also more useful. The crystal diode merely rectifies, but the transistor takes detection in its stride, and amplifies at the same time.

To make a transistor behave as a detector as well as an amplifier the circuit must be modified, because otherwise it will not rectify. One method is to bias the transistor so that it operates in class B. That is, the transistor is biased at or near the cut-off point.

In the absence of a signal practically no collector current will flow in the transistor. If a signal is then applied, the signal will add to and subtract from the bias. One half of the input signal will subtract from 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 add to the existing small forward-bias voltage, and collector current will flow.

The collector current will follow the variations of one half of the input signal, which occur at audio frequency, and thus perform detection (or rectification). The collector current flowing through the collector load produces an enlarged (or amplified) version of that half of the signal.

A transistor detector circuit is shown in Fig. 5.5. The emitter is

connected to chassis. Note the voltage divider made up of resistors R_1 and R_2 in series, which are connected across the battery. The similarity between this and the base bias potential divider used in the i.f. amplifier of Fig. 4.3 will be recognized.

Normally, in an earthed-emitter circuit using a pnp 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 emitter current is obtained and, as a consequence, collector current.

In the circuit of Fig. 5.5 a current flows through R_1 and R_2, making the top end of R_1 negative. This point is connected to the base through the very low resistance of the secondary of the i.f. transformer. The bottom end of R_1 is connected directly to the emitter. The base is negative or, stating the same thing in other words, the emitter is positive with respect to the base. This would be a correct con-
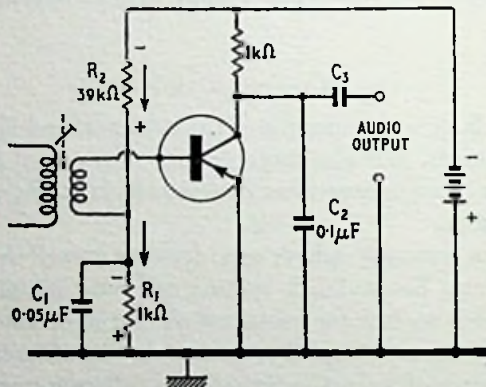
Fig. 5.5—Schematic diagram showing a transistor used as a detector in an American receiver. The transistor has an advantage over the crystal diode in that it amplifies the rectified signal

dition for amplifier action, except for the fact that the bias voltage is very small. The voltage is so low that very little emitter current flows.

Before continuing further, examine the secondary winding of the i.f. transformer. One end is connected to the base and the other end to R_1. The signal voltage that will appear across the secondary will alternately add to the voltage across R_1 and oppose it, in sympathy with the alternating polarity of the signal. Capacitor C_1 across R_1 helps to maintain a steady bias voltage on the transistor.

THE A.G.C. SYSTEM

The idea of automatic gain control—abbreviated to a.g.c.—is partly 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, but its original purpose was to compensate for periodic fading of the signal. Most a.g.c. circuits are simple, and their purpose is not to make a weak, hard-to-pull-in station sound as

(a)   (b)
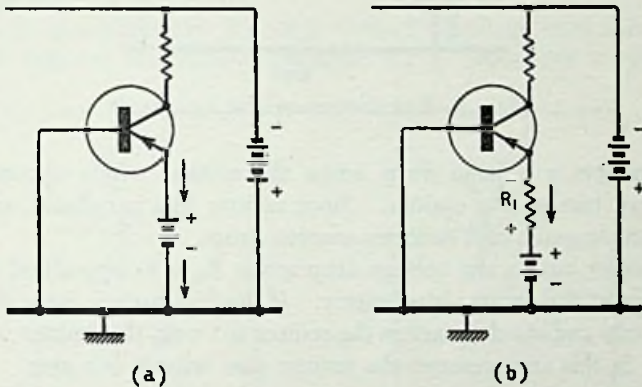
Fig. 5.6—Fundamental operation of an a.g.c. circuit

good as a local broadcast. They do not increase the sensitivity of a receiver. All a.g.c. can do is to cut down on the gain of the r.f. and i.f. stages when a strong signal comes through.

We have been comparing transistor circuits with those used in valve radios, but when it comes to a.g.c. we have again to watch the polarity. A.G.C. in a valve receiver is always a negative voltage. This adds to the negative bias of the r.f. or i.f. sections. In a transistor receiver, however, a.g.c. can be positive or negative, depending upon whether we are working with pnp or npn units.

As in valve receivers, a.g.c. is fed back from the second detector to the i.f. stages, and in some instances to the r.f. amplifier as well.

To see how a.g.c. can be made to function, consider the simple case of a single pnp transistor stage with an emitter bias battery in Fig. 5.6(a). The arrows near the emitter indicate the direction of electron flow from the collector circuit.

Suppose now we were to insert a resistor R_1 in series with the emitter bias battery as in Fig. 5.6(b). When current flows through R_1,
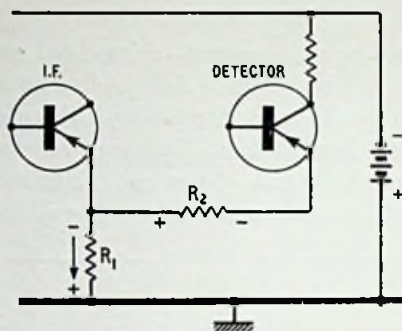
Fig. 5.7—Basic arrangement of an a.g.c. circuit

it produces a voltage drop across the resistor which opposes the forward bias on the emitter.   Since emitter bias is reduced, emitter current decreases and collector current drops.

In other words, the voltage drop across R_1 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, the emitter voltage is 2.   In this arrangement, the emitter gets what is left over.
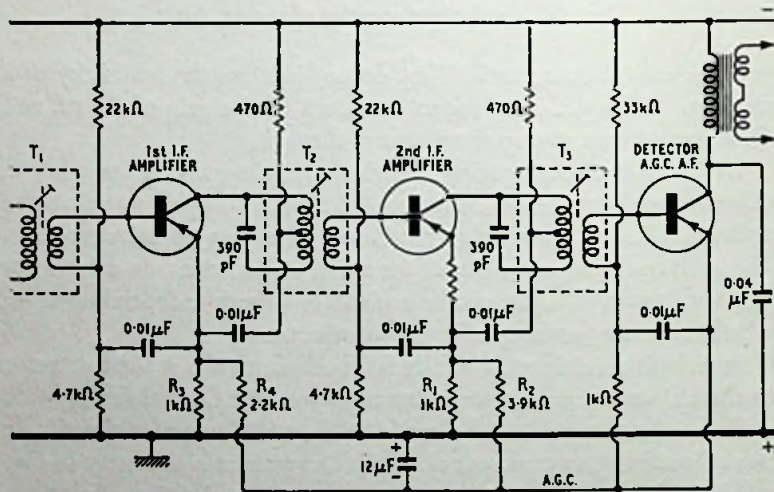
Fig. 5.8—Automatic-gain-control circuit.   The transistor at the output of the i.f. stage acts to supply a.g.c. and audio voltages in addition to working as a detector.   While in this circuit the a.g.c. controls the i.f. stages, in some receivers (especially car radios) the a.g.c. is fed back to the r.f. amplifier as well

An elementary a.g.c. circuit is shown in Fig. 5.7. The collector is tied to the negative terminal of the battery through a load resistor. Both emitters, the i.f. and the detector, go to the positive end of the battery. Now suppose that a strong signal comes into the detector. To handle the strong signal, the detector needs more emitter current, and the only place it can get this is from the battery. Electrons start to move from the negative terminal, through the detector collector and resistors R_2 and R_1.

But in going through R_1, they produce a voltage drop across R_1 which opposes the battery voltage. R_1 is connected to the i.f.

(a)   (b)
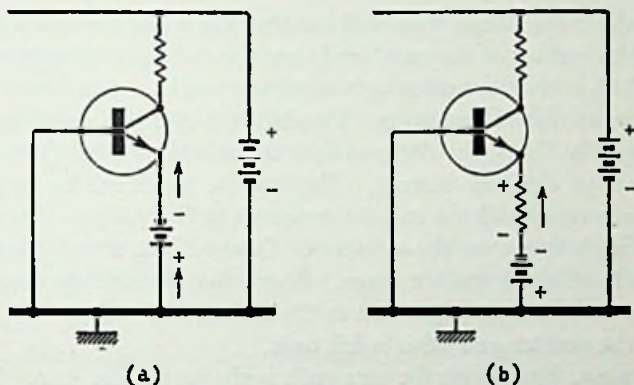
Fig. 5.9—The gain of the transistor is reduced by putting a resistor in series with the emitter

transistor because the emitter of the i.f. transistor will now get a reduced forward-bias voltage, and its gain will go down. As a result, the signal going into the detector will become reduced in strength. That is how a.g.c. works.

Now let us imagine that a very weak signal reaches the detector. Much less emitter current flows and, as a result, a smaller demand is made on the bias battery. Since a weaker current will now flow through R_1, the i.f. transistor gets a larger forward-bias voltage. But this condition of maximum bias voltage permits the i.f. transistor to work at full gain—amplifying the weak signal.

A representative a.g.c. circuit is shown in Fig. 5.8. The a.g.c. consists of resistors R_1, R_2, R_3 and R_4. These resistors are in the emitter circuits of the first and second i.f. amplifier stages. If you
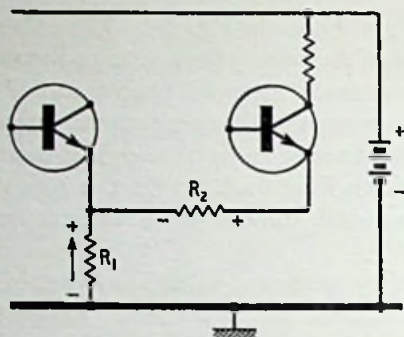
Fig. 5.10—A.g.c. bias net-work for pnp transistors. Note that the voltage across bias resistor R_1 is in opposi-tion to the direction for forward emitter bias voltage. Current flowing from both the emitters through R_1 reduces the for-ward bias, thereby lowering the gain of the transistor stage

trace the connections, you will see that these resistors are also tied in to the emitter of the combined detector and a.g.c. transistor.

A.G.C. in receivers using npn transistors works in a manner exactly opposite to that of pnp units. Consider the simple circuits shown in Fig. 5.9. In Fig. 5.9(a) electrons flow to the emitter from the negative terminal of the bias battery. This can be modified by putting a resistor in series with the emitter, as shown in Fig. 5.9(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 gets what is left over.

An a.g.c. bias circuit for npn units is shown in Fig. 5.10. This is exactly the same circuit as that for pnp transistors in Fig. 5.7 except that the current flow is reversed. All that has actually been done is to reverse the polarity battery. Once again the emitter resistor opposes the battery voltage—and the stronger the signal, the greater will be the opposition voltage developed across R_1.

A.G.C. voltage does not necessarily require that there is a transistor as a detector. In fact, in British receivers it is a rarity. A diode demodulator is normally used and the required a.g.c. will still be obtained. But before getting too deep into this discussion, let us turn back for a minute to Fig. 5.6. In examining this circuit, we see that the emitter is positive with respect to the base. Another way of saying the same thing is that the base is negative—with respect to the emitter. We can reduce the gain of the pnp transistor by making the emitter less positive or by making the base less negative. These statements apply to npn transistors, except that the polarity of the voltages is reversed.

In Fig. 5.11(a) is shown the circuit of a crystal detector. It is essentially the same as the one we saw in Fig. 5.3. The crystal is tapped down on the i.f. transformer of the last stage. To make the action a little clearer, that part of the circuit that interests us is shown in Fig. 5.11(b). An i.f. voltage appears between points A and B. When the polarity of this voltage is favourable, electrons will flow from point B, through the volume control and diode in the direction shown, passing through the chassis, or common connector, and back to point A. If the connections to the diode were reversed, the direction of the electron flow would also be reversed.

When this current flows through the volume control, the voltage that develops across it is positive at the top and negative at the bottom. This voltage (*see* Fig. 5.11(a) *once again*) is fed back via R_2 to the base of an earlier stage. The voltage fed back is positive, and it opposes the negative voltage on the base of the pnp 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 pnp transistor, reduces the forward-bias voltage between base and emitter. Result—gain goes down. If the signal is weak, the a.g.c. voltage is lower and the transistor is permitted to operate with more gain.
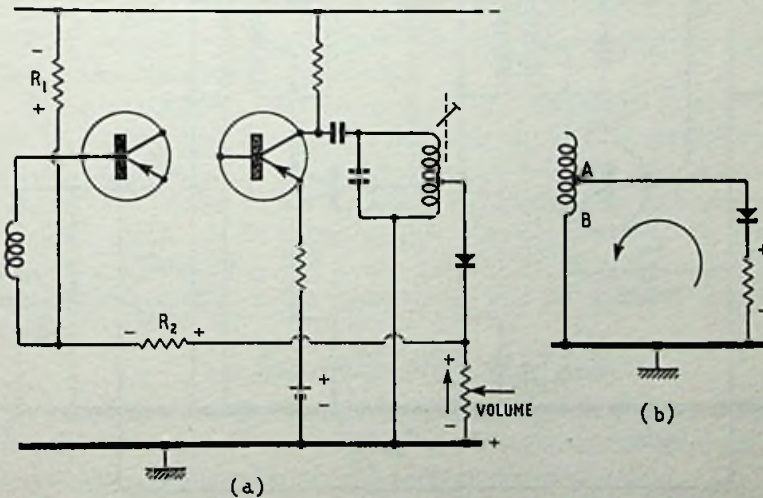
Fig. 5.11—*A.g.c. bias circuit for receivers using pnp transistors. The a.g.c. voltage is applied here only to one i.f. stage*

BRITISH A.G.C. CIRCUIT

The i.f. and detector circuits in most British transistor portables are arranged as shown in Fig. 5.12.   As we saw earlier, base bias is taken from a potential divider like R_8, R_9 from which TR_3 derives its bias. TR_2 derives its base bias from a similar potential divider R_4, R_6, but R_6, instead of going straight down to chassis and thus to the positive terminal of the battery, returns to chassis via R_{13}, which acts as the volume control and the detector diode load.

Base bias from either potential divider is negative with respect to chassis, and the emitters of TR_2 and TR_3 are positive with respect to their bases and they are therefore forward biased.

The direction of the rectified current from the detector diode X_1, however, is such that the top of the volume control becomes positive
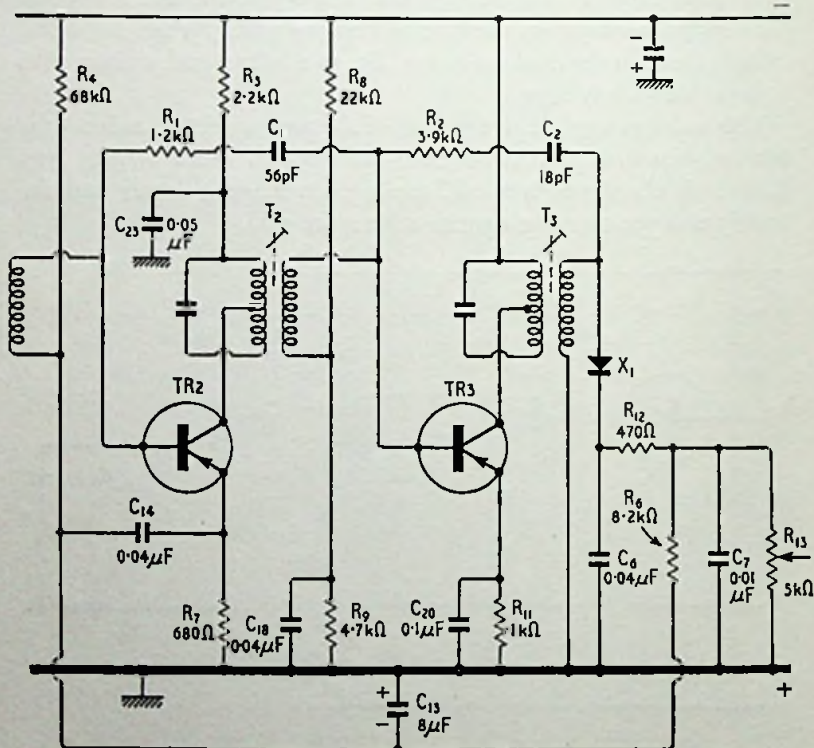
Fig. 5.12—*A.G.C. bias in most British receivers is derived from the d.c. voltage developed across the volume control resistance R_{13}*

with respect to chassis. That is to say, the direction of the electron flow is upwards from chassis and towards the rectifier.

In the absence of a signal the top of the volume control is negative, because it forms part of the potential divider R_4, R_6, R_{13} whose polarity at the chassis end is positive. There is no current through the diode. Upon the arrival of a signal the flow of rectified current causes a voltage-drop along R_{13} whose polarity is opposite to that of the potential divider.

How large the opposing voltage is depends on the strength of the signal, but its effect is to offset the negative voltage on the potential
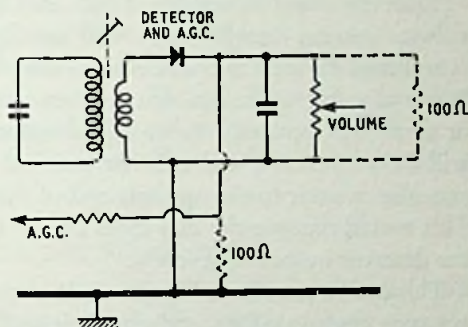
Fig. 5.13—*To remove the a.g.c., connect a 100-ohm resistor from the a.g.c. line to chassis*

divider, reducing the base bias on TR2. Thus the forward bias on TR2 is reduced, reducing the gain of the stage, just as negative grid bias reduces the gain in a valve stage.

In Fig. 5.12, C_6, R_{12} and C_7 form an i.f. filter which helps to remove the i.f. carrier signal, leaving only the audio signal across the volume control R_{13}. In some receivers R_6 goes in the other side of R_{12}. The network C_1, R_1, C_2 and R_2, will be recognized as the neutralizing feedback circuit, but the values used here vary considerably. R_3 and C_{23} form a decoupling feed to the collector of TR2, but it is not often necessary. The values shown in Fig. 5.12 are typical of British practice.

REMOVING THE A.G.C. VOLTAGE

Sometimes in servicing, and particularly in alignment, it is helpful to remove the a.g.c. bias. A.G.C. cuts down on receiver sensitivity and so can interfere with the alignment or repair of a stage.

If a crystal detector is used for both signal rectification and also as the a.g.c. source, a.g.c. can be removed by connecting a 100-ohm

resistor from the cathode of the crystal to chassis as shown in Fig. 5.13. If the crystal isn't easy to reach, connect one end of the resistor to the chassis and the other end to the high potential side of the volume control.

Since it is quite a usual routine to isolate the a.g.c., 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 is not critical—a 200-ohm resistor will do just as well. A half-watt size is adequate.

With the 100-ohm resistor as indicated in Fig. 5.13, as it shunts the volume control heavily there will usually be insufficient output if you intend to use the speaker as an output indicator for alignment. When aligning, make sure that the volume control is set for maximum or there will probably be no signal output. Even then the output will be very small, and a better method would be to connect the 100-ohm resistor to the opposite end of the a.g.c. resistor in Fig. 5.13. This would remove the bias from the i.f. transistor without shunting the detector output so severely.

This can be seen from Fig. 5.12. If a 100-ohm resistor is connected between the top of R_6 and chassis it will virtually short-circuit the volume control and R_6. If it is connected between the bottom of R_6 and chassis the shunting effect will be negligible, but the base bias on TR2 would be upset, and this would be likely to affect the alignment of T_2.

There are two other ways of muting or suppressing the a.g.c. action. One is to disconnect the top of R_6 from R_{12} and connect it to chassis; the other is to insert a milliammeter in the a.g.c. line somewhere between R_{13} and R_4 and adjust the i.f. transformer cores for maximum a.g.c. action as indicated by the change of current in the meter.

Both of these methods require the unsoldering of a component lead, usually from a printed circuit board, and that is not usually considered desirable if it can be avoided. The a.g.c. line voltage could be measured instead of inserting a milliammeter, but a strong signal would be required and alignment should be performed on a weak signal.

So the best and simplest method is to feed in a very small signal from the signal generator, and measure the output from the speaker, where almost any kind of meter can be used so long as it shows a

reading. Adjustments are then made for maximum deflection, using the smallest signal that can be detected.

Some manufacturers say nothing in their alignment instructions about suppressing a.g.c. voltage. Using a very small input signal, alignment can be carried out without suppressing the a.g.c., but if the signal is large enough to actuate the a.g.c. circuit it tends to make tuning adjustments rather broad. When working with very low values of signal voltage from the generator, the amount of a.g.c. developed will be so little as to be of no consequence. However, many inexpensive generators are not very well shielded and leak an appreciable amount of test signal. It is advisable to keep the generator as far from the receiver as the test leads 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, remember to keep the test signal turned down as low as possible when alignment or repair brings up the gain of the set.

WEAK OR DISTORTED SIGNALS

Faults in the a.g.c. circuit can cause signals to be weak or distorted. If a.g.c. is excessive, the effect will be to reduce the gain of the controlled transistor(s) to such an extent that output will be very low. The a.g.c. represents a bias which adds to or subtracts from the existing bias of the controlled stages, whether r.f. or i.f. Thus, the a.g.c. shifts the operating point of the transistors, and if this shift is strong enough, the signals will be distorted.

If distortion occurs on weak stations, but 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 a.g.c. voltage is of the proper polarity. Check the a.g.c. voltage with a high-impedance instrument such as a valve voltmeter.

In some receivers an overload diode is used to cut down the gain of i.f. stages for strong signals. If distortion occurs with strong signals, try substituting a new overload diode. It is usually connected between the collector tap on the first i.f. transformer and the collector tap on the second one.

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

is turned down, try turning the receiver around so that the aerial picks up less signal. If the distortion disappears when this is done, it is quite possible that the receiver is not capable of handling the signal voltage being fed into it. Another well known cause of distortion that must not be overlooked, of course, is a warped speech coil which can sound very much the same.

BIASING THE DETECTOR DIODE

In some transistor receivers using a crystal diode as the detector, a small amount of d.c. voltage is applied to the detector. This resembles the forward-bias used between base and emitter of a transistor. It may seem strange to bias a diode, since this is a technique usually reserved for transistors or valves, but the bias on the crystal diode is useful.

When examining the characteristic curve for a diode you will see that it is curved at the beginning. This is the region in which distortion takes place, and by biasing the diode it is possible to avoid using the curved part of the characteristic. This is very useful when the input signal is weak since the use of bias on the diode permits reception of weak signals with little distortion.

CHECKING A.G.C. OPERATION

The bias voltage existing between base and emitter of the usual transistor r.f. or i.f. amplifier stage is quite small—a fraction of a volt. The effectiveness of the a.g.c. network can be checked by connecting a valve voltmeter between base and emitter. Do not use an ordinary multi-range meter. The valve voltmeter must be able to read 3 volts full-scale deflection (d.c.), preferably less; at the base end it should be connected to the junction of R_4 and C_{13} in Fig. 5.12. Its other terminal should go to the emitter, although it could go to chassis.

Set the instrument on its lowest scale. For pnp transistors, connect the positive test lead to the emitter, and the negative one to the base. For npn units, reverse these connections. With the leads connected, adjust the tuning knob 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.

Bear in mind that with npn transistors the a.g.c. voltage becomes more negative as the signal increases. If the circuit uses pnp transistors, the a.g.c. voltage becomes more positive as the signal increases.

CHAPTER 6

Audio Amplifiers

THE audio amplifier is another example of electronic progress. Some older readers may remember the time when the only job of the audio amplifier was to make the signal loud enough to use a loudspeaker. It made little difference if the sound was distorted or not. Earphones became unnecessary and ownership of a loudspeaker put one a notch above the neighbours who had to strain their ears. The loudspeaker was the Cadilac of its day.

Today, however, the amplifier is very carefully designed, and there is a variety of audio systems that is comparatively complex. The audio amplifier found in transistor receivers is quite specialized, and it needs to be properly understood when it requires servicing.

THE VOLUME CONTROL

The volume control is often located directly at the output of the second detector, where you would expect to find it. In this position it works as the second detector load, whether a diode or transistor is used.

Fig. 6.1 is another representative example of a volume control circuit. As before, the volume control forms a series network with the detector and the secondary of the last i.f. transformer. The volume control is an adjustable voltage divider that taps off the desired amount of audio voltage that appears across it.

The signal is coupled to the first audio amplifier stage through a small electrolytic capacitor. In a representative receiver, the volume control would be 5,000 ohms, or less. The 0.01-μF capacitor across the volume control is an i.f. by-pass which serves to keep the i.f. carrier out of the audio system. Incidentally, note that the detector

operates at both i.f. and a.f. but it is actually the i.f. that it rectifies· 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 at the earth end.

Sometimes the volume control is part of the input to the first audio stage, as shown in Fig. 6.2. In such cases a fixed resistor would be used for the diode load. The volume control might be connected across the secondary of the input audio transformer, as shown in Fig. 6.3, although this is rare. The 0.01-μF capacitor across the secondary of the audio transformer does the same job as the capacitor usually found connected to the anode of the audio output valve in a valve set. This capacitor by-passes the high-frequency portion of the audio. By comparison, the bass part of the audio now sounds stronger (or boomier), and the set will sound better—to some people at least.

TONE CONTROLS

Tone controls are variable, and tone correctors are fixed. Sometimes the tone corrector can be situated in the audio section of a receiver
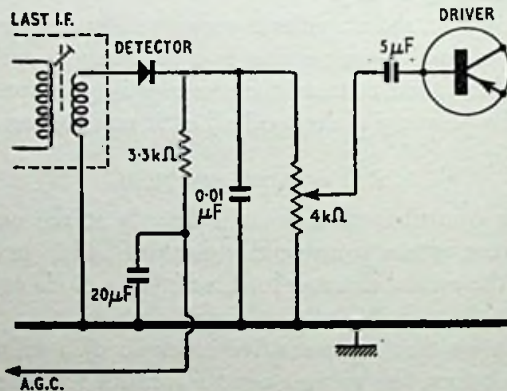
Fig. 6.1—*Volume control circuit. Note the large-value coupling capacitor between the volume control and the base input circuit of the driver stage*

in such a way that we will not immediately recognize it. The fixed capacitor across the primary or the secondary of any audio transformer might be either a tone corrector or an r.f. by-pass (Fig. 6.4(a)). The effect of the capacitor on the reproduction is quite simple to understand. As audio frequencies go up (higher tones), the reactance
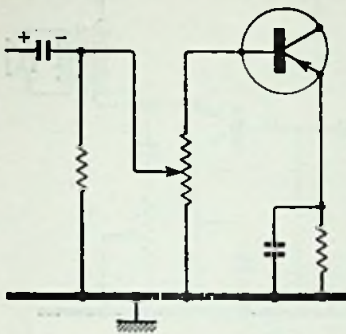
Fig. 6.2—In this circuit the volume control is part of the input circuit of the first audio amplifier
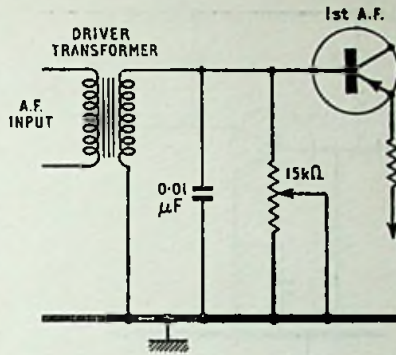
Fig. 6.3—In this circuit the volume control is connected across the secondary of the audio driver transformer

of the capacitor goes down. As a result, if the capacitor shunts the circuit the higher frequencies are by-passed and are either not heard or are very weak. By comparison, the bass notes seem to be stronger. Actually nothing has been made stronger, but it appears that way by comparison.

The capacitor just described is a fixed unit, and the owner of the receiver has no control over it. If he objects to the sound as being too bassy or boomy, you could substitute a capacitor with a lower value to reduce the effect. For instance, if the capacitor is a 0·05-μF unit, you could try a 0·01 in its place.

The simplest type of variable tone control (Fig. 6.4(b)) is one using a potentiometer in series with the capacitor 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 permits the owner of the receiver to adjust it as he likes. When the variable resistor is set to its maximum value the high notes will be reproduced fully, but when it is set at its minimum value the high-note response will be at minimum.

TONE CONTROL FAULTS

Many set owners are " knob twiddlers ". Something compels them to adjust and readjust the controls of the receiver. The tone control is particularly subject to this treatment. The result is that this type of control gets worn and noisy. In servicing, tune in a station and

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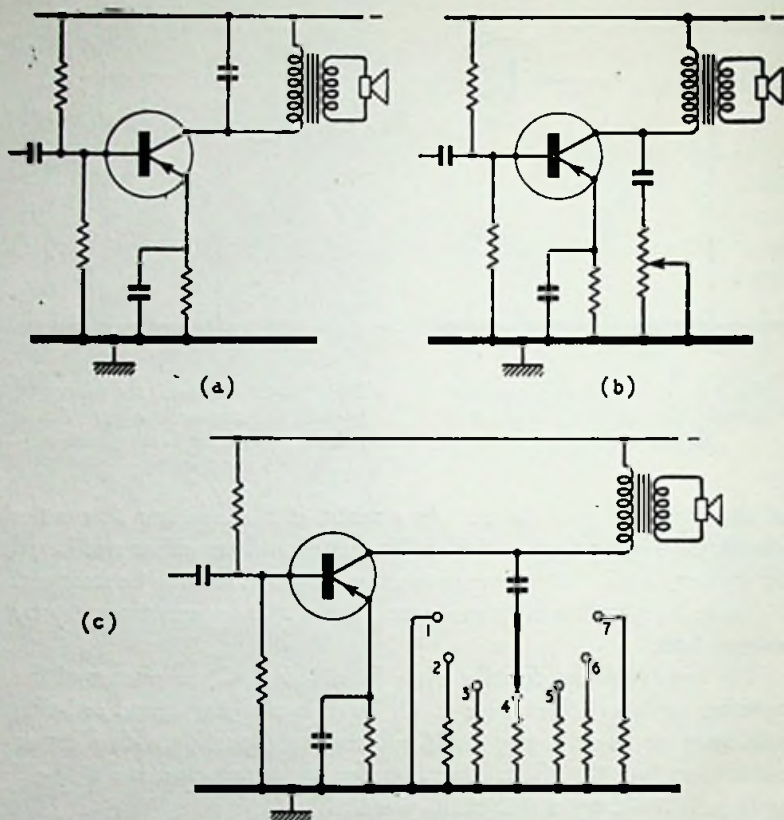
Fig. 6.4—*Typical tone control circuits. The resistor can be a potentiometer or a number of resistors which can be switched in and out of the circuit. The tone control can be part of the driver stage or can be located in the audio output*

rotate the control. If you hear scratches in the loudspeaker, either replace the control or try improving 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-circuited (likely) or the capacitor to which it is connected is open-circuited (much less likely).

A very elaborate type of tone control is shown in Fig. 6.4(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 in position 1. This type is unlikely to be found in a domestic receiver.

Troubles with this type of control would be much the same as for the circuit of Fig. 6.4(b), plus a few of its own. A rotary wafer switch is used to select resistors. Switches can get jammed or dirty. If the switch will not turn, the rotor of the switch should be examined to see what prevents it from moving.

SINGLE OUTPUT STAGE

Some audio-amplifier stages are elaborate, others less so. The audio-output stage can consist of a single transistor stage driving a loud-speaker, as illustrated in Fig. 6.5 (an American circuit) and earlier in Fig. 3.15 (a British circuit). There is some useful information to be found in these diagrams. First, we see that the on/off switch and the volume control form a single unit operated by a single shaft. This is standard practice.

A useful and now common feature, though, is the optional use of an earpiece (of the hearing aid type) or loudspeaker. Earphones are
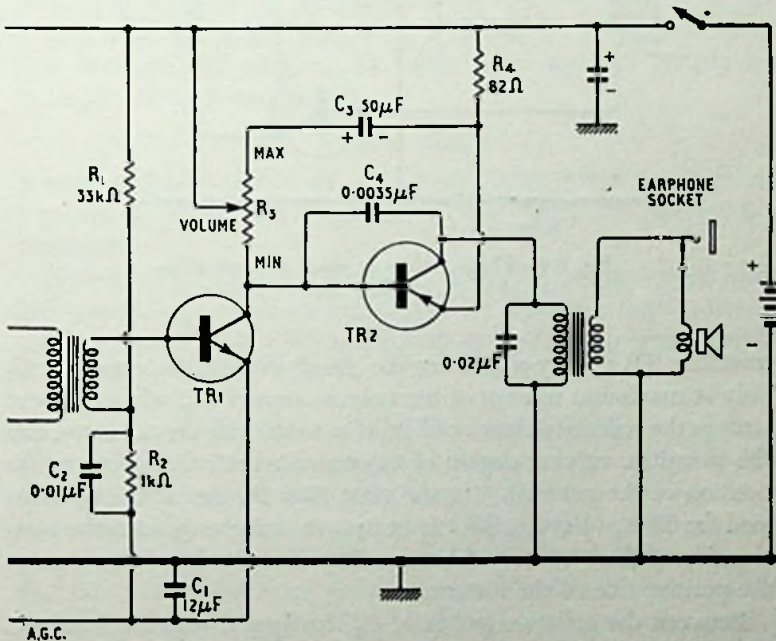
Fig. 6.5—*American direct-coupled audio amplifier using two transistors. The detector transistor in an earlier stage also supplies some audio gain*

not used with a.c./d.c. valve receivers owing to the risk of shock and because the hum level is so high. But transistor receivers are battery-operated, so the hum is not present. It is amusing to reflect that thirty years ago you had to have headphones if you had a radio, and today earphones are becoming popular again. In some sets, plugging in the earphones automatically disconnects the loudspeaker, but this is not always the case.

Note that in the circuit of Fig. 6.5 the audio signal is directly (d.c.) coupled into the output stage. The emitter resistor R_4 of the output
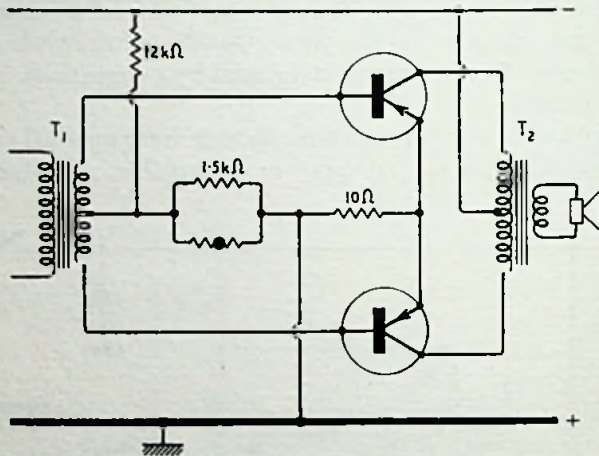
Fig. 6.6—The thermistor is placed in shunt with one limb of the base bias potential divider

transistor TR2 is by-passed by the 50-μF electrolytic capacitor C_3 only at maximum settings of the volume control R_3, while at lower settings the resistance element of R_3 is in series with the capacitor, and this permits a varying degree of negative feedback (according to the position of the control). At the same time R_3 acts as the collector load for TR1. Because TR1 is an npn, its collector goes to the positive side of the battery, and because TR2 is a pnp its emitter goes to the positive side of the battery.

Between the collector and base, C_4 also applies negative feedback. Disconnecting this capacitor increases volume and distortion, but it is also possible that the output circuit may start oscillating. The

0·02-μF capacitor (a simple tone corrector) across the primary of the audio output transformer cuts down high audio frequencies and gives the impression of a good bass response.

The primary and the secondary of the output transformer are connected together at one end and earthed. This is difficult to get accustomed to after working on a.c./d.c. receivers, where the output transformer represents a positive H.T. point.

THE THERMISTOR

The thermistor is a type of resistor whose value changes with temperature. While it is still a resistor, it is distinctive in that it has a high negative temperature coefficient. This means that the hotter it becomes the lower the resistance of the thermistor. When the temperature goes down, the resistance of the thermistor goes up.

Mounted very close to the audio output transistor, but connected in the input circuit of the audio power amplifier (that is, it is connected between base and emitter) it helps to keep emitter current steady. It does this by reducing the negative base bias when connected as shown in Fig. 6.6, where it shunts the lower limb of the base bias potential divider. Its value varies between 10 and 150 ohms according to temperature.

DRIVER STAGES

A single transistor used as an audio output stage is both a voltage and a power amplifier, and it gets some help when the detector is a transistor.

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

COLLECTOR CURRENT STABILIZATION

Power transistors bring along a few problems 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 leakage 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 this; two of these have been mentioned; one is the heat sink and the other is the thermistor.
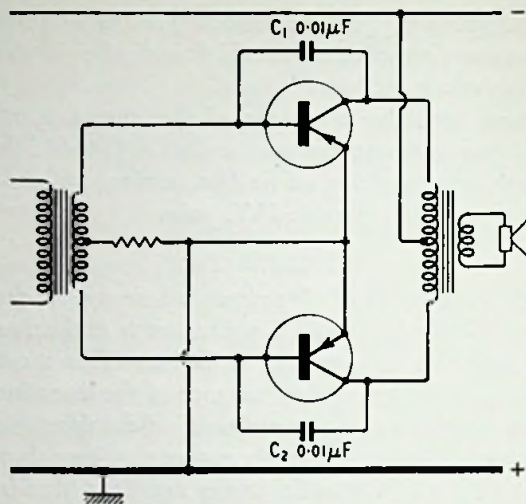
Fig. 6.7—Feedback capacitors are used to improve the stability of the output stage

PUSH-PULL OUTPUT

The arrangement of a push-pull transistor stage (seen in simplified form in Fig. 6.6) resembles that of a valve circuit, but in transistor circuits the two transistors invariably work in class B. The push-pull input transformer supplies phase opposing audio voltages (and currents) to the inputs of a pair of transistors. The input transformer T_1 is a step-down 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 T_2 (when used) is also of the step-down type.

The use of a step-down transformer is quite interesting. In valve circuits, we use only voltage to drive the grids of the valves. In other words, the input of the usual valve circuit is a voltage-operated device (although appreciable currents flow in class B grid circuits). 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 earthed-emitter circuits you will see a capacitor. usually 0.01-μF, connected from the collector to the base of each of the push-pull transistors (Fig. 6.7). These are feedback capacitors which are used to stabilize each of the transistors. The exact amount

of capacitance of the feedback capacitors varies with the circumstances. What is more important is that the two capacitors be as closely matched as possible—that is, the units should be nearly 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 as used in an American receiver is illustrated in Fig. 6.8. It is different in several respects from the general design of British receivers, even though it uses pnp transistors, and at first sight it appears rather confusing because the *negative* end of the battery goes to chassis.

Actually this makes no difference to the operation of the receiver because both ends of the battery are at earth potential, but when we are used to seeing the " bottom " of a circuit go to chassis, that is to say the cathode circuits of valves and the emitter circuits of transistors, it is confusing to see the battery side of the collector circuit (centre-tap of output transformer primary, for instance) go to chassis.

The same thing applies to the 68-kΩ resistor on the base of the driver transistor, which looks as though it goes back to the emitter circuit. Actually it is the upper (negative) limb of a base bias potential divider (like R_2, R_3 in Fig. 3.21) with the 10-kΩ resistor going back to the emitter.
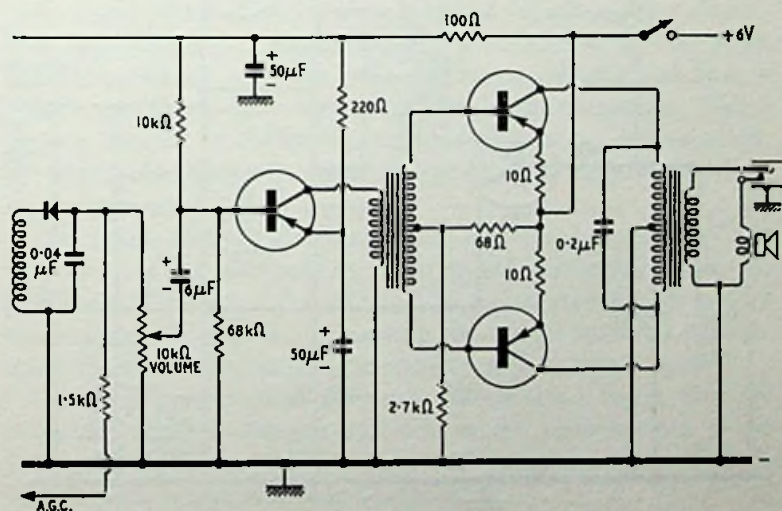
Fig. 6.8—Transistor audio amplifier using push-pull output

A typical British audio and output circuit was seen in Fig. 4.3, where the positive side of the battery goes to chassis. This does not mean that this is a characteristic feature of British receivers, because in some of them the chassis is on the negative side. It is usual in British receivers to employ negative feedback between the output and driver stages, and in Fig. 4.3 this is seen in the connection between R_{23}, R_{16} and the driver transistor (TR4) base.

Another British circuit is shown in Fig. 6.9, where the two class B push-pull output transistors are connected in series with each other. Separate secondary windings are used on the driver transformer, and these go to separate bias points on the potential divider R_1, R_2, R_3, R_4. As each half-cycle of signal is applied, the impedance of TR5 rises and that of TR6 falls, so that practically the whole battery voltage is applied across TR5; on the opposite half-cycle the effect is reversed, and the battery voltage is applied across TR6.

Thus the voltage (or rather potential) at the point where TR5 emitter is joined to TR6 collector see-saws up and down at audio
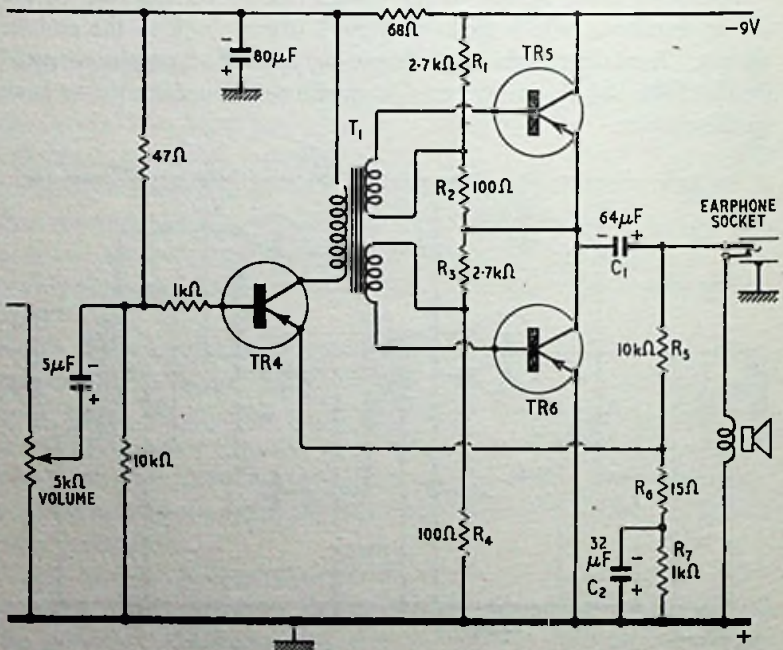
Fig. 6.9—A push-pull output circuit that avoids the need for an output transformer
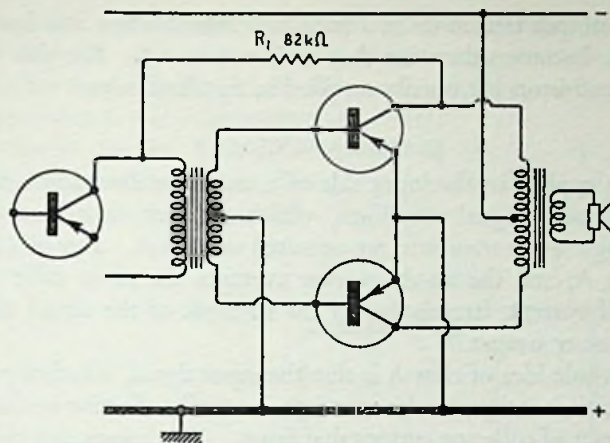
Fig. 6.10—Resistor R_1 in this circuit supplies negative feedback

signal frequency, delivering a large signal to the loudspeaker, to which it is coupled via C_1, whose value is 64 μF. The value of R_1 and R_3 is 2,700 ohms each, and that of R_2 and R_4 is 100 ohms each. Feedback is applied to the driver emitter from the potential divider R_5, R_6 (10,000 ohms and 15 ohms respectively). R_7 is the emitter stabilizing resistance (1,000 ohms) by-passed by 32 μF capacitor C_2.

To avoid the necessity for using matched capacitors for collector-base back-coupling, a single resistor is sometimes used. However, if we were to use only 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. 6.10. In this circuit, the 82,000-ohm feedback resistor R_1 goes back 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. 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, they are connected between collector and base in the same manner as the balanced feedback capacitors. A typical value for balanced feedback resistors is approximately 18,000 ohms.

In British receivers, manufacturers strongly advise the replacement

of both output transistors in a push-pull circuit when one has to be replaced, because otherwise they will not match. For this reason output transistors are usually supplied in matched pairs.

CLASS A AND CLASS B

The bias applied to the input side of a transistor determines its class of operation. Signal amplifiers, whether driver or output stages, involving a single transistor, are operated on class A. Less bias is used for class A, and the anode current averages the same value as the no-signal current, irrespective of the strength of the signal and the audio power output.

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. 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, and it increases in proportion to the strength of the signal, each transistor working on an alternate half-cycle of the signal. The situation in each transistor individually is almost like that of a rectifier. Since half of the signal disappears, we need to have two transistors working in push-pull, each handling half the signal, so that the whole signal appears at the output. Class B is much more efficient in terms of battery current than class A. A properly balanced push-pull audio amplifier also cancels second-harmonic distortion.

ELIMINATING THE TRANSFORMERS

Most transistor receivers that use push-pull in the output stage employ transformers for input and output coupling, although we saw one (in Fig. 6.9) that did not. Because the impedances involved are much smaller than in valve circuits, the number of turns of wire required for the primaries 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 quite small.

However, both input and output transformers can be completely eliminated. The technique is shown in Fig. 6.11. The principle of operation depends on the use of two matched transistors, one npn and

one pnp, and is based upon some information given in one of the earlier chapters. In a pnp transistor, electron current flows from a battery into the collector while in an npn unit it moves in the opposite direction—out of the collector into the battery.

The driver for the push-pull amplifier in Fig. 6.11 is a single transistor stage. The base of the npn transistor and that of the pnp transistor are connected in parallel. C_1 and C_2 are coupling capacitors
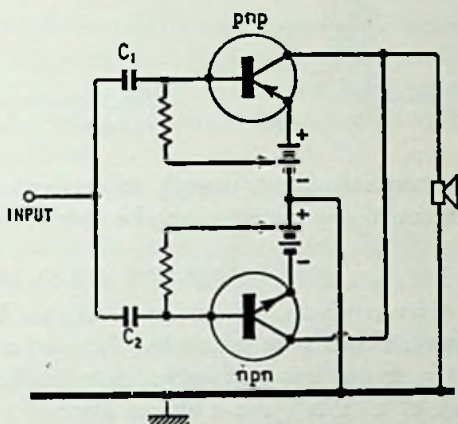
Fig. 6.11—Push-pull circuit does not use input or output transformers

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 suppose that the input signal is positive at this particular moment. Since, as far as the npn unit is concerned, it is now biased in the forward direction, we get a flow of collector current. But the positive input signal applied to the base of the pnp transistor 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 pnp transistor has its base made negative, thus biasing it in the forward direction and permitting collector current to flow. Each transistor handles one half-cycle of the signal.

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 a loudspeaker as the load for the two transistors, but unfortunately the collector is a high-impedance point and most loudspeakers have very low-impedance speech coils.

Special high-impedance speech-coil loudspeakers are manufactured, but there does not seem to be much advantage in it, and there is no reason why a transformer should not be used. A speech coil has to move; a transformer sits still. At the moment the transformer seems to have the upper hand and the circuit is not widely used.
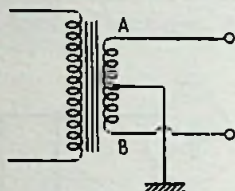
Fig. 6.12—An easy way to get out-of-phase voltages is to use a tapped transformer

It is very interesting, though, to see how the diverse characteristics of npn and pnp transistors can be employed together.

NEAR-EQUIVALENT POWER TRANSISTORS

In valve receivers, the service technician has often found that one valve 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 is inadvisable to intermix power transistors—exact replacements are best. And as we saw earlier, push-pull output transistors should be replaced in pairs.

PHASE INVERSION

A driver transformer, like many parts used in radio sets, does 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 see-saw—when one end is up, the other end is down. In push-pull, as the collector current of one transistor increases, the collector current of the other push-pull transistor decreases. The easiest way to do this is to supply signal voltages that are in opposite phase, and a convenient way to get the out-of-phase signal is to use a centre-tapped transformer. This is shown in Fig. 6.12.

A current flowing through the primary will induce a voltage across the secondary. When point A is positive with respect of the centre 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 cannot depend upon a reversal of a.c. current flow in the primary. The primary current fluctuates, but it moves in only one direction.

The driver transformer now so widely used in push-pull transistor receivers has practically disappeared from high-quality valve receivers. In place of the transformer a valve is used which costs less, is easier to install, and does the job as well as the transformer. Such a valve is sometimes called a " phase splitter ".

A transistor can be used as a phase splitter; the circuit is shown in Fig. 6.13. The arrangement is much the same as in a valve circuit where the load is split between the anode and cathode circuits—that is to say, half the load resistor is in the collector circuit and the other half is in the emitter.

In Fig. 6.13, the collector load and emitter load have identical values. In an earthed-emitter stage, the collector output is 180°
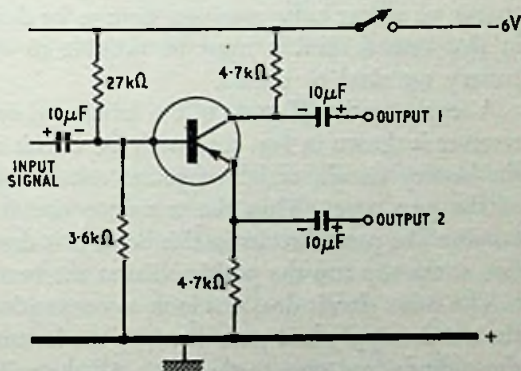
Fig. 6.13—A single transistor can be used to supply two outputs

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 mutually 180° 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.

HYBRID CIRCUITS

Modern car radio receivers usually employ a hybrid mixture of valves and transistors, the valves being used in the r.f., f.c., i.f. and a.f. stages and a transistor (or two transistors in push-pull) in the output stage. Valves are used because greater gain can be obtained from them than from transistors at high frequencies; economy of power is of no importance in a car, the modest demands of a radio receiver being easily met from the car accumulator.

In order to avoid the need for the vibratory converter that has been used in the past to step up the car battery voltage from 12 volts (and in some cases 6 volts) to the 250 volts or 350 volts usually required to run the valves, special types of valves with coated anodes are employed that will operate from a " high tension " supply as low as 12 volts. Such valves are usually tetrodes and triodes, which work quite well in all stages except the output, where a transistor is employed.

It is customary in cars to connect the positive terminal of the battery to the car chassis, so it is desirable to design the car radio with chassis at the positive side of the battery supply circuit, because the one can then safely be bolted to the other. On the other hand, some cars are still made with the negative terminal connected to chassis, so all car radio receivers have to be designed to be reversible in that respect, and it must be possible to connect their negative battery terminal to chassis.

A representative diagram of the driver and output stage of a hybrid receiver is shown in Fig. 6.14 with the chassis on the positive side of the battery circuit, which of course suits the transistor because it is of the pnp type. Thus the transistor circuit looks fairly normal, because like most circuits in this book it is drawn with the negative line at the top and the positive line at the bottom.

The valve circuit does not look so conventional, however, because the anode supply lead goes down to the bottom of the diagram and the cathode lead goes to the top. All the valves in the receiver are connected up like V5, and except that we are looking at them " upside down " so to speak, the circuits in which they are connected appear quite conventional, just like a mains-driven circuit, only fewer decoupling components are employed.

It can be seen from Fig. 6.14 that the transistor circuit conforms with all that has been said already about transistor circuits. The

principal differences from its predecessors are that it is a " power " transistor (which is not apparent in the diagram), that it operates from a higher battery voltage (12 volts) and that its base bias potential divider R_1, R_2 has an adjustable element.

A power transistor of this type can supply an output power of up to 2 W, driven from the valve-operated driver stage shown in Fig. 6.14. The valve V_5 receives its input signal from an audio-frequency amplifying stage that might employ a triode valve. Collector current, which is usually only a matter of a few milliamperes in transistor
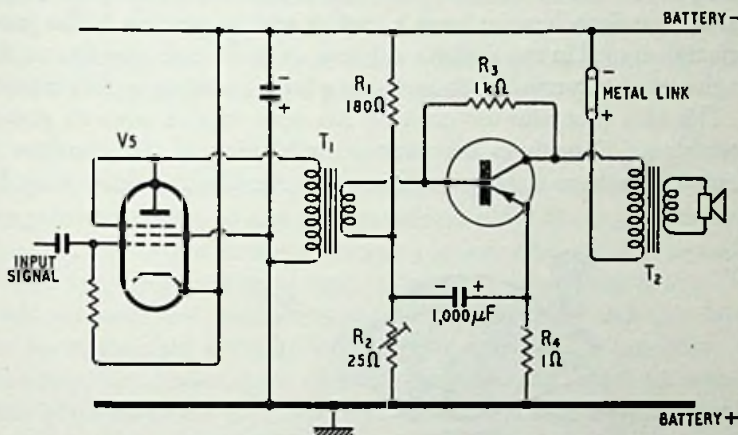
Fig. 6.14—A valve-operated driver stage

circuits, might be as high as half an ampere (500 mA) in a power output transistor, even when " quiescent " (not being driven with a signal).

The purpose of making the resistor R_2 adjustable is to ensure that the collector current is correct, and R_2 must be adjusted when a new transistor is fitted. If the correct quiescent collector current is, say, 400 mA, an ammeter (full-scale reading 1 ampere) is inserted in place of the metal link in Fig. 6.14, the correct polarity being observed. R_2 is then adjusted until the meter reads 0·4 A (400 mA). The meter is removed, and the link replaced.

This link permits the condition of the transistor to be checked. If the slider on R_2 is set to one end of its travel so that the resistor is short-circuited, thus removing the forward bias, current measured on the meter would be leakage current, and this should not exceed 1 mA.

POWER TRANSISTORS

Special power transistors have been developed to handle large amounts of audio power. One of these is shown in Fig. 6.15. Because such transistors have been designed to work with power measured in watts, they generate a considerable amount of heat. There is the same problem with a power transistor as there is with the engine of a car. Something must be done to get rid of the heat.

In a car a water-filled radiator and a fan are used. Some transmitting valves also use fans or a water coolant. For a transistor, where small size is so important, the usual method adopted to get rid of heat is to have as large a surface area as possible. The same principle is used in any radiator at home, or in 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 a large surface area. Or the transistor may be
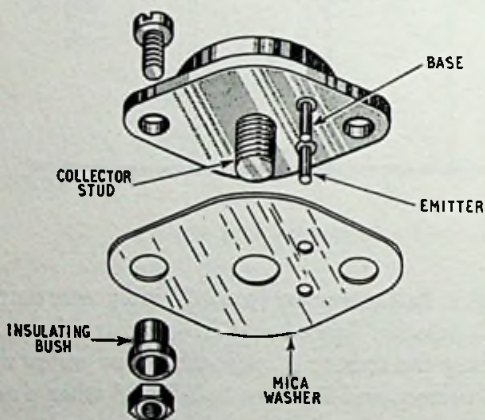
Fig. 6.15—A transistor suitable for handling large amounts of audio power. The collector stud and the separate fixing screws both provide a method of bolting down the unit, but they are not usually both present as shown here

mounted on the chassis to give more area. Sometimes, as in the case of power transistors used in car receivers, the transistor is mounted on a little radiator or wavy fin arrangement. All these devices are known as heat sinks, the idea being to run heat away in the same way as water goes down a drain.

It can be seen from Fig. 6.15 that power transistors are of special construction, and usually the collector is connected internally to the

large case, which can be bolted firmly to the metal case of the car receiver, which itself then acts as a heat sink by conducting away the heat dissipated in the transistor.

For this reason, some circuits are designed with the collector connected to chassis, but that is very uncommon. It is not done in Fig. 6.14, and the transistor there cannot therefore be bolted directly on to the metal case of the set. Instead, a thin sheet of mica is inserted between the transistor and the case, and the fixing nuts are also insulated, isolating the case of the transistor from the metal case of the set. In order to ensure efficient conduction of heat between the two, which is essential, the mica is first coated with silicone grease. It is most important that both mica washer and silicone grease are carefully used when fitting a power transistor.

THE LOUDSPEAKER

Loudspeakers in portable transistor sets are usually small permanent magnet units (Plate 9) and seldom present problems but, when they do, they can be just as time-consuming as any other receiver trouble. If you keep loudspeakers in stock, store them away from heat. The little magnets used in modern ones are fairly sturdy and they have to be mishandled severely for them to lose their magnetism. If you have any doubts about a loudspeaker, however, check the attraction of the magnet with a small screwdriver, inserting a piece of cardboard between the two to prevent them from actually touching. If they actually touch, the magnet field distribution will be distorted. The pull should be strong and positive.

A rattling sound can be caused by a tear in the speaker cone, a gritty sound or severe distortion can be caused by dirt (usually metallic particles) between the speech coil and the surrounding magnet, and a rasping sound can result from a warped or off-centre speech coil.

A loudspeaker can be checked with an ohm-meter. Set the instrument on the low-ohms scale and briefly touch the leads to the speech coil terminals. There should be an audible click.

Loudspeaker replacement is not difficult if an exact replacement is available. If not, there may be a physical difficulty in mounting the unit. 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 speech coil is earthed to the chassis. If such is the case, the speech coil may be part of a feedback network.

9

If, when making a replacement, you get an oscillating sound out of the loudspeaker, try transposing the leads to the speech coil. If they are accidentally reversed, negative feedback becomes positive feedback.

If, when removing a loudspeaker from its cabinet, there is a screwdriver floating around on the bench, you can be certain that it will find its way right through the cone of the speaker, so the best thing is to prevent the accident. Cut a piece of carboard to the outside diameter of the cone and fasten it to the metal surround of the loudspeaker with pieces of self-adhesive 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 loudspeaker magnets are much stronger than most people realize, so make sure that the bench is clean. It's practically impossible to get metal filings out from inside a speaker.

It is always helpful to have at least one test loudspeaker (with an 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 hearing aid type of earphone or earpiece 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 that its plastics earplug fits right into the ear opening (Plate 9). 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 can be obtained: that is, hooked over the ear in a manner similar to spectacles, and the sound-producing unit resting gently against the ear opening. A better idea then is the old headband.

Since these earphones plug into the set, check a faulty one by 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 loudspeaker.

Trouble could occur in any of the components from the shorting type earphone jack to the loudspeaker. 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 best be cleaned 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, use only the extra fine types of abrasive paper 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 loudspeaker operation, with the sound from the earphone either intermittent or non-existent. This is one reason why it is better to substitute a suspected earphone assembly than try to test it.

Any one of three impedances may be used in the types of earphones likely to be encountered. Those earphones intended to replace the loudspeaker 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-impedance ", is made of the same material as the crystal cartridges used in popular record players.

In the record player, the movement of the stylus 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 gramophone records. Of course, there it is necessary to use considerable power to move the stylus when cutting the acetate layer on the recording disc.

When the earphone is connected to the loudspeaker 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 loudspeaker impedance. Prolonged testing of a receiver can be done silently this way. An

oscilloscope or voltmeter of the audio or a.c. variety can be used as an indicator. It is inadvisable to run a receiver without its speaker working unless a resistor is connected in its place to provide a load.

COLOUR 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 loudspeaker.

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 or six leads. The extra leads in these cases are for the centre-tap connections of the transformer.

In American receivers these leads are colour-coded. The primary of the driver transformer may be colour-coded blue and red. The blue lead goes to the collector and the red lead to the collector supply. In this case the secondary will be colour-coded green and black, with the black lead earthed directly or through a resistor. The green lead (or signal-carrying lead) is then connected to the base input of the following stage. In some receivers, white is used instead of green, and in still another set, the signal lead is an uninsulated wire while the " earth " lead is yellow.

The output transformer may have the same colour coding as the driver transformer. If a receiver has only one transformer, it will be necessary to decide whether it is an output transformer, with resistance-capacitance coupling used between voltage and power amplifier stages, or whether it is a driver transformer used with an output stage like that in Fig. 6.9. 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 colour coding, or if the colour coding is quite different from that described here, it still is not a serious problem. First, before installing 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 collector supply lead. Work the same way with the secondary. Do not worry as to which secondary lead is the " signal lead ". If, after making these connections, you get a howl out of the receiver, simply transpose either the primary connections or the secondary connections, but not both. This condition of howling is particularly likely to occur in cases where the output transformer is replaced and one lead of the secondary (speech-coil lead) is earthed.

Transformers used in push-pull stages are often coded as follows: *Driver transformer*—Primary, red and blue; secondary, green and yellow; centre tap, black.

Output transformer—Primary, blue and brown; secondary, green and black; centre tap, red.

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 (or four) leads. If the transformer is an output type, the primary has three leads.

REPLACING TRANSFORMERS

When replacing transformers, try to get exact replacements, but if for any reason these are not obtainable, try to use shielded types. It is always a good idea to mount transformers at right-angles to each other, and if the transformer is an uncased type, shield it with soft magnetic foil. This material can be cut with scissors and wrapped around the transformer and kept in place with a small piece of tape. In all instances make sure that the shield is connected to the earth or common lead of the receiver. The purpose of these is to avoid magnetic coupling between different parts of the circuit, which if it occurred might lead to instability.

MAINTENANCE

We have now covered the complete transistor receiver from stem to stern, from input to output. All of the material we have studied so far is extremely useful, but there is not much use in fashioning a tool and then not using it. And so, in the next chapters we will learn servicing procedures and more about the various ailments that afflict the transistor receiver, 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 so far at least they are not found in domestic radio receivers. 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.

Servicing Methods—Part I

TRANSISTOR radio receivers can be serviced using the same test equipment as you already 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 there should at least be a r.f. signal generator capable of covering the complete broadcast bands and a sufficiently wide range of intermediate frequencies.

You should also have an audio signal generator so that you can trace through stages, starting with the detector diode load and proceeding to the loudspeaker. As an alternative, you can use the audio output terminal of your r.f. signal generator, but unfortunately, many of the less expensive signal generators have no means of controlling the strength of the audio signal. If such is the case, you can attenuate the audio by feeding it into a potentiometer, and then taking the audio output from the potentiometer itself, as shown in Fig. 7.1.

You should have a multi-range meter, preferably a valve voltmeter. Since transistor receivers are characterized by very low voltages, a low-voltage scale on the valve voltmeter is extremely important. Of course, the valve voltmeter can also be used for measurement of resistance.

In the next few paragraphs are described special tools for use in servicing the miniaturized components so widely used in transistor receivers. Equally important is a bench lamp which can be moved into any desired position so that a strong light can be focused 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 invaluable in the workshop and is ideal for examining tiny connections in a confined space.

Because receivers (including the superheterodyne) can be small, many service technicians handle them very gingerly, treating them with a caution they do not deserve—or need.   Care is needed to avoid damaging the small and delicate components, but the transistor itself is physically stronger than a valve, and the overall structure is sturdy.   The transistor has only three enemies—wrong or excessive
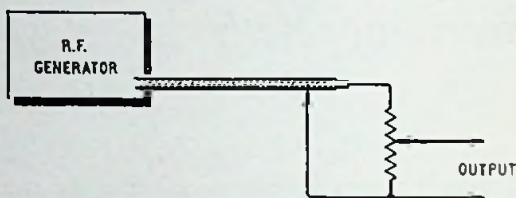
Fig. 7.1—Some signal generators have an audio output connection but no provision is made for controlling the audio level.   You can make a simple control unit with a 500,000-ohm potentiometer as shown

bias voltages, excessive current and high temperatures.   A little care and common sense can prevent this 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 normal tools are too big for the job.   Additional tools will also be required which you probably would not otherwise have in the workshop. Some of these are shown in Plate 8, and they have the following features.

Screwdrivers—The very small screwdriver used for valve receivers is still useful.   In addition, obtain a set of jeweller's screwdrivers, which are so designed that you cannot apply excessive rotating force. Stripping the threads of tiny screws is a nuisance, especially if a replacement screw is not available.

Tweezers—At least two types of tweezers are necessary—a pair that comes to a sharp point and a pair of duck bills, with large flat surfaces near the ends.   When buying tweezers, do not get the short types but get the long ones that will enable you to reach into remote parts and still give ample grip.

Watchmaker's Eyeglass—You have probably seen the way in which your local jeweller examines the interior of a watch assembly.   He
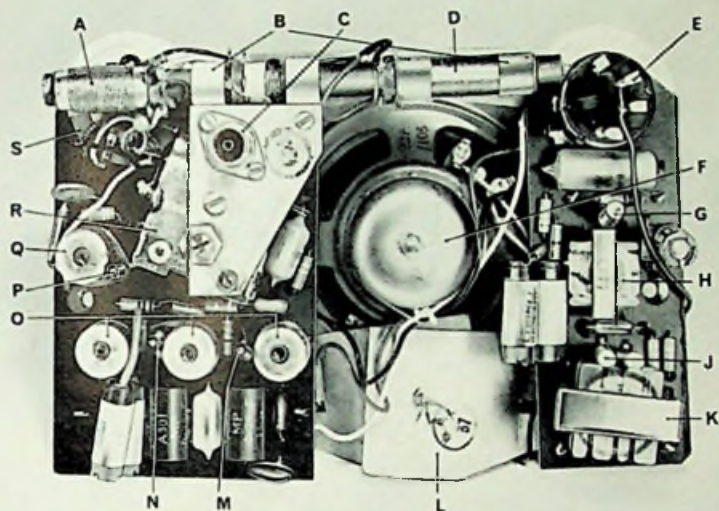
Plate 6. Chassis layout of a six transistor receiver

A   Aerial L.W. winding
B   Ferrite rod aerial
C   Car aerial socket
D   Aerial M.W. winding
E   Volume control with battery switch
F   Loudspeaker
G   Transistor TR4
H   Intervalve or driver transformer
J   TR5 and 6

K   Output transformer
L   Battery compartment
M   TR3
N   TR2
O   I.F. transformers
P   TR1
Q   Oscillator coil unit
R   Tuning gang
S   Waveband switch unit
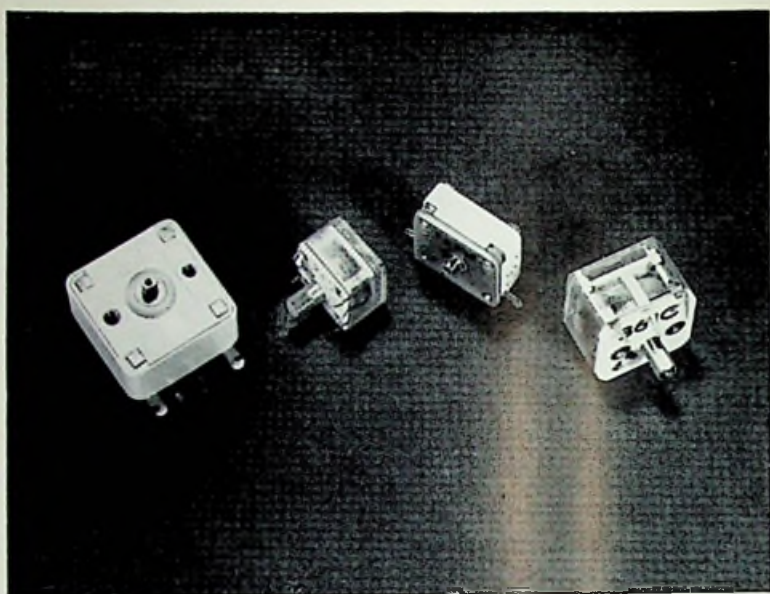
Plate 7. A group of 2-gang tuning capacitors. That on the left (Plessey) also performs waveband switching. Others are by G.E.C. and Perdio

Plate 8. Typical small tools used in servicing transistor radios
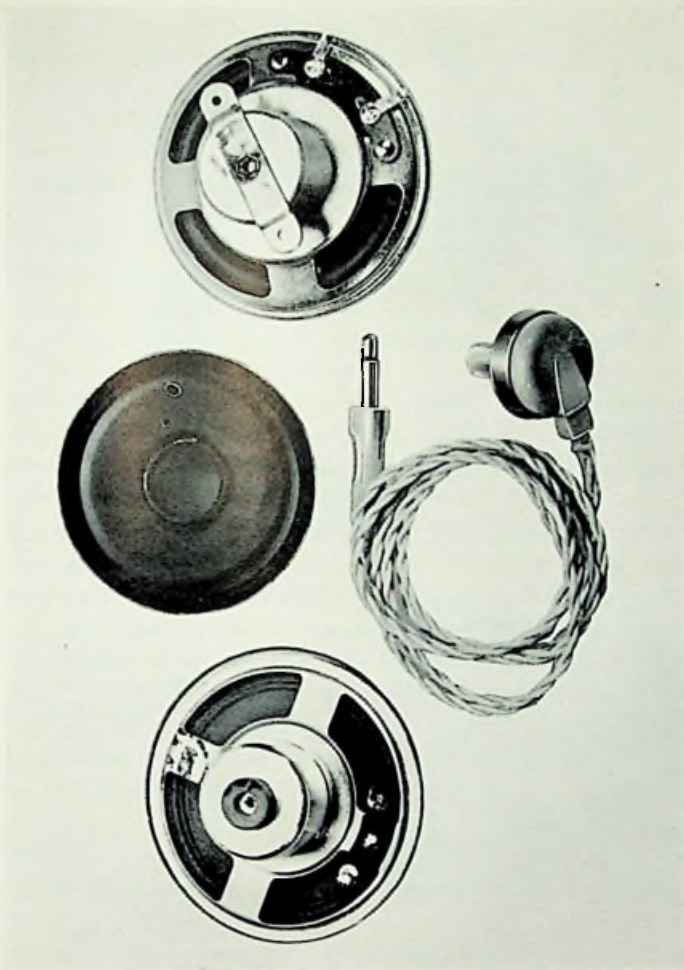
Plate 9. Permanent magnet speakers compared with an earphone which plugs into the ear cavity, excluding almost all outside noise
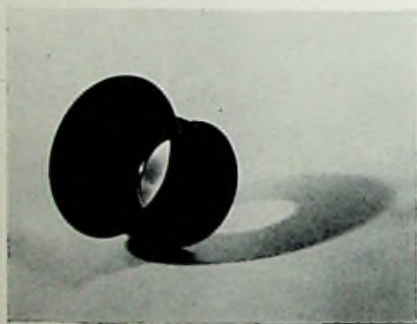
Plate 10. *Various types of magnifying lenses which are useful when working with transistors. The top one houses a fluorescent lamp to illuminate the work (Severn Lighting Ltd.)*

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 both hands are left free to work.   If you prefer, you can obtain a lens mounted on a stand, some of which 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 inconvenient.   Various types are shown in Plate 10.   You could use one that is held in position by an elastic band round the head.

Soldering Irons—The most useful tool will probably be an iron rated somewhere between 15 and 32 watts.   An iron having interchangeable tips is best.   It all depends on your own skill.   But always bear in mind that a 25-watt iron held on transistor leads for 10 seconds can do more damage than 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 25-watt iron is no guarantee that the transistor will not be damaged.   What is required is " quick " heat.   Do not use a soldering gun, because its heat is extremely high. Further, the intense magnetic field surrounding it 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.   This should be avoided if at all possible.

There are a number of techniques to protect the transistor from the heat of a soldering iron.   The easiest method is to use a heat sink, which could consist 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 the transistor, is shunted away by the large amount of metal of the pliers.   Put a rubber band around one end of the pliers to hold them in place and be sure to keep them attached for at least several seconds after the iron has been removed.

Alternatively, 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 a crocodile clip as shown in Plate 11.   Clips

called thermal shunts are made specially for this purpose, and one of them is shown in Plate 11.

Specially shaped soldering iron bits, or heads, are manufactured to make unsoldering the components of printed-circuit boards considerably easier. An American set is shown in Plate 13. Shaped to make contact with valve socket terminals etc., the specially formed bits enable the iron to heat the several tags or a multi-tag component simultaneously and to straighten tags on sockets, controls and transformers while keeping the solder in a liquid state.

Not all solder has the same melting point. Using a high-melting-point solder will probably damage the transistor long before the solder
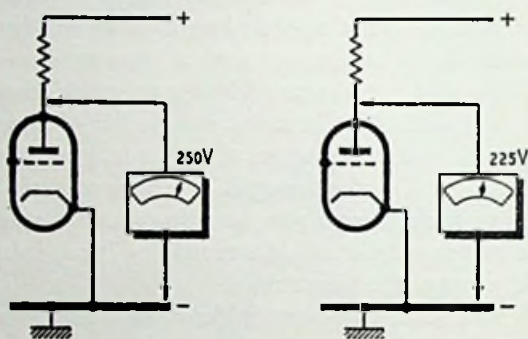
Fig. 7.2—If the voltage at the anode of a valve should be 250, but your meter measures 225 volts, you have a 10 per cent. difference between the actual voltage and the one specified. For most valve circuits this small difference is of no importance

has melted. As a precaution, use 60/40 resin-core solder. The same arguments that are used against acid-core solder in valve receivers apply here.

It is inadvisable to replace a transistor unless you are certain that it is the transistor that needs to be replaced. Most service technicians are conditioned to the fact that troubles in radio and TV sets are mostly valve 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.

Some manufacturers claim that their transistor radios are built like a fine watch—and if size is the determining factor, they are certainly right. Do not use man-sized tools for these midgets.

D.C. VOLTAGE MEASUREMENTS

When making voltage measurements in a transistor receiver, remember that working with low voltages may require a different approach. As an example, consider a valve receiver in which the anode voltage is supposed to be 250. If for any reason, there is a 10 per cent. decrease in anode voltage, you will measure 225 volts. Ten per cent. of 250 is 25, and subtracting this from 250, gives 225 (Fig. 7.2).

Now assume you are supposed to measure a potential of 6 volts in a transistor receiver, and let us further assume that there has been a 10 per cent. decrease. But 10 per cent. 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 valve receiver it would be very easy to recognize a 25-volt difference. A difference of 0·6 volt on a valve voltmeter scale might not be so easy to detect (Fig. 7.3).

When working with low voltages, it is always preferable to adjust the range switch on the valve voltmeter so that the meter needle will have to swing full-scale or almost full-scale. This will make any
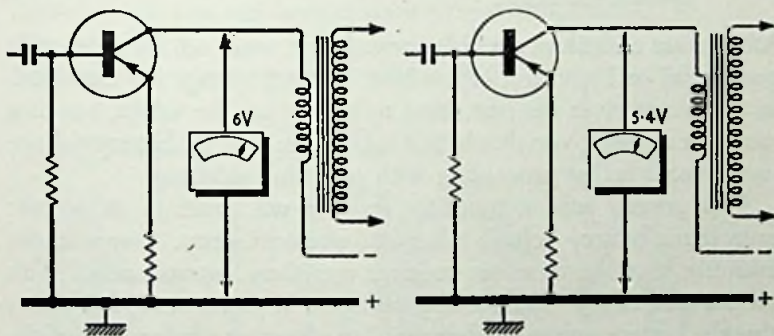
Fig. 7.3—A 0·6-volt difference in collector voltage is difficult to observe but in a transistor circuit it may be important

slight deviation much more recognizable. If you have any doubt about the accuracy of the valve voltmeter on the low-voltage scale, it can easily be checked by using one or more fresh penlight (or fountain pen) batteries as a calibrating voltage, as shown in Fig. 7.4. Four such cells, when fresh, should give 6 volts. With mercury type cells, four of these in series will give a total voltage of 5.36.
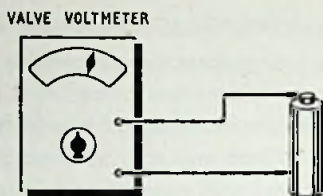
VALVE VOLTMETER

Fig. 7.4—Low-voltage measurements in transistor receivers are very important. To check the low-voltage scales of a valve voltmeter switch to a low range and then use a fresh penlight cell (or other type of dry cell) as a calibrating voltage

Before going into a detailed analysis of transistor receiver faults, consider the symptoms apparent in the majority of cases. The complaints, all caused by common faults, 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 cell (in series with good cells) or by several cells whose terminal voltage has decreased. In a valve receiver the first thing to suspect are the valves, but 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 per cent. drop. Suppose, for example, that the transistor receiver uses three 1·5-volt cells. This gives a total of 4·5 volts. Using the figure of 30 per cent., this means that the battery voltage had dropped to about 3·15 before any of the symptoms mentioned became noticeable or annoying. Similarly if the transistor receiver uses a 9-volt supply, as a general rule the voltage can drop to about 6 volts before one or more of the symptoms mentioned begins to appear. However, if the symptoms show themselves and the battery voltage has dropped, say, only 5 per cent. to 10 per cent. of fresh battery voltage, then the fault is not in the battery supply but elsewhere in the receiver.

In making a battery voltage check in the receiver, remember to turn the receiver on with a station tuned in and the volume control

adjusted to give a large output. This is a condition of heaviest load for the batteries and, if the batteries are weak or defective, the voltage will drop. If the internal resistance of the battery is high the reading will change when you detune the receiver. If you do not wish to make a voltage check, you can always test instead by substituting batteries. The voltage check is faster, however, and does not require you to have replacement batteries on hand (Fig. 7.5).

In practically all valve receivers, the chassis is common with earth and H.T. negative. Because of this many service technicians have got into the habit of considering the chassis as the negative battery reference point. In a transistor receiver, however, the chassis can be positive or negative (Fig. 7.6). Offhand, you might think that you should be able to determine the polarity by considering whether a receiver uses pnp or npn transistors, but this is no help. You can determine the polarity by (1) 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 backwards, transpose the connections. Some instruments have a minus/plus switch so all you will have to do is to turn this control.
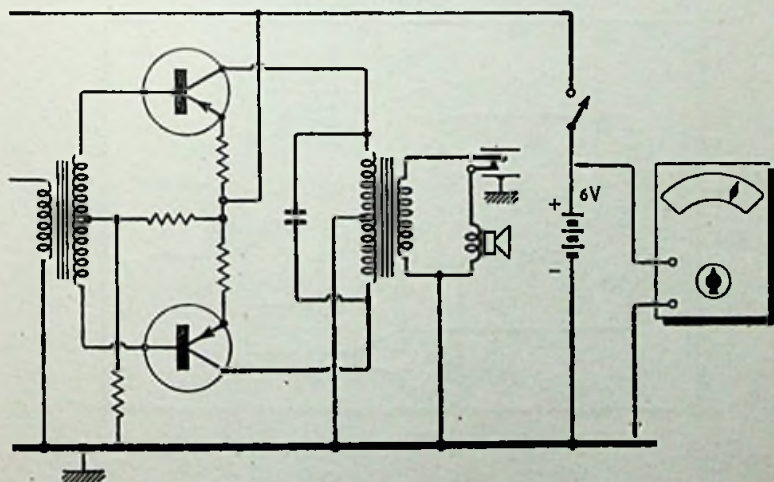
Fig. 7.5—To check the condition of the battery, connect the meter as shown. The set must be turned on since the battery must be tested under actual load conditions. Tune in a station and then detune, noting if this has any effect on the meter reading

The two circuits shown in Fig. 7.6 are almost identical, yet the battery connections are different for each. In both cases the emitter is made positive with respect to the base. In the circuit Fig. 7.6(a) the collector is marked zero volts, but observe that the collector is earthed through the primary of the output transformer. The col-

(a)

(b)
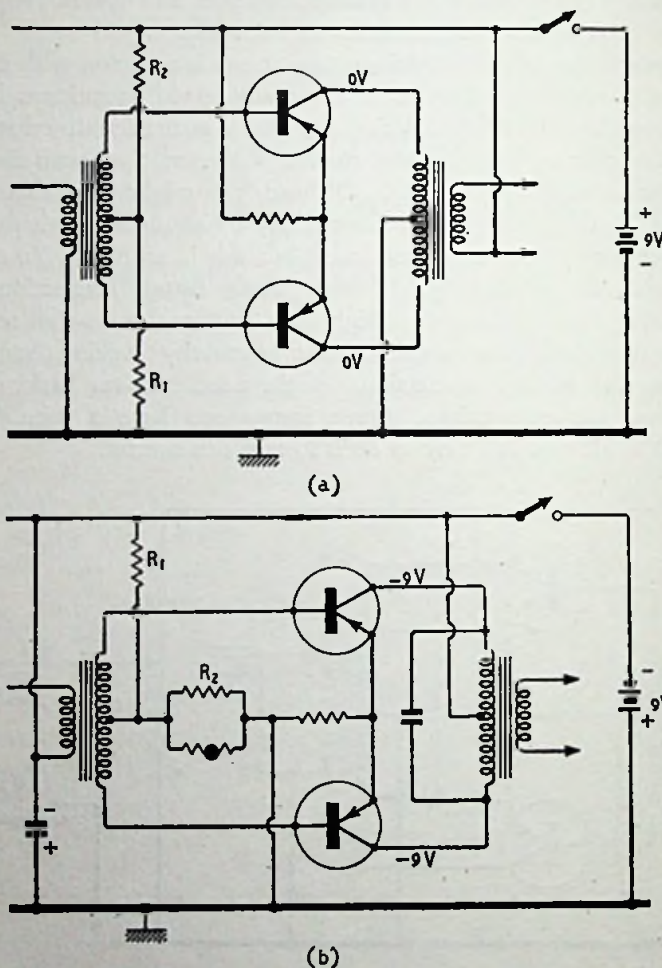
Fig. 7.6—Showing that chassis can be at the negative side, as at (a), or the positive side, as at (b), of the battery. Other small differences, such as the thermistor in (b) are shown, but in both diagrams R_1, R_2 form the base-bias potential divider, with R_2 at the positive end

lector is negative with respect to the base and the emitter. In Fig. 7.6(b) the collector also has its return through the centre 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 earthed and in the other the plus terminal, in each circuit the collector is connected to the negative end of the battery supply. Note that pnp transistors are used in both circuits.

Batteries tend to deteriorate whether they are used or not, and the batteries in transistor receivers are no exception. Customers who
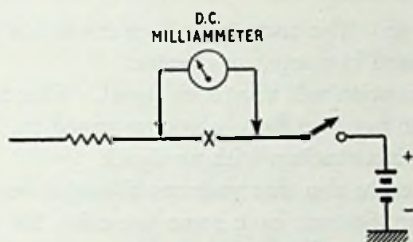
Fig. 7.7—To check receiver current drain, unsolder the wire connected to the switch on the volume control and insert a d.c. milliammeter as shown. The point of insertion is shown by the letter X in the diagram. After the meter is connected, close the switch. Sometimes you can avoid unsoldering leads by lifting the battery connector and inserting the meter between the battery connector and the battery

operate their transistor receivers sparingly, with the idea of battery economy in mind, might easily overdo it. You 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 quite possible for short battery life to be a legitimate complaint. If battery life is much less than would be reasonably expected, make 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. 7.7. 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.

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
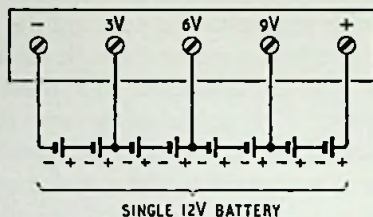
*Fig. 7.8—A set of 3-volt dry batteries or a tapped 12-volt battery will
supply all the voltage and current needed for testing transistor receivers*

be 15 mA or more. The current drain of car 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 multi-range meter will come in
handy. Most multi-testers have some provision for measuring cur-
rent, and if you have such an instrument you can put it to good use.
Valve voltmeters are not designed for measuring current. If you do
not possess a multi-range meter a 0·1-mA d.c. milliammeter provided
with suitable shunts will do the job.

SHORT BATTERY LIFE

Where the customer's complaint is short battery life, open the lead
to the switch on the volume control, insert a milliammeter and take
three current readings. The first of these is with the set turned off,
then one with the volume control turned on (but at its minimum
setting) and finally one 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 a current reading in this position, check the switch or
look for some short-circuit condition. If there is an unusually high
current reading with the volume control turned down, look 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,
it should be observed that the low-voltage supply of a transistor

receiver has its advantages, but also its disadvantages. In servicing a valve receiver, a defect can sometimes be spotted very readily because the component will show burn marks or will be hot to the touch. This rarely happens in transistor receivers, since the voltages and currents involved are so small. At the same time, you can work with the voltages in a transistor receiver with 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 car radios), you will have to exercise 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.

BATTERY LIFE

It is very difficult to give accurate estimates of 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 life in excess of 400 hours, but remember, when cells are 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 cells 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 non-reversible connectors, but not all are so equipped.

WORKSHOP POWER SUPPLY

It is possible in servicing a transistor receiver that you may find the cause to be defective batteries and it is also possible that you may not have a suitable replacement on hand. Even in bench work it is inadvisable to use a valve-operated power pack or a selenium-rectifier type supply. An excellent power source would be $1\frac{1}{2}$-volt cells of the type commonly associated with door bells.

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These cells are rather large, but they have a long useful life. Another substitute supply that you could use would be a storage battery (accumulator). 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 it might still be useful for servicing work, provided of course that the battery is not too far gone. If a 12-volt battery is used, as in Fig. 7.8, you can tap off at suitable voltages as 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. They can be kept charged by a small disc rectifier charger as shown in
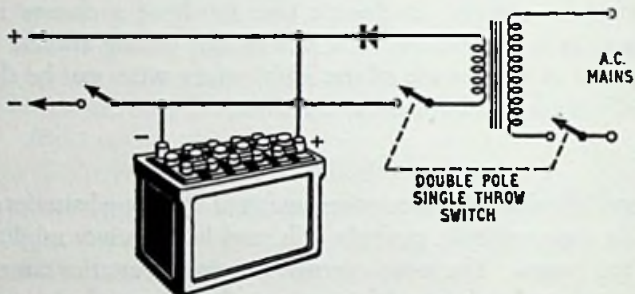
Fig. 7.9—A dry rectifier type charger can be used to keep the test storage batteries ready in operating condition. The double-pole single-throw (d.p.s.t.) switch should be in the open position when the third switch is closed

Fig. 7.9. These are readily available and inexpensive, but the charger must not remain connected when the storage battery is being used. As a precaution it would be desirable to arrange that the charger switches are opened automatically when the battery switch is closed. If a good quality transformer is used, the primary switch can be omitted with very little power loss, and the remaining two switches can take the form of a single-pole double-throw switch.

SPARKING TEST

A fairly common servicing procedure is to " spark " either the grid or anode leads of a valve in an effort to locate a defective stage. This is a risky form of quick testing, and it must not be done in transistor receivers. If, for example, you accidentally short the base lead to

chassis, 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. 7.10. The voltage between the emitter and the base is very small—actually in this case, only 0·1 volt. A "disturbance" test in a circuit like this would put the base at chassis potential and will put R_1 and R_2 across the battery.

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 indicated in the manufacturer's service notes or you
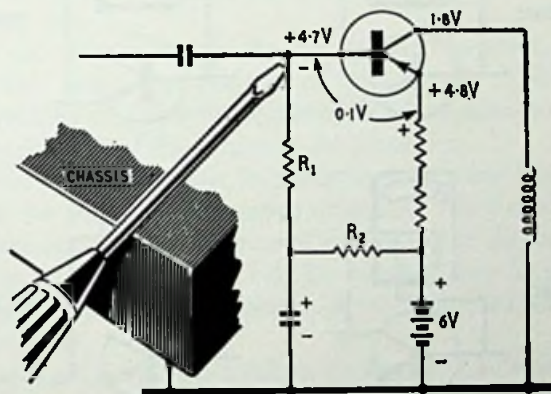
Fig. 7.10—" Sparking" the base to the chassis removes the bias between emitter and base and can ruin the transistor

can get this information from your supplier or from radio parts catalogues. The fact that one battery pack has the same voltage as another does not always mean that it can be used since 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 valve voltmeter. If the transistors are in plug-in sockets, which is unusual, they can then be removed for checking. If, however, the transistors are soldered into place, it is better to check them in position. Make sure the receiver is turned off and the battery disconnected.

In an earlier chapter, you will recall, it was mentioned that a transis-

(a) HIGH RESISTANCE

(b) HIGH RESISTANCE

(c) LOW RESISTANCE

(d) LOW RESISTANCE

(e) HIGH RESISTANCE

(f) HIGH RESISTANCE
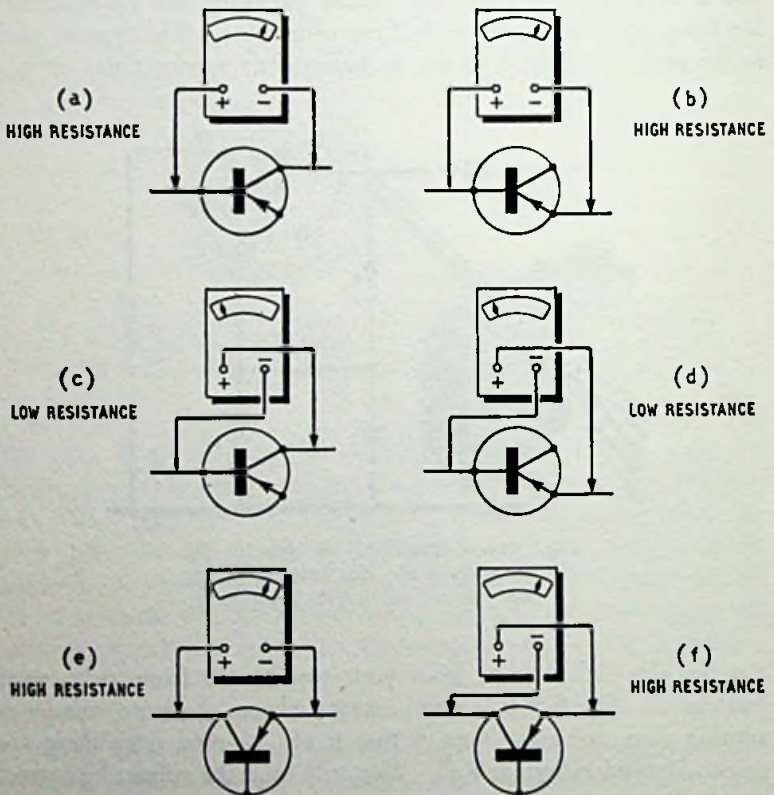
Fig. 7.11—Techniques for measuring the reverse and forward resistances of a pnp transistor

tor resembles a pair of crystal diodes placed back to back. We can take advantage of this when checking a transistor. The test consists simply of measuring the forward and reverse resistances of the transistor. Fig. 7.11 shows how to do this.

Set the range selector of your valve voltmeter on the R × 10 scale. This scale is to be used for making all forward resistance measurements. In the R × 10 position, the range selector on the valve voltmeter automatically inserts a resistor between the transistor and the test instrument.

First, consider measurements of pnp types. Connect the positive terminal of the valve voltmeter to the base lead, and the negative lead to the collector lead (Fig. 7.11(a)). High reverse-resistance should be measured, giving a value of 50,000 ohms or more. With the positive lead of the valve voltmeter 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. 7.11(b)).

Before checking transistors in this manner however, acquaint yourself with the circuit diagram of your meter. You will not obtain correct results unless the negative lead of the 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 but in other cases the polarity of the internal voltage might be opposite. It can be checked with another meter, of course.

With your valve voltmeter still set on the R × 10 scale, connect the negative lead of the instrument to the base terminal of the pnp transistor. Touch the positive lead of the instrument to the collector lead as shown in Fig. 7.11(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. 7.11(d). Once again you should measure a low resistance, 500 ohms, or less.

Finally, check between emitter and collector, as in Figs. 7.11(e) and (f). For these two measurements the resistance should be high with the meter leads either way round.

Npn transistors can be measured in the manner just described except that the test leads must be transposed.

PRECAUTIONS IN USING OHM-METERS

The use of a valve voltmeter has been stressed because it is becoming quite common among service technicians. However, an ohm-meter can be used just as well. Normally, with an ohm-meter or a valve
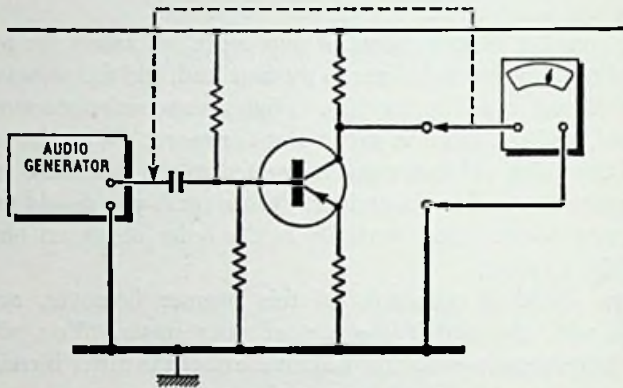
Fig. 7.12—Checking the gain of a suspected transistor stage. The valve voltmeter is alternately connected across the input and output of the audio amplifier circuit

voltmeter there is a red and a black lead. The black lead is known as the common, earth or negative lead, and the red is called the plus or positive lead.

However, 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, but is simply the way in which the instrument is constructed.

A similar situation exists in a car with the plus terminal of the battery connected to chassis, and not the negative one, as you might expect. If you have any doubts as to the polarity of the test leads, all you have to do is to connect a voltmeter across the ohm-meter test leads, and see which way it reads. Set the range selector on the highest range, and reduce or rotate the range switch until a reading is indicated. If the meter needle moves backwards, transpose the test

leads. You must, of course, use a voltmeter that is marked with its polarity. A voltmeter having a full-scale range of 5 to 10 volts is suitable.

Another method that can be used to check a transistor is to measure the resistance in both directions between all three pairs of wires as before and note the ratio of the two readings in each case. You do not need to know the polarity, but you look for a high ratio between base and collector and between base and emitter, of the order of several hundred to one. Between collector and emitter the readings should both be very high, but the ratio between them should consequently be low.

Otherwise it is important to know the polarity of the test leads of the ohm-meter or valve voltmeter for checking transistors, but it should be remembered that other components such as electrolytic capacitors are also polarized. Electrolytics are used in transistor receivers both as coupling capacitors and as emitter by-pass 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 npn or pnp transistors depends entirely on the manufacturer. You will sometimes find both types used in the same set, which means one must be careful when making the forward- and back-resistance checks first described. Remember that pnp transistors operate with the emitter positive with respect to the base (the first letter of the abbreviation pnp represents positive). In the case of npn transistors, the emitter is negative with respect to the base. The voltage difference between base and emitter and the transistor type are usually specified in the service manual for the receiver.

FURTHER CHECKS ON TRANSISTORS

The general tendency in modern transistor manufacture is to solder the transistor in place, which is sensible since a transistor is such a durable device and its operating voltages are very low. The method for testing audio transistors dynamically is that shown in Fig. 7.12.

Connect an audio signal generator to the coupling capacitor leading to the input side of the transistor. Connect a valve voltmeter across the output load of the transistor. In checking an audio stage, for example, one could use the 400-c/s audio output of an r.f. generator

METER OR OSCILLOSCOPE
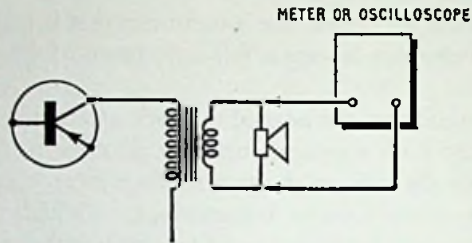
Fig. 7.13—When signal tracing through a receiver, connect an oscilloscope or a meter across the speech coil as a signal indicator.   The speaker can be used instead but it is not as sensitive an indicator as a test instrument

or an audio generator itself.   Since an a.c. signal is being fed in and not rectified at all, the output will be that same a.c. signal, amplified, and of course it must be measured with a valve voltmeter set to read a.c. volts.   To determine the gain of the stage, connect the valve voltmeter across the signal generator (or input to the transistor) and then switch the high-potential test lead to the output side of the transistor.

Since the input will be a fraction of a volt, and the output 1 volt
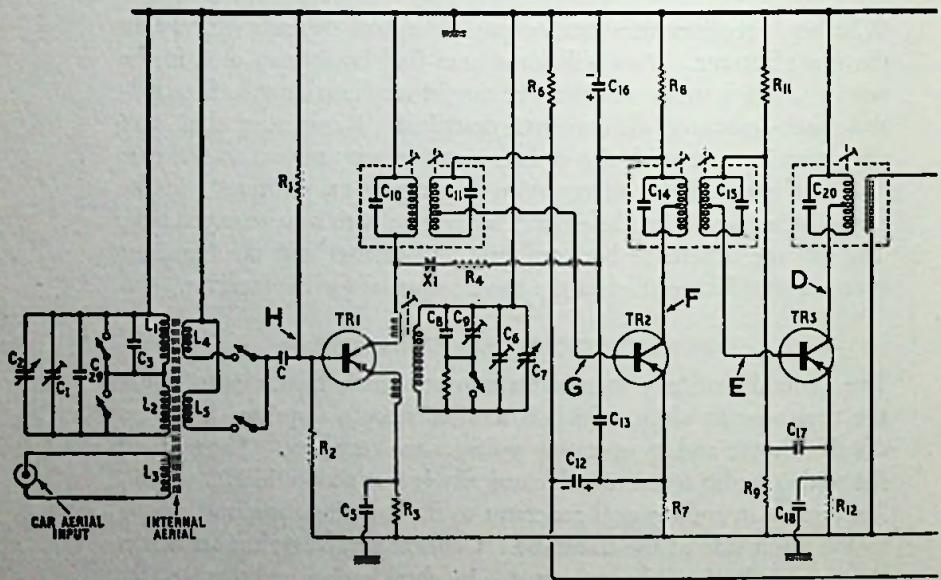
Fig. 7.14—Voltages are measured from the points indicated to chassis with a valve volt-

or less, the range selector on the valve voltmeter will have to be set for full-scale deflection on the lowest voltage range. The gain of the stage should be approximately equal to the β of the transistor. Thus, if the β 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 the transistors in the receiver, continue with the valve voltmeter or the cathode ray oscilloscope (often abbreviated to C.R.O.) connected as shown in Fig. 7.13 while working back towards the front end of the set, using the signal generator. Once the r.f. or i.f. side of the crystal detector is reached, however, the frequency of the signal generator must of course be changed. Obviously, when signal tracing through the i.f. stages, a modulated i.f. signal should be used; when the signal generator reaches the aerial a modulated r.f. signal should be used.

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 to short-circuit the a.g.c. line.
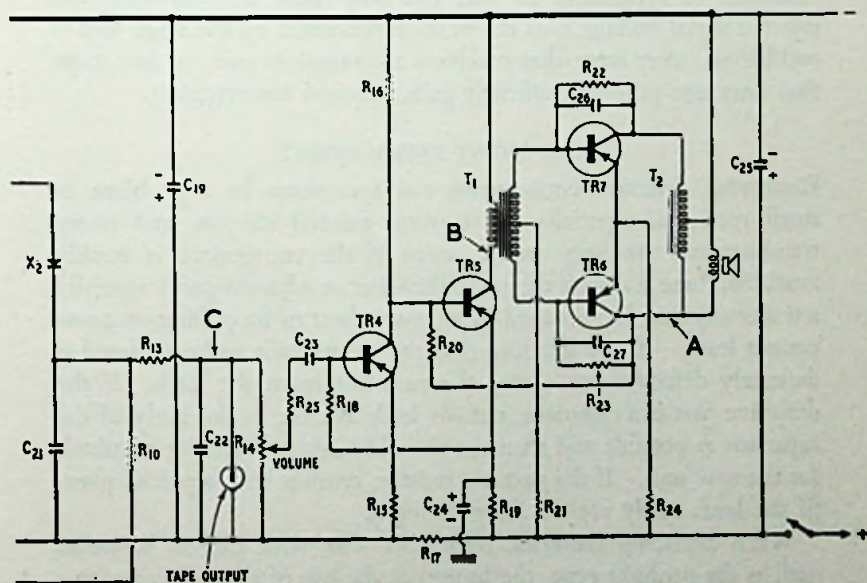
meter. *Resistances are measured with the transistors disconnected from the associated circuits*

Fig. 7.14 is a circuit diagram of a representative transistor radio. On this diagram is marked a number of test points, starting with the letter A on the speech coil of the speaker and proceeding (using letters of the alphabet) until the aerial is reached. There is no law that says you must start at the loudspeaker and work towards the front end —you can start at the aerial and work to the loudspeaker or at the detector and proceed to the front end or loudspeaker if you want to.

When using a signal-injection technique, the valve voltmeter makes a much more sensitive indicator than the loudspeaker. Many technicians prefer a speaker as an output indicator, but it takes quite a large change in sound level energy to be really noticeable. A good method is to disconnect one lead going to the speech coil of the loud-speaker and to connect a 5-ohm, 2-watt resistor across the output transformer secondary leads. The lead to the valve voltmeter can then be connected across this resistor. As you work from the output stage to the front end of the set, the a.c. voltage reading on the valve voltmeter should increase at each stage except the detector.

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, so that you will really be measuring the injected signal voltage plus the voltage generated by the stage that is oscillating. Any stage that produces a decrease in gain, or any stage that does not produce sufficient gain, requires investigating.

COMPONENT REPLACEMENT

Removing defective components can sometimes be a problem in small receivers, especially those using printed circuits, and many transistor sets are very small. Even if the component is readily available, there is always the possibility that an adjacent part (especially a transistor) may be damaged by excessive heat or by pulling on component leads. If you are sure that the component to be replaced is definitely defective, cut away the part but leave the leads. 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, crush it with a pair of pliers (if the leads really are not long enough).

When replacing batteries, remember that with carbon batteries, such as the penlight type, the button at the top of the cell is positive and the metal part of the case negative (the reverse of mercury cells).

WATCHING THE VOLTAGE

In servicing valve receivers, the test-equipment leads are often connected directly to the control grid. The grid return is usually to earth through a high 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 the generator may be of low resistance—it can be the low-resistance winding of a transformer or a resistor. In any event, when connecting 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 $1 \mu F$ will do for audio, or $0 \cdot 1 \mu F$ for r.f. and i.f. and it should be connected between the base and the " live " generator lead.

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 it 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.

FAULTS IN THE AUDIO SECTION

The words " audio instability " cover a number of problems that are often listed under other names. An example of audio instability is that the receiver howls, especially when the volume control is turned up. Sometimes this will be regularly intermittent—a symptom which you will promptly recognize as " motorboating ".

This can be produced by a variety of causes. Suspicion should be directed to the battery. As a battery gets older, its internal resis-
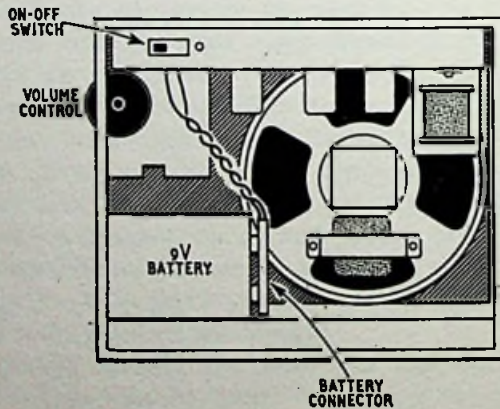
Fig. 8.1—A loose battery connector can cause audio instability

tance increases. As the internal resistance gets larger, it provides a
common feedback coupling impedance. Most of the voltage drop
takes place inside the battery itself, and the result of that is a reduction
in the voltage available for the different circuits of the receiver. As a
consequence, the volume control must be advanced to increase the
driving signal voltage to the various stages. This results in a con-
dition of instability and the receiver tends to howl or motorboat.

Audio instability can also be caused by poor connections. In one
instance known to the author it occurred at the battery itself. The
battery holder was riveted into place and the rivet had become loose.
The problem was solved by soldering over the rivet. 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 should be a positive one and you
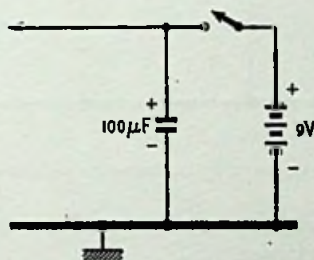
Fig. 8.2—Electrolytic capacitors are often shunted across the power supply battery

should hear a definite click as the snap fastener is pushed into position.
One type of " snap " connector is shown in Fig. 8.1.

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
in case the fault is not in the audio stages after all.

Another cause of audio instability is leaky or otherwise defective
electrolytic capacitors connected across the battery power supply.
You will find one or more of these with capacitances ranging from
10–100 μF (Fig. 8.2). To check, turn the receiver on and produce
the condition of instability. Take a capacitor known to be good and
shunt it across the suspected defective electrolytic. If the howl
disappears or is reduced, replace the capacitor. Instability can also

arise from inefficient screening, and this may result from a poor connection between a screening shield and earth or chassis.

Sometimes, inadequate filtering is used in receivers sold in the form of a constructor's kit at a low price. Howling or motorboating in such sets may be due not to any defect, but simply caused by an insufficient amount of filter capacitance. In such instances, if you can
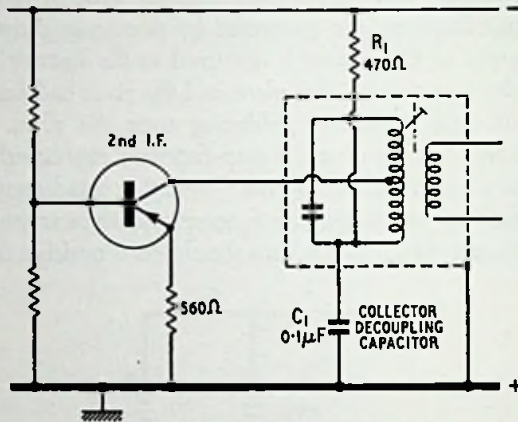
Fig. 8.3—Instability can be caused by an open-circuited collector decoupling capacitor

find room for it, parallel the existing capacitor with another having an equal or greater capacitance.

Motorboating or howling can also be caused by an open-circuited collector coupling capacitor (Fig. 8.3). To check if this is the trouble, shunt the existing capacitor with a similar one. When shunting a test capacitor across a suspected defective electrolytic unit, make sure that the positive terminal of the test unit is connected to the positive terminal of the defective one in the receiver. Similarly, the negative terminals of the two capacitors should also be connected. Do not transpose the 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. R_1 and C_1 in Fig. 8.3 form a decoupling circuit.

Finally, the remaining suspect in our search for the cause of instability is 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 ohm-meter check (with one end of the resistor disconnected) will soon reveal whether the resistor meets the value specified in the manufacturer's circuit diagram. One position in which the audio feedback resistors may be found is seen in Fig. 8.4, but it may be in the collector or the emitted circuit. When feedback coupling is taken from the secondary winding of the
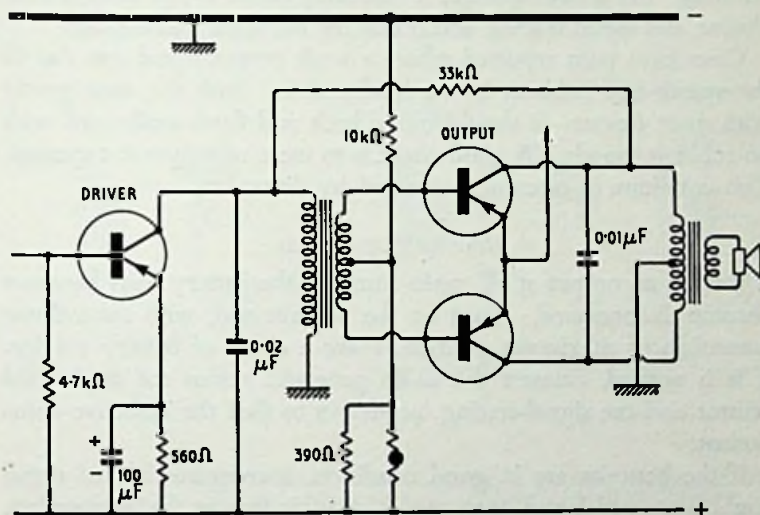
Fig. 8.4—An open or changed value feedback resistor which may be in collector or emitter circuit can cause instability. Check the value of each resistor against the circuit diagram. The 390-Ω resistor is shown here shunted by a thermistor

output transformer, as it sometimes is, reversal of the connections of one winding with respect to the other will render the feedback positive instead of negative and cause severe oscillation.

WEAK AUDIO SIGNAL

If the signal is weak, 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 electrolytic capacitors. Remember that electrolytic capacitors are often used in a transistor receiver as coupling capacitors and in this position they 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 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, but signal tracing will reveal the defective transformer.

Cases have been reported where a weak output signal was due to the speech coil rubbing in the loudspeaker. Push the cone gently with your fingers—it 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

If there is no output at all, make sure that the battery leads have not become disconnected. Turn on the receiver and, with the volume control in its maximum position, make a check of battery voltage. If it 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 speech coil winding in the loudspeaker, an open-circuited output transformer (either the primary or the secondary winding could be defective) or by an open-circuited 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-circuit 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 loudspeaker. In some sets, inserting the earphone jack automatically disconnects the loudspeaker, putting a load resistor across
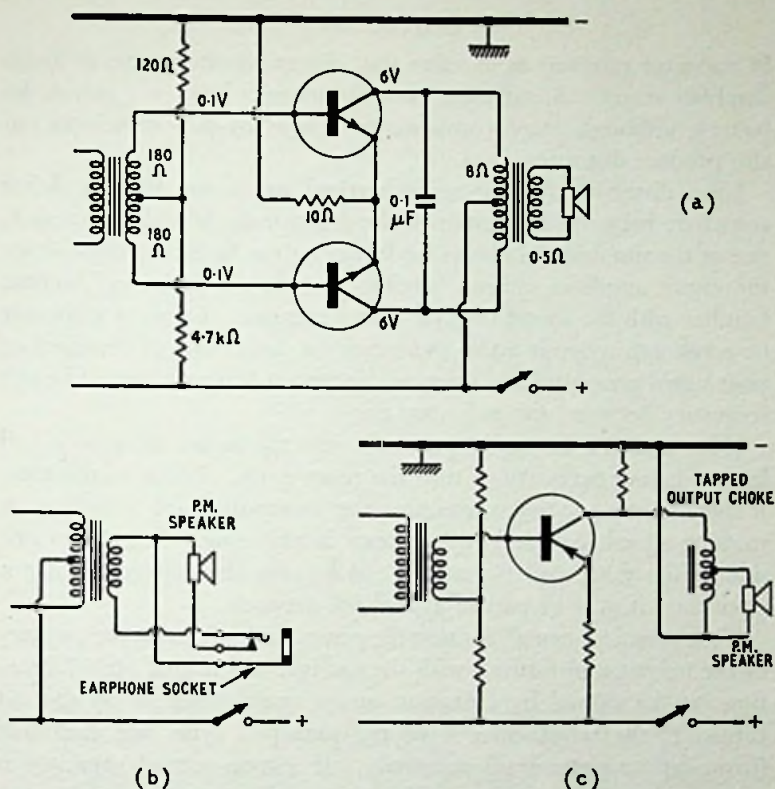
Fig. 8.5—*Some transistor receivers (a) have loudspeaker output only. Others (b) have one or more jacks for earphones. Impedance coupling is used in (c). The choke is tapped down to match the impedance of the speech coil. In some receivers, the 'phone jack is placed in the output of the driver stage instead of in the push–pull stage*

in place of the speech coil. In other sets, no load resistor is used. If the earphone jack is defective, it is possible that the speaker is not reconnected into the circuit when the earphone jack is removed (Fig. 8.5).

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 this is greatly in excess of normal receiver requirements, then you have a leaky or shorted component.

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DISTORTION

In transistor receivers as in valve sets, distortion often arises in audio amplifier stages. A common cause is incorrect bias, or a run-down battery, although other components such as by-pass capacitors can also produce distortion.

Since distortion (in the audio section) can come from a defect anywhere between the output of the detector diode and the speaker, one of the simplest techniques for localizing the fault 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 c/s.

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

If the sound is normal, connect the generator leads across the primary of the output transformer, with the receiver still turned off. Distortion can be caused by corrosion in the transformer or by shorted turns. If the transformer is of the push-pull type, test each half (from tap to outer lead) separately. If a tone-control capacitor is connected to the output collector, unsolder one end (the one connected to the battery or chassis) and note whether the distortion 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 position only, then the capacitor connected to that position is defective. If the receiver sounds shrill or tinny, the tone-corrector 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. Switch 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 by-pass capacitor, if any. If convenient, remove the transistor 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 valve voltmeter set to read low d.c. volts. Measure the base-to-emitter voltage to make sure the bias for the transistor is present. If the transistor is in a push-pull stage, make the check by connecting the generator across the primary of the input transformer.

By now you have undoubtedly 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 high-potential 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 a.g.c. network, starting at the detector, or at the separate a.g.c. 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 usually sold as matched pairs and should be replaced as such.

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

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. This gives us a clue for checking push-pull stages without the necessity of removing the transistors. Connect a milliammeter in series with the lead going to the centre tap of the output transformer, as at B in Fig. 8.6. 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. If volume control and switch are separate, the total current can conveniently

be read by connecting the meter across the battery switch, as shown at A in Fig. 8.6, instead of as shown at B, and then switching off. It is then unnecessary to unsolder a lead.

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
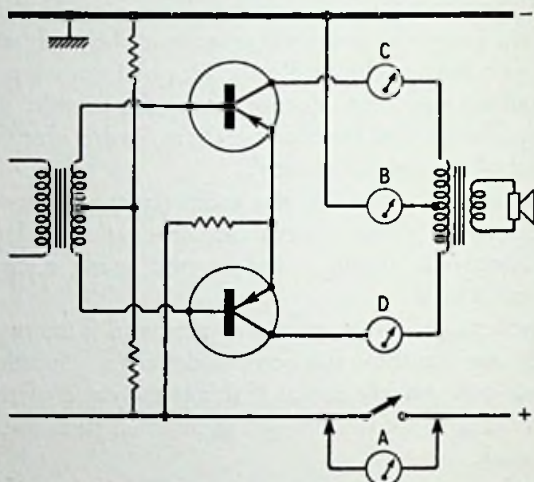
Fig. 8.6—Methods for making current checks. If the meter is shunted across the on/off switch it reads total current (A). At B it reads collector current of both output transistors. When making the test at A, keep the switch open. Note: if volume control and switch are ganged, the test shown at A does not permit adjustment of the volume control

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 (although if you replace one you must replace both), put the milliammeter in series with the individual collector lead; that is, the lead between the collector of the output transistor and the primary of the output transformer (C and D in Fig. 8.6). 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 faults described so far are those which will most commonly

appear in the driver and power output stages of a transistor receiver. Many of the troubles encountered in valve 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
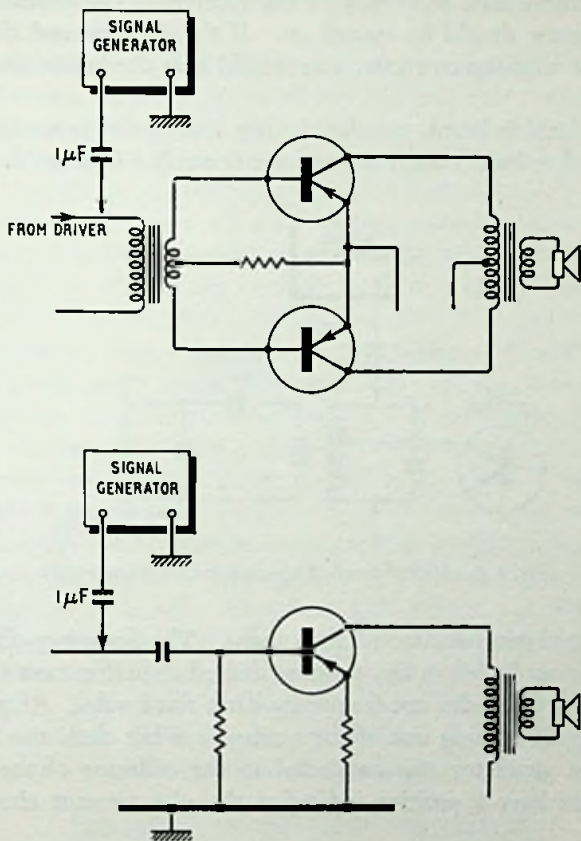
Fig. 8.7—Signal generator connecting point for checking single-ended and push–pull audio output stages

part of the routine in servicing such sets. However, you can easily see that servicing transistor receivers is no more difficult (and in many cases is easier) than servicing valve sets. Fig. 8.7 shows how an audio generator (or the audio output of a signal generator) can be used to check single-ended and push-pull stages.

THE DETECTOR

There is a quick and easy way to determine if the detector is defective. Connect the signal generator to the output (collector) of the last i.f. stage preceding the detector (Fig. 8.8). 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 (usually the volume control). Change the output
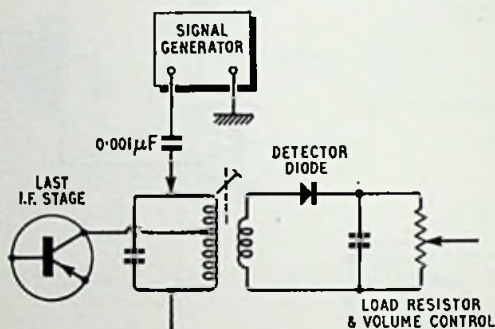
Fig. 8.8—Method for checking the transistor detector stage

of the signal generator from i.f. to audio. The frequency dial of the generator can be left in any position desired since (for most i.f. signal generators) the audio test frequency has a fixed value. If you now hear a signal coming out of the loudspeaker but there was not one when the generator was connected to the collector of the last i.f. stage, you have a positive indication that the detector circuit is at fault.

Many of the symptoms discussed in the preceding paragraphs on the audio amplifier 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 crystal detector, the volume control and a coupling capacitor, usually connected to the base of the first amplifier transistor. The a.g.c. network is generally made part of the detector circuit.

To determine if the volume control and the coupling capacitor

are functioning properly, connect an audio signal across the 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 get a strong output tone, and can vary this with the volume control, then the trouble lies in the detector itself or in the secondary of the last i.f. 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 loud-speaker when the generator is so connected indicates that either the volume control or the coupling capacitor following it is defective.

An ohm-meter check of the volume control will soon reveal whether it is in good working order.   Make this test by connecting one lead of the ohm-meter to either outer terminal of the potentio-meter and the other ohm-meter lead to the slider terminal of the potentiometer.   Vary the potentiometer and note whether you can make the ohm-meter 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 ohm-meter accordingly.   If the potentiometer check is satisfactory, try shunting the coupling capacitor between the volume control and the base of the audio amplifier transistor with another capacitor.

The coupling capacitor is generally an electrolytic, having a value in the region of 1–10 μF.   Here is a spot where you must watch polarity and not make any assumptions.   Usually the negative lead of the coupling capacitor is connected to the base of the first audio amplifier, but sometimes the positive terminal is so connected.   Disconnect one lead of the suspected capacitor and then use the 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 i.f. by-pass capacitor in the detector circuit.   The purpose of this capacitor is to keep i.f. out of the following audio stage.   Of course, if the coupling capacitor between detector and first audio stage is shorted, distortion will also result.   In addition distortion can be produced if one or more of the filter capacitors in the a.g.c. network connected to the detector become defective. In some instances, distortion is caused by a wrongly adjusted core in

the secondary side of the last intermediate-frequency transformer. This is really part of the detector circuit.

THE I.F. AMPLIFIER STAGES

The number of intermediate-frequency amplifier stages depends entirely upon the type of receiver being serviced. However, no matter what number of stages the receiver has, you can check through for trouble by signal tracing, working back from the detector to the output of the frequency changer (Fig. 8.9). 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 i.f. stages are functioning, connect the signal generator at the output side (generally the collector) of the frequency-changer transistor. The set-up 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 frequency changer stage, there is no signal out of the loud-speaker, work forwards 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 i.f. stages but no audio signal on moving back towards the input of that same transistor, you have obviously located the defective stage.

The troubles encountered 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 i.f. stages are similar to those produced by the audio stages. 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 a fault anywhere in the i.f., 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 I.F. AMPLIFIER

Weak signals are occasionally caused by misalignment in one of the i.f. circuits. The i.f. transformers in transistor receivers are quite selective and a small amount of turning of a core will produce either
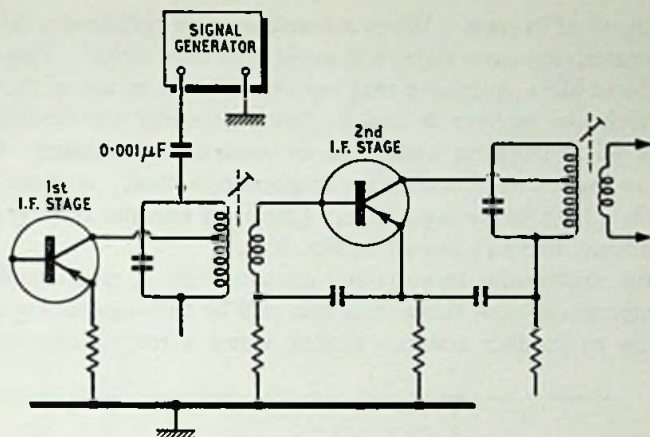
Fig. 8.9—Method for checking the i.f. stages

distortion or loss of signal. Realignment will not be discussed here since complete alignment instructions for a typical receiver are given in Chapter 10.

In the case of weak signals check the battery voltage with the receiver volume control turned fully on. If this has already been checked and none of the audio or detector stages is defective, and the cause of the weakness is definitely located in the i.f. section, then it would be helpful to check the i.f. bias voltages.

Bias voltages in a transistor receiver are not easy to check. As mentioned previously, the valve voltmeter must be capable of measuring small voltages, and you must learn to look at the meter needle more carefully than is usually necessary with valve receivers. Although the normal bias voltage for a transistor may be a small fraction of a volt, this small fraction is extremely important. A decrease in bias voltage, for example, of only 0·05 volt (5/100 of 1 volt) is enough to cause a serious decrease in receiver gain.

Open by-pass capacitors in the i.f. section can also reduce gain. With the receiver turned on, shunt each by-pass capacitor with a similar unit and note any possible increase in gain.

OSCILLATION IN THE I.F. AMPLIFIER

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 it 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 use feedback by means of neutralizing capacitors or neutralizing resistors. Check these to make sure that they are in good condition. A more likely cause is a fault in the a.g.c. line. Check all resistors and capacitors in the a.g.c. network shown in Fig. 8.10.

If the neutralizing resistors and capacitors check satisfactorily, do not experiment with them since this will be time-consuming and is unlikely to produce results. Instead, shunt a 100,000-ohm resistor
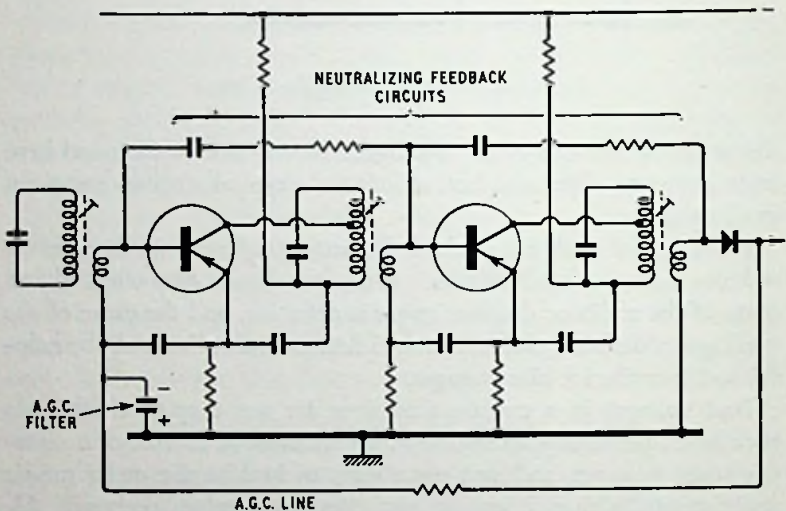
Fig. 8.10—*Defective resistors and capacitors in the a.g.c. circuit can result in oscillation*

across the primary of each i.f. transformer (one transformer at a time) until you have managed to kill the oscillation. A decoupling capacitor should also be added. This may be done even if the receiver has an existing decoupling unit (Fig. 8.11).

If the resistive shunt method is successful, the reason is simply that the gain of the stage has been lowered, and that may dispose of the oscillation even though it is due to a fault in another stage. To regard this as a repair would be to " bodge " the job, so the investigation

Fig. 8.11 (right)—A 100,000-ohm resistor shunted across the primary of the i.f. transformer and an additional decoupling capacitor (0·01 μF) will help to eliminate oscillation
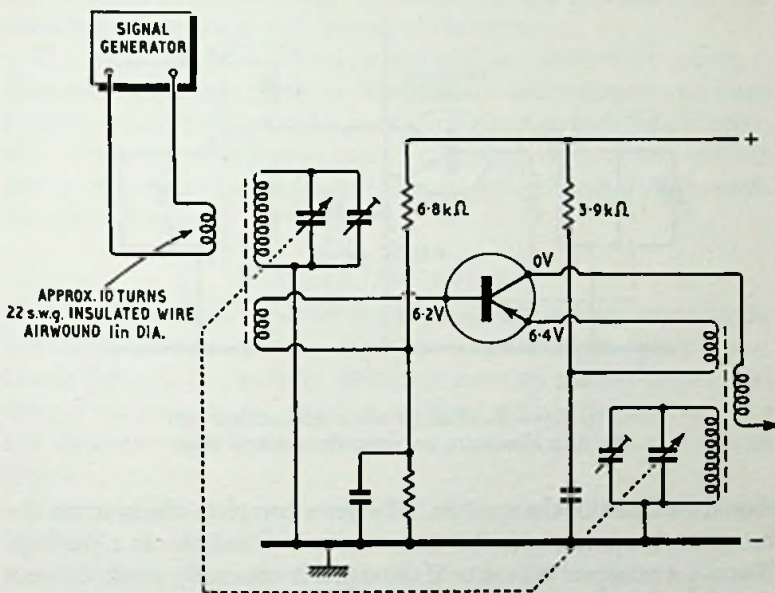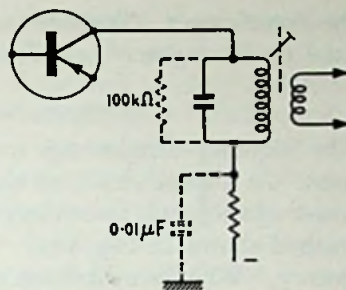
Fig. 8.12—Method of checking the frequency-changer stage

should be continued until the cause of the instability is found. By-passing existing decoupling capacitors with a new one, one at a time, might reveal the faulty one. The original is not doing its proper job if the oscillation stops, or even if the note changes, when it is shunted with a new one.

Oscillation is sometimes caused by substituting an equivalent type of transistor instead of an exact replacement, especially if the replacement has a higher gain. Use the transistor type specified by

the manufacturer. Transistor substitution can also lead to distortion since the biasing may be different.

FREQUENCY-CHANGER STAGE

The frequency-changer stage can also supply its own share of problems. As a quick check, set the dial of the signal generator to the low-frequency end, somewhere in the region of 600 kc/s, using the method shown in Fig. 8.12. Tune the receiver to the same frequency. With the modulation of the generator turned on, the output
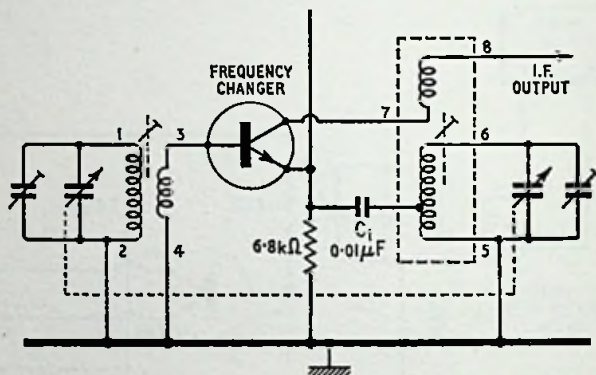
Fig. 8.13—To check the mixer and oscillator coils with an ohm-meter, test across the numbered points

should be heard in the speaker. To get a complete check across the broadcast band, run a similar test at 1,000 kc/s and also at 1,500 kc/s. If you get no signal output or if the signal is extremely weak, connect the signal generator lead to the output of the frequency changer and tune the signal generator to the intermediate frequency of the receiver. If at this time the signal comes through loud and clear, then a fault in the converter is definitely indicated. It is probably not oscillating.

"FRONT-END" FAULTS

In speaking of the front end of a transistor receiver we are referring to the frequency changer or, where they are used, a mixer and local oscillator, and of course the aerial circuit. Since most transistor receivers do not use an r.f. amplifier, faults in this section will be left until we reach Chapter 9. Car radios do use an r.f. amplifier.

There is a variety of front-end troubles ranging all the way from complete inoperation to poor reception. In discussing these symptoms, it must be borne in mind that a single fault can cause a number of symptoms. For example, a defective transistor used as a frequency changer 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, it is much better to know that a bad transistor can cause a number of different troubles than to imagine that each fault has one, and only one, specific symptom. Knowing the various troubles that a component can produce enables you to narrow your search for the culprit.

RECEIVER NOT WORKING

If the receiver doesn't operate and the trouble has been traced to the front end, then an open-circuit or short-circuit might be the cause. Check the coils in the front end for continuity and make sure that there is no break in the aerial or oscillator coils. Remember aerial and oscillator coils have primaries and secondaries, so check both (Fig. 8.13).

If you decide to make a resistance check, remember this is not a valve set. A valve with no voltage on it is just an empty space surrounded by some glass or metal. A transistor is quite different, resembling a group of resistances placed in the circuit. As a result, every time a resistance check is made, some part of the transistor will affect the result, giving completely misleading readings. If the transistor has a socket, take the transistor out, but if it is soldered into place, it is advisable not to tamper with it.

If, having made a resistance check, it shows that the coils are good, then it is possible that the oscillator is not working. There is a number of tests that can be made depending on the equipment at your disposal. In Fig. 8.13 is a typical frequency-changer stage using a Hartley circuit as the local oscillator. Set the dial of the receiver to about the middle of the scale, connect an oscilloscope lead to the

emitter of the transistor and see if you can pick up the i.f. voltage being impressed on the emitter by the local oscillator. The same result should be obtained on either side of C_1. If you have an r.f. type of voltmeter, the r.f. voltage at this point can be measured. Use an isolation probe with the valve voltmeter. The technique used for determining oscillator operation in a TV or radio set (by measuring the voltage developed across the grid return resistor of the oscillator) can sometimes be used in transistor receivers.

If you do not have the test equipment just described, but do have a signal generator, you can still test the local oscillator in the receiver. Connect a loop to the test cable of the generator as shown in Fig. 8.12. The dimensions of the loop are not critical—it can consist of about 10 turns of insulated wire (22 s.w.g.), coupled 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 plus the i.f. For example, suppose you have set the dial to 1,000 kc/s (300 m) and the i.f. is 455 kc/s. The sum of these two frequencies is $1,000 + 455 = 1,455$ kc/s. This is the frequency at which you should set your generator.

The output of the generator should be an i.f. signal, with no modulation. If the local oscillator in the receiver is not working (and you have the receiver correctly tuned), you should now be able to receive a station at 300 m. Rotate the dial of the signal generator back and forth over a narrow range if you do not hear anything.

The next step is to check the voltage at the base and emitter of the frequency-changer transistor to make sure that proper voltages are reaching the transistor. (Another method of checking the local oscillator is described in Chapter 9.)

If you are obliged to 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.

HETERODYNE WHISTLES

When seeking the cause of heterodyne whistles you must first make sure that this condition is originating in the receiver and is not confused with interference picked up from outside sources. If you are checking the receiver on a bench equipped with fluorescent fixtures, turn the receiver on but switching off the light. Notice if there is

any improvement in receiver operation. If there definitely is, then the cause is outside the receiver.

Heterodyne whistles in the sound can be caused if the oscillator voltage of the receiver is too high. This condition can be relieved by using a frequency-changer 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. If the maker's service information is available the type number of the transistor should be checked against it. If it is correct, do not change the transistor, but find the fault. Perhaps the battery voltage is too high.

QUICK CHECK

We have previously discussed the use of a milliammeter in series with the battery power supply to measure receiver current under various operating conditions. Inserting a milliammeter is not difficult since all it entails is lifting (or disconnecting) one battery lead (either one). One can connect the milliammeter leads directly across the switch on the volume control as shown at A in Fig. 8.6. This will indicate 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.

As a quick check on receiver operation, connect the milliammeter in series with the battery by some other means and measure the total receiver current with no signal coming in. Make a note of the 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 should be about 24 mA or more. This technique was described earlier but it is repeated here for its value as a quick check. The increase is due to class B operation, so of course it will not apply to sets that do not use push–pull output.

INSUFFICIENT GAIN

Loss of amplification can be caused by an open-circuited by-pass capacitor. Shunt suspected units with a known good capacitor. Weak signals on all stations can be due to a misaligned i.f. In aligning

i.f.'s remember that some stages may have a double-peaked response. That is, while there may be a theoretical flat-top bandpass, it is not really so. Generally, one peak will be higher than the other. To get more gain and selectivity, align for the higher peak, using a sensitive output indicator, and not relying upon the signal output of the loudspeaker.

Also, instead of connecting the valve voltmeter across the speech coil of the loudspeaker, put it across the volume control, using the two outer terminals. Rotate the core of the i.f. transformer and watch the meter needle. If it swings up, then down and up again, there is a double-peaked i.f. response. Then align for the higher of the two peaks.

The increased gain and selectivity will be obtained at the expense of high-note response. This is not very important in a transistor portable, but it could result in instability, so a check should be made by tuning the receiver to several different signal frequencies (in each waveband if more than one are provided) listening for whistles and howls.

If the i.f. transformer seems to tune very broadly, its Q is too low, which may be caused by a shorted turn. Also check for open i.f. by-passes connected to the transformer.

Sometimes gain is reduced when a new transistor is used to replace an existing one. Do not assume that the two transistors are identical —replacing a transistor may mean that you have to re-align the i.f. If you transpose transistors, you may also have to re-align.

Finally, if you still do not have enough gain, take a look at the diode detector; if, for any reason, it has been turned round the a.g.c. voltage will be incorrect.

MEASURING BIAS

The bias is the voltage existing between base and emitter. However, the bias is very small—usually a fraction of a volt. In a typical case, the bias might be 0·2 volt, which is very difficult to read on a meter.

An easier technique for measuring bias is illustrated in Fig. 8.14. Measure the voltage between base and the emitter end of the battery using the correct reference point (chassis positive in the drawing) and then make a voltage measurement between emitter and the emitter end of the battery. The difference between the two voltage readings will be the bias. If the meter indications are still too low

for convenient reading, reverse the meter leads and connect them between the opposite end of the battery and the transistor. The advantage of this technique is that it moves the meter needle further up the scale where it can be read much more easily. However, the difference in the two voltage readings will be slight, so you will have to make the test with care. Moreover, any current taken by the meter itself will affect the readings slightly.

TEST INSTRUMENTS

For servicing transistor radios, both the multi-range meter and a voltmeter are needed. It is true that both can measure voltage, but
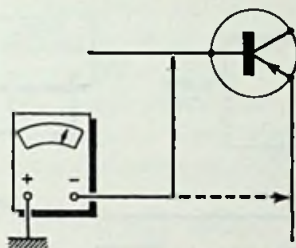
Fig. 8.14—To measure bias use a valve voltmeter. Set it to read d.c. volts but use the lowest possible range so that the meter needle will read as far over to the right as possible. The difference between the two meter readings is the bias voltage. With npn transistors the polarity would be reversed

you need the multi-range meter for measuring current, although many valve voltmeters also measure current.

However, since the valve voltmeter also has voltage scales, it might seem that we could dispense with the valve voltmeter and work with just one instrument. The whole point hinges around the sensitivity of the test units. A multi-range meter 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 wished to measure the voltage at the base of a transistor and that this was indicated on the manufacturer's circuit diagram at −1·35 volts. We would set our multi-range meter on its lowest d.c. range. But at 1,000 ohms per volt, if we are using a

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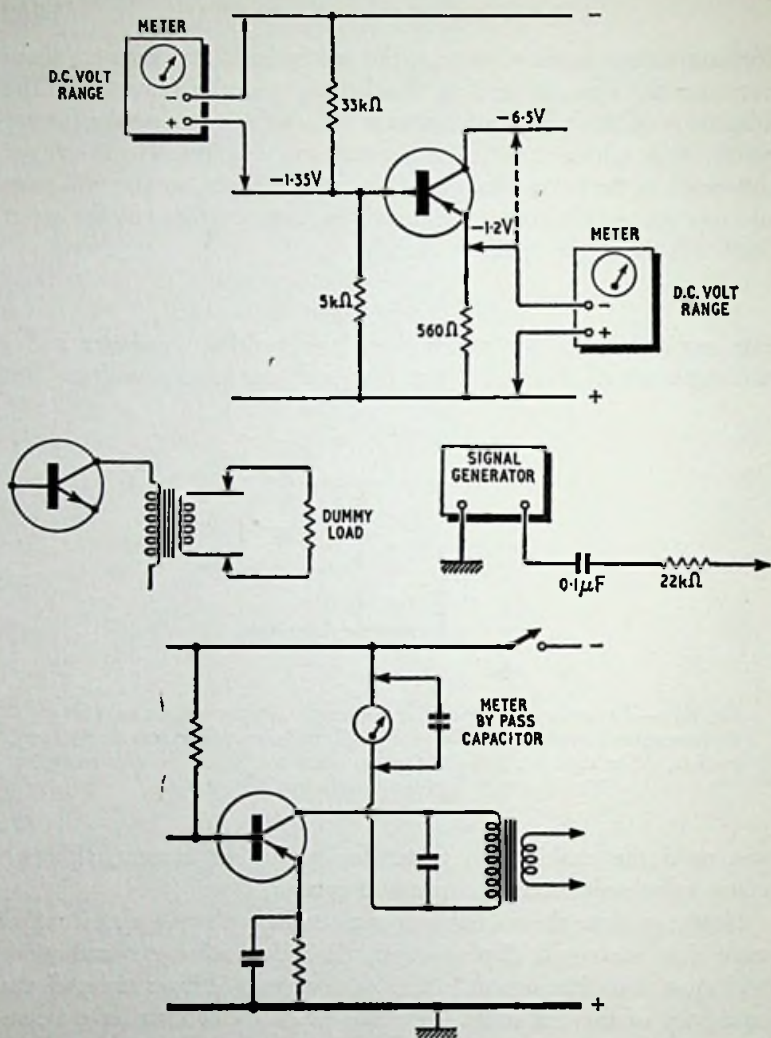
Fig. 8.15 (top)—A meter (used to measure voltage) will load the circuit, giving an incorrect reading. Use a valve voltmeter

Fig. 8.16 (middle, left)—Put a dummy load across the secondary of the audio output transformer if you want to make tests with the speaker disconnected

Fig. 8.17 (middle, right)—Use a blocking capacitor in series with the " live " lead of the generator. A 22,000-ohm ½-watt resistor will provide isolation when checking in r.f. or i.f. stages. The resistor is not needed for audio circuit testing

Fig. 8.18 (bottom)—Use a meter by-pass capacitor when making current measurements

range with a full-scale deflection of 2 volts, the meter represents a resistance of only 2,000 ohms. For a full-scale deflection of 5 volts it would only be 5,000 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. 8.15 we see that doing this has the effect of reducing the 33,000-ohm base resistor to an equivalent of just under 1,900 ohms.

If you use a multi-range meter having a sensitivity of 20,000 ohms per volt, this would be 200,000 ohms on the 10-volt (full-scale deflection) scale. Making the test indicated in Fig. 8.15 reduces the base resistance only slightly, which is much better (but not good enough) since the more sensitive meter does not load the circuit seriously. A valve voltmeter would be better still since its internal resistance is rated in megohms, and it has practically no effect on the circuit being tested (one megohm is one million ohms).

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

SOME TEST HINTS

Never operate a transistor without a load. If you remove a loudspeaker, remember that keeping the test instrument leads connected across the secondary of the output transformer is not an adequate load. Keep a 5-ohm, 2-watt resistor handy for connecting across the leads to the secondary of the transformer as shown in Fig. 8.16.

Always use a blocking capacitor in series with the "live" lead of your signal generator. Some technicians put a 22,000-ohm resistor (Fig. 8.17) 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 by-pass the meter for i.f. or r.f. Use a 0·01-μF capacitor for these frequencies, and a 10-μF capacitor when measuring current in audio circuits (Fig. 8.18). While this technique is a desirable one, it is not always observed. When it is used, if it is to be effective, the meter and capacitor leads must be kept short.

Transistor receivers can be click-tested,* but you must be careful

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* Clicks produced by touching various parts of the circuit with a small insulated screwdriver indicate that the intervening stages pass a "shock" signal.

not to short-circuit the input bias of the transistor.   You can check hum by holding the metal shank of a screwdriver and then touching the metal end of the screwdriver blade to the base lead.

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

Car Radio

As you might expect, transistors lend themselves very well to use in car radio receivers. They can operate with considerably lower power drain from the car's battery than can a valve receiver; the transistor receiver 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 faults and servicing procedures analysed earlier are also applicable to the transistor car receiver. However, it still needs further study since it has a few problems of its own.

SPECIAL FEATURES

The transistor car radio is a superheterodyne, just as are the various portable and home receivers. This means that the fundamental circuitry of all these sets is the same, and yet the receiver designed to work in the home certainly has better operating conditions than one that is obliged to compete with a car engine. The engine not only moves the vehicle, but it also acts as a miniature transmitter. The programme it sends out, however, consists not only of noise, but of noise that is at times somewhat difficult to eliminate.

Because the car radio is located within a shield (the body of the vehicle) it must have an external aerial. Since it is impossible to have one of any great length, a loading coil is sometimes used in series with it, as shown in Fig. 9.1, which produces an effect equivalent to using a longer aerial.

Practically all car radios have the distinction of using an r.f. amplifier stage, which would be exceptional in home radio receivers, but it is

almost invariably present if the receiver is designed to work in a car.

It is exceptional for a British car receiver to use transistors throughout. Most, known as "hybrid" receivers, make use of both valves and transistors. When valves are used, they are special types which will operate with only 12 volts on the anode and screen. This was explained in Chapter 6.

In place of the vibrator power supply, some car radios make use of what is known as a d.c.-to-d.c. converter but these are not found in
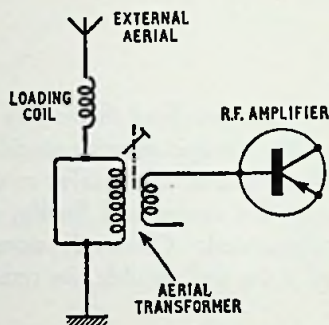
Fig. 9.1—In some receivers a loading coil is inserted in series with the aerial. The loading coil occupies a small space but makes the aerial effectively longer

British receivers. Finally, there are car radios that come equipped with "search" tuners. This is simply an automatic tuning circuit, permitting the driver of the car to keep both hands on the wheel, letting the receiver select and tune in the signal. Again, this is not found in British receivers, which often use press-button tuning instead.

In Fig. 9.2. we have block diagrams showing the essential difference between home and portable receivers and receivers used in cars. Fig. 9.3 is a circuit diagram of a representative car radio using transistors throughout, while Fig. 9.4 shows a hybrid car radio. The fully transistorized diagram is that of an American receiver.

POWER CONSUMPTION

Car radios using transistors but no valves do not put a heavy drain on the car battery. A typical transistor auto radio will draw a total of about 1 ampere (at 12 volts) compared with about 3 to 6 amperes for

a valve type car radio. On American cars using 6-volt batteries these current ratings would be doubled.

The general features of the hybrid type of receiver so far as they affect the subject of transistors were explained in Chapter 6, and in the next few pages are described the features of an American all-transistor car radio receiver.

THE FRONT END

For best operation, it is important to get the maximum amount of signal into the first stage of the transistor car receiver, the r.f. amplifier. Fig. 9.5 shows a typical front end of an American all-transistor receiver.

This receiver is permeability-tuned. The r.f. amplifier, the mixer and the local oscillator are ganged together and tuned simultaneously,
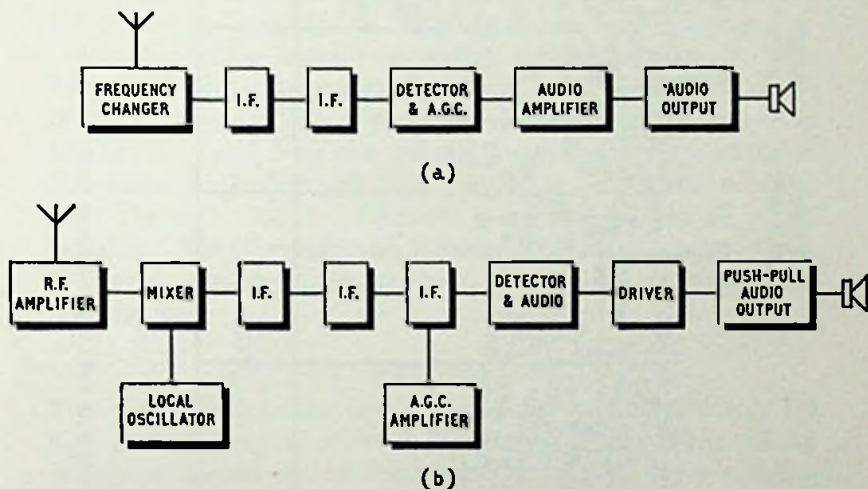
Fig. 9.2—Block diagram of a portable domestic receiver at (a) compared with an all-transistor car radio receiver at (b)

the iron cores being moved in and out of their respective coils by a suitable mechanism. The emitter of the npn r.f. amplifier is connected to the a.g.c. line through a resistor. The loading coil generally has a value of less than 20 μH, while the trimmer capacitor across the primary of the r.f. transformer generally has a range of 3–30 $\mu\mu$F. The setting of the trimmer is simple. This is usually a screwdriver
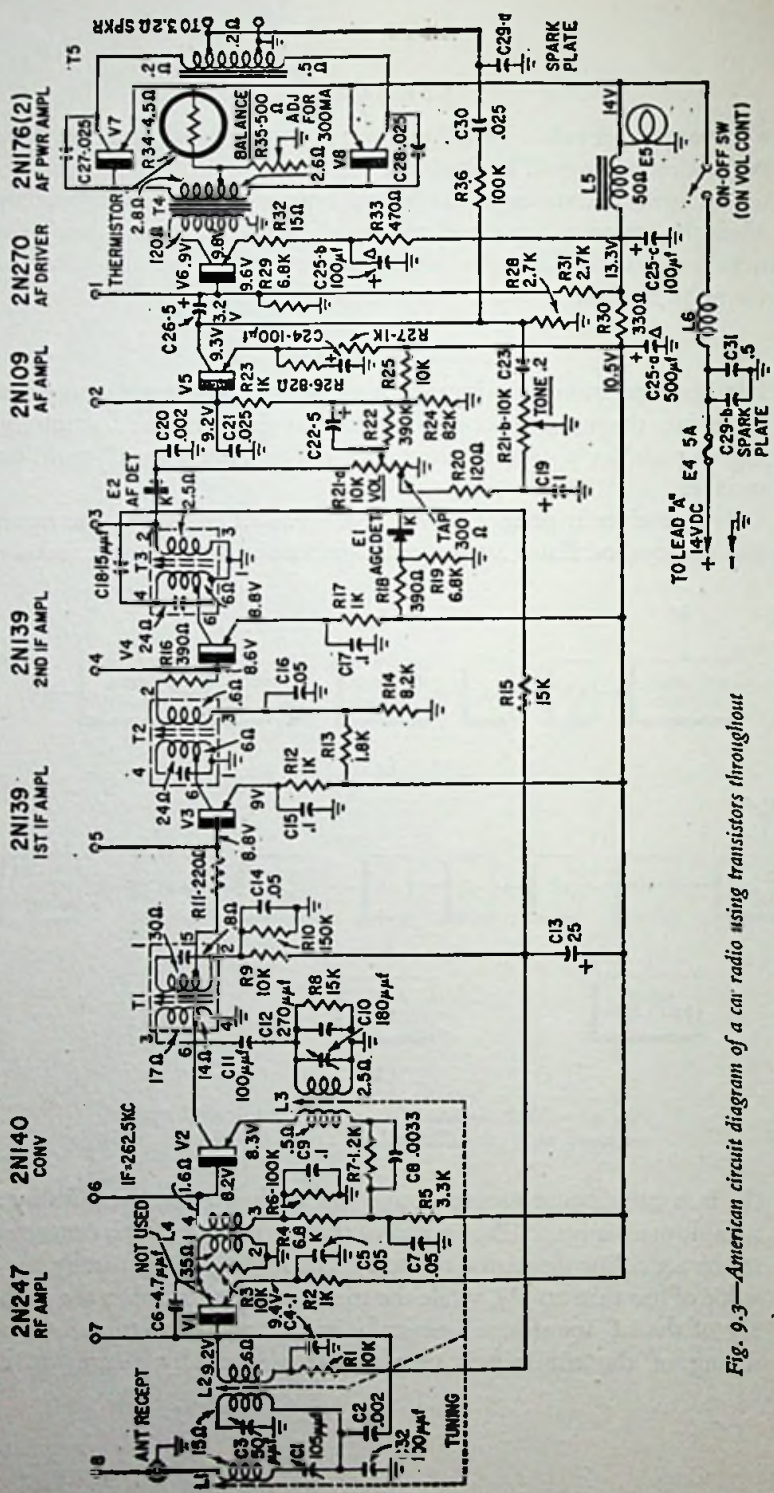
Fig. 9-3—American circuit diagram of a car radio using transistors throughout

adjustment and can be made without removing the receiver from its case.

A hole is provided in the chassis to allow the use of a small screw-driver. The dial of the receiver is set to approximately 1,400 kc/s, a very weak station is tuned in, and then the trimmer is adjusted 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 a.g.c. will operate to keep the signal strength constant. If, however, you select a weak station, the a.g.c. 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 adjust-ment with the trimmer capacitor. This trimmer compensates for the variations in capacitance of aerials (and their leads-in). A signal generator cannot be used, because the signal must be picked up by the aerial. Fuller details of receiver alignment are given in the next chapter, where a special note, "Aligning the car radio", appears.

The r.f. amplifier stage has tuned input and also tuned output. The stage, however, is not transformer-coupled to the mixer in the circuit of Fig. 9.5. In this case, a resistance-capacitance network is used to transfer the signal from the collector output of the r.f. amplifier. Sometimes, however, transformer coupling is used as shown in Fig. 9.6. The a.g.c. line in this instance is fed into the base of the r.f. amplifier. The r.f. transformer in the collector circuit is tapped down to provide a better impedance match between the transformer and the collector.

THE LOCAL OSCILLATOR

The local oscillator stage (Fig. 9.7) oscillates because of energy fed back from the output (collector) to the input (base). The oscillator voltage is injected into the mixer circuit by capacitative coupling (C_1). The output coil of the oscillator is shunted by two series capacitors, C_2 and C_3. These two capacitors form an impedance-dividing network, permiting impedance matching between the oscillator and the mixer. C_1 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 C_2 and C_3 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.
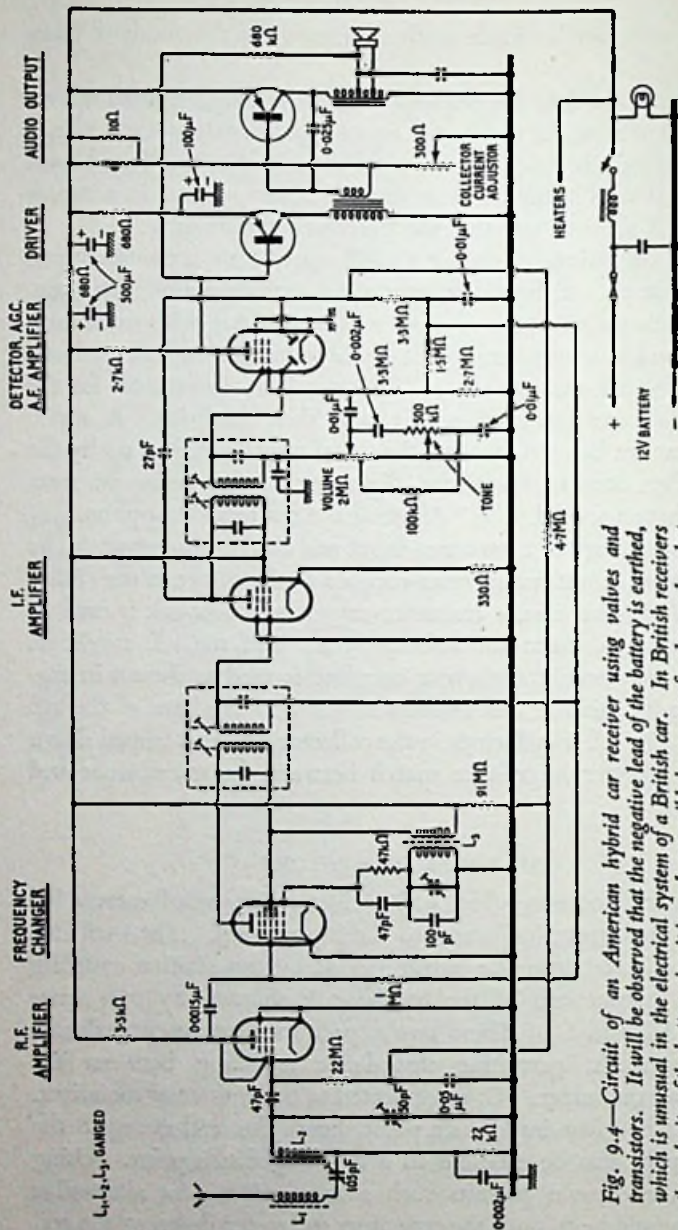
Fig. 9.4—Circuit of an American hybrid car receiver using valves and transistors. It will be observed that the negative lead of the battery is earthed, which is unusual in the electrical system of a British car. In British receivers the polarity of the battery circuit is made reversible by means of a plug-and-socket device, so that it can easily be adapted to suit either type of car installation. In either case, where pnp transistors are used the transistor circuits will appear to be "upside down" with respect to the valve circuits (or vice versa) as they are here, where the emitter circuits go upwards to the positive battery line, and the valve cathode circuits go downwards to the negative line. If the negative line were at the top, of course, the valve circuits would become inverted, and their cathodes would go to the top of the diagram
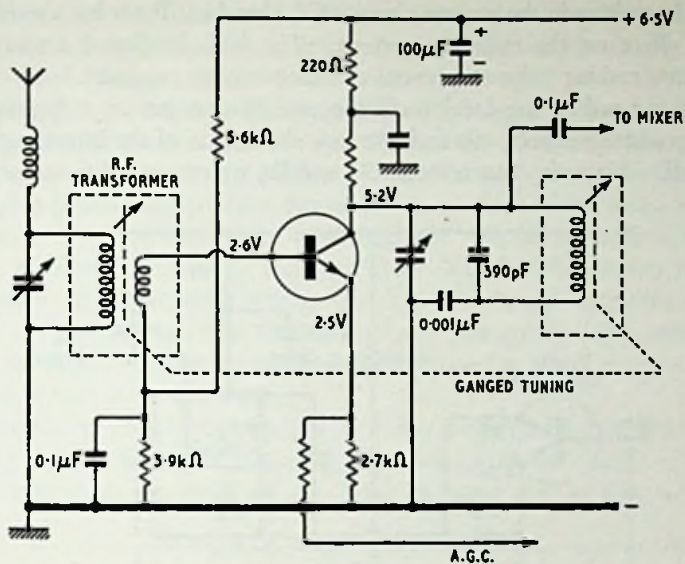
Fig. 9.5—Typical 6-volt car radio npn r.f. amplifier stage
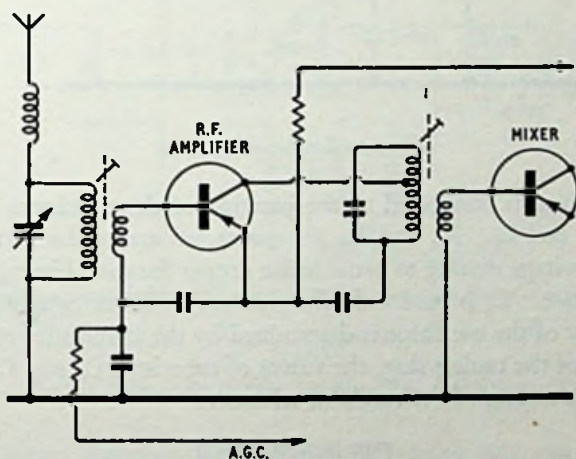
Fig. 9.6—R.F. amplifier pnp stage transformer-coupled to the mixer circuit

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 to prevent collector-current runaway.

In car radios the local oscillator usually operates at a frequency somewhere between 260 and 480 kc/s above that of the incoming r.f. signal. Note also that resistors R_1 and R_2 are connected in series and
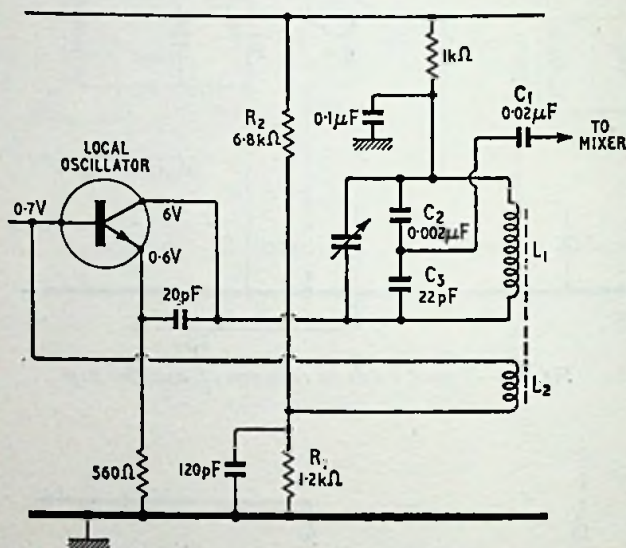
Fig. 9.7—Local-oscillator stage

that the base is connected to the junction of these resistors through feedback coil L_2. R_1 and R_2 are connected across the battery and act as a voltage divider to provide the proper forward-biasing voltage for the base. L_2 is used only for reaction feedback coupling. The frequency of the oscillator is determined by the inductance of L_1, the position of the tuning slug, the values of capacitors C_2 and C_3 and of course the setting of the oscillator trimmer.

THE MIXER STAGE

The mixer receives r.f. and local-oscillator voltages; it gets its own d.c. voltages from the power supply, and (in some sets) receives an a.g.c. voltage. A mixer circuit is shown in Fig. 9.8.

The function of the mixer is to heterodyne (or mix) the r.f. and local-

oscillator signals. The output of the mixer contains four main frequencies, one of which is selected by the tuned circuit of the following i.f. stage.

In Fig. 9.8, the r.f. 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 npn type, but despite that, the voltage on the emitter is higher (more positive) than that on the base. Part of this voltage on the emitter is 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.

Knowledge of this fact provides us with a simple test for oscillation. If the emitter voltage is measured, the reading should change if the oscillator stops working. If the local oscillator coil in Fig. 9.8 is
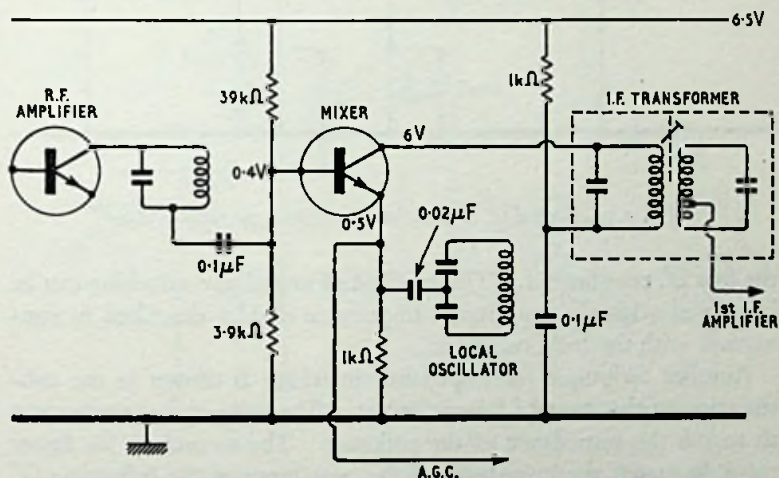
Fig. 9.8—The triode mixer receives a number of d.c. and signal voltages

short-circuited, therefore, and the emitter voltage does not change, that indicates that the oscillator was not working originally.

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

THE I.F. STAGES

As a general rule, transistor radios have at least one more i.f. stage than a portable or home transistor receiver, and certainly more than a valve set. This is to supply additional gain and selectivity, since transistors do not provide as much gain as the pentodes used in valve circuits.

A representative i.f. stage is shown in Fig. 9.9. Because the base is a low-impedance point, it is connected to a tap on the secondary of
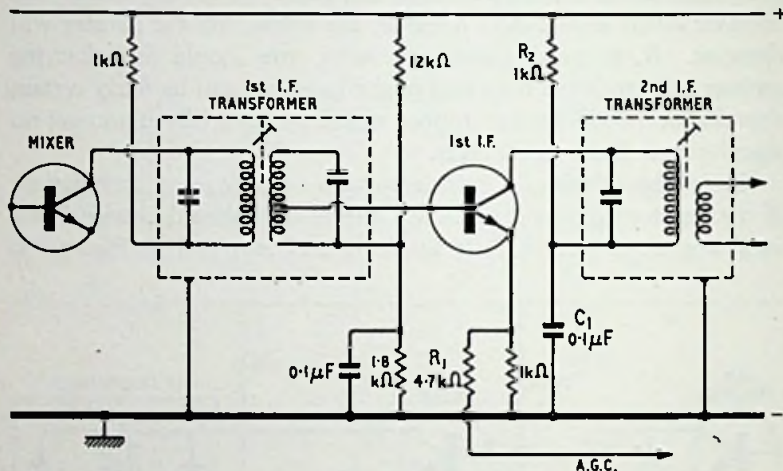
Fig. 9.9—Typical i.f. stage in an all-transistor car radio receiver

the first i.f. transformer. This method of impedance matching can be compared 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 i.f. 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 i.f. stage network. R_1 is part of the a.g.c. R_2 and C_1 form a decoupling unit inserted between the collector of the first i.f. stage and the battery.

THE DETECTOR

As you can see in going through this chapter, circuits used in car radios are similar to those examined previously in connection with portable

and home receivers. The detector is no exception. The only difference is that in all-transistor car 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 is not a fixed rule, however, and you may very well find car radios with diode detectors (like the one in Fig. 9.3) and an occasional portable set using a transistor for this purpose.

A typical detector circuit using a transistor is shown in Fig. 9.10. This circuit has a few unique features that were not discussed when detectors were studied previously. For example, the last i.f. transformer has three windings instead of the usual two. The primary couples the i.f. signal into the secondary, connected to the detector.
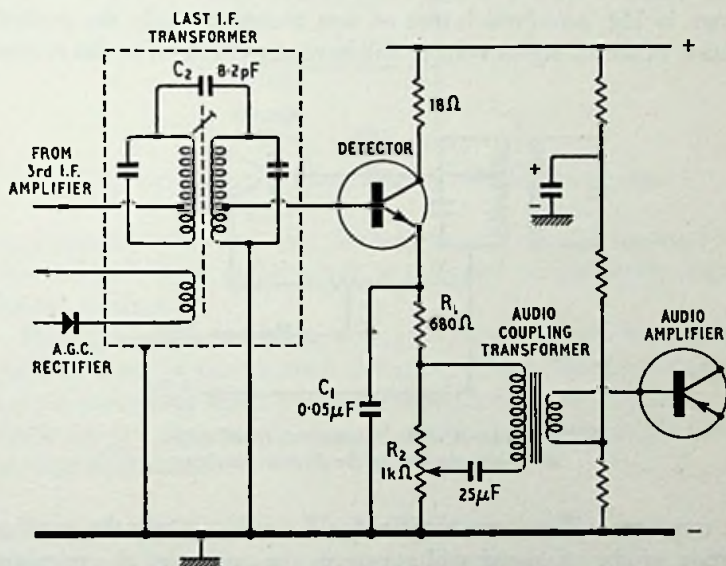
Fig. 9.10—Transistor detector. Note the use of a separate a.g.c. rectifier

At the same time, the primary winding is also coupled to a coil which is connected to a separate a.g.c. rectifier.

Examining Fig. 9.10 rather 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 apply this bias voltage on the base, collector current will be almost zero. Any bias developed across the emitter resistor R_1 would be of a negative character; that is to say, not forward-bias.

In other words, by not biasing the transistor we have reduced collector current to cut-off or almost to cut-off. But this is class B operation, which is exactly what is required in a detector.

The base of the detector is connected to the secondary of the i.f. transformer. On those half-cycles of the incoming signal that have 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. 9.10 (which uses an npn transistor), only the positive portion of the i.f. signal voltage will have any effect. For this reason,
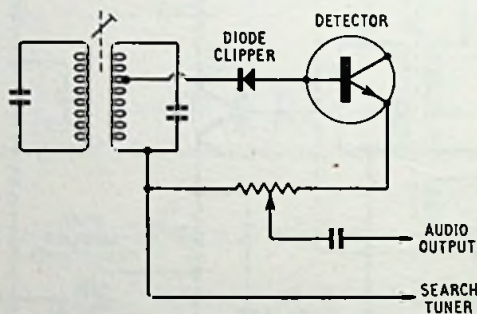
Fig. 9.11—A diode is sometimes connected in series with the base of the detector transistor

the transistor will act as a rectifier (or detector). Only the rectified portion of the i.f. signal will appear in the output of the transistor detector.

The output of the detector is in the base-emitter circuit. Capacitor C_1 acts as a by-pass for it. The volume control R_2 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 a resistance-capacitance arrangement, as already described for a home portable receiver.

In Fig. 9.10 and earlier drawings the i.f. transformer is surrounded by a dashed line which represents a screening can. All components inside the dashed lines are inside the shield can. The small capacitor C_1 connected between the primary and the secondary of the i.f. transformer is part of the bandpass tuning of the unit. Most i.f. transformers do not have this capacitor. When making a transformer
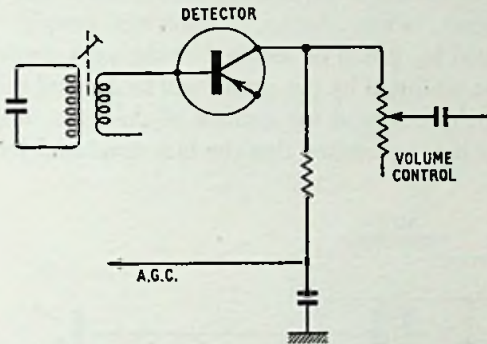
Fig. 9.12—Simple a.g.c. system used in some American car radios

replacement, make sure that the transformer has this capacitor if it was included in the original unit, as indicated on the circuit diagram for the receiver.

Sometimes, as shown in Fig. 9.11, a crystal diode is put in series with the base input of the transistor detector. This is usually included in car receivers using search tuners (described later in this chapter). The diode acts as a clipper, helps prevent mistuning, and provides a certain amount of isolation.

AUTOMATIC GAIN CONTROL (A.G.C.)

There is a variety of a.g.c. circuits used in car radios. Some of these are quite simple, as shown in Fig. 9.12, and simply consist of one or more resistors and capacitors fed back from the collector output of the transistor detector. In this arrangement, the a.g.c. set-up is almost the same as the type found in most valve a.c./d.c. radio sets.

A somewhat more complex arrangement is shown in Fig. 9.13. The i.f. signal is coupled into the detector, as usual, through the secondary of the i.f. transformer. However, there is another coil coupled to the primary of the i.f. transformer, and it is this coil which feeds the

13

signal voltage to a crystal diode which acts as the a.g.c. rectifier. The rectified a.g.c. voltage is then fed into a transistor working as an a.g.c. amplifier.

The a.g.c. 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 d.c. bias voltage. This means that the transistor has no forward-bias and so the collector current is extremely small. However, when the i.f. transformer couples some signal voltage into coil L_1, it will be rectified by the a.g.c. diode.

The voltage produced by this action will be d.c. and will appear as a bias between the base and the emitter of the a.g.c. amplifier. The a.g.c. rectifier is so connected that the bias developed by the rectifier
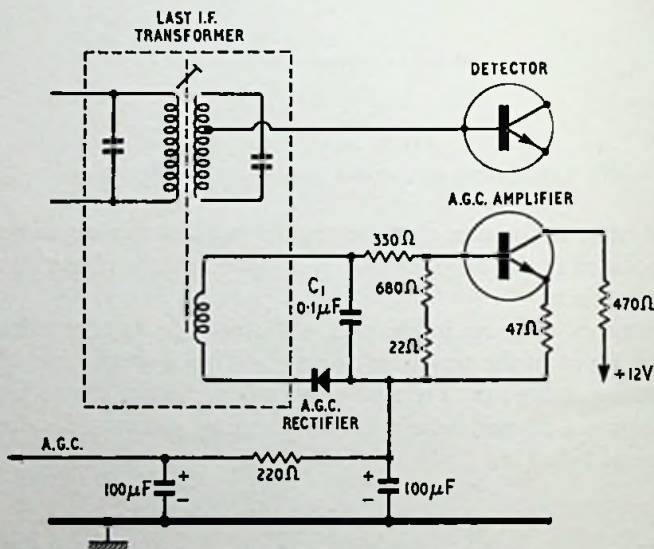
Fig. 9.13—Some American car radios use
a transistor as an a.g.c. amplifier

has the proper polarity. Capacitor C_1 is a filter unit, making certain that the output of the a.g.c. rectifier is smooth d.c. According to the point at which the circuit is connected to the chassis line, it can be made to give positive or negative a.g.c. bias to suit npn or pnp transistors, which in turn can go to base or emitter circuits.

A.G.C. DELAY

Sometimes a diode is used in series betwen the a.g.c. line and the r.f. amplifier transistor. The gain of the r.f. amplifier is important since it is multiplied by the gain of all the following stages. In other words, the r.f. amplifier is much more sensitive to a.g.c. voltage and the results of the application of a.g.c. to this transistor are more drastic than those
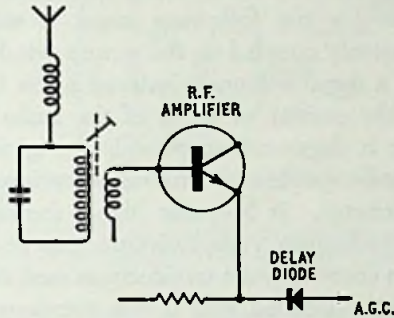
Fig. 9.14—A crystal diode is sometimes used in American car radios to delay the application of a.g.c. voltage to the r.f. amplifier

of the following stages. For this reason, it is advisable to delay or prevent the application of a.g.c. to the r.f. amplifier for weak signals but to permit it for strong signals.

A simple delay arrangement is shown in Fig. 9.14. It is just a diode connected between the a.g.c. line and the emitter input of the r.f. amplifier. The diode acts as an open circuit or very high resistance until the a.g.c. voltage reaches a certain point, produced by a moderately strong signal. When the a.g.c. voltage becomes strong enough, the delay diode becomes conductive, and high resistance of the diode suddenly becomes very low, connecting the emitter of the r.f. amplifier to the a.g.c. line.

AUDIO AMPLIFIER (DRIVER)

Most all-transistor car receivers use push–pull output. While it is true that portable transistor receivers also have push–pull output, many less expensive portables do not, and often hybrid car receivers do not. The output of the detector stage in a car radio, even though an amplifying transistor is used as the detector, is not enough to drive push-pull transistors. For this reason, car 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. 9.15. Resistor R_1, across the primary of the audio input transformer, helps to maintain stability and prevents ringing or oscillation. It lowers the Q of the transformer and helps broaden its pass band.

A feature of interest in the driver transformer (this is really the inter-stage transformer for the following stage) is winding L_1. This winding is inductively coupled to the output winding L_2. Because of the coupling, a signal voltage is induced across L_1. This voltage is injected into the emitter or input of the audio transistor. This fed-back voltage is degenerative, providing negative feedback and stabilizing the audio amplifier. The capacitor across L_2 is a simple form of tone corrector. It by-passes higher frequencies, giving the output a low-audio-frequency emphasis that many people find pleasant.

In the previous chapter, audio transformers used in home and portable receivers were discussed, and it was mentioned that these had either four or five leads. In the case of a car radio, however, at least one of the transformers (the one between the audio driver and the push-pull output) can have as many as seven leads.

AUDIO OUTPUT STAGE

The audio output stage is similar to those described for portable and home receivers (Fig. 9.16). There are a few differences, however. This stage uses a thermistor, described in an earlier chapter. The push-pull circuit operates two loudspeakers, one for the front of the car and one for the rear.

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 0·25–0·5 ampere. If a transistor car radio has a single power output transistor, it will most probably be class A operated. 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 car receivers are equipped with a bias adjustment control (Fig. 9.16). When replacing a power tran-
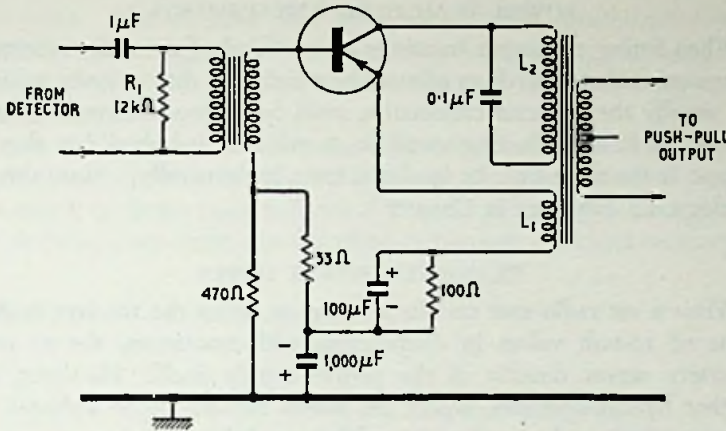
Fig. 9.15—Audio driver circuit with negative feedback used in some American car radios. The driver transformer is the one on the right
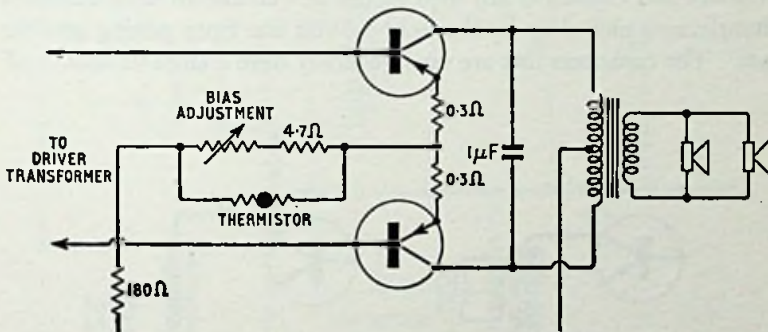
Fig. 9.16—Push–pull power output circuit using an output transformer and a thermistor

sistor, vary this resistor until the power stage draws the amount of idling (or quiescent) current recommended by the manufacturer.

LOUDSPEAKER COUPLING ARRANGEMENTS

There is a number of ways in which a transistor can be connected to the speech coil of a loudspeaker (Fig. 9.17). The most common technique is to use an output transformer. In some instances, however, a choke is used. This is called impedance coupling, or choke coupling. The loudspeaker is connected to a tap on the choke for better impedance matching. Finally, the speech coil can be connected directly in the emitter or collector circuit.

POWER TRANSISTOR REPLACEMENTS

When fitting an output transistor in any kind of car radio receiver, remember that it needs an efficient heat sink, and that its body, which is usually the collector connection, must be in good thermal contact with the heat-conducting metal on to which it is bolted, but that it must at the same time be insulated from it electrically. How this is achieved is explained in Chapter 7.

TRANSISTOR POWER SUPPLY

When a car radio uses transistors only, or when the receiver makes use of 12-volt valves in conjunction with transistors, the 12-volt battery serves directly as the power supply itself. However, in other hybrid receivers, where the valves require anode voltages in excess of 100, a d.c.-to-d.c. 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 electrical interference picked up by the 6- or 12-volt line from getting into the set. The capacitors that are used generally have a large value—15 μF

(a)   (b)

(c)
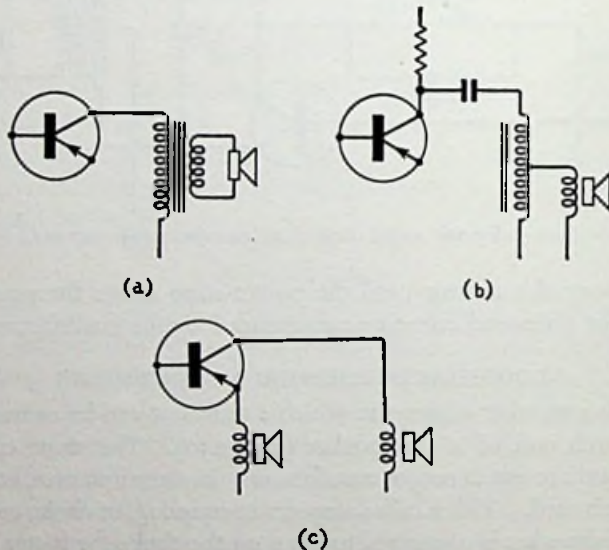
Fig. 9.17—Three methods of coupling a speaker to the output stage. That shown in (a) is the most common, (b) is rarely used, while (c) is a possibility being explored

or more.   One or more pilot lights are generally shunted across the
power line coming from the car battery.   Immediately preceding the
on/off switch, you may find a choke-capacitor filter, which operates
in the d.c. line.

For workshop use, both for car radio receivers and for all types of
transistor receivers, it is advisable to have a 12-volt d.c. source of supply
so that it is always ready to hand.   The best method of achieving this
is to instal a car battery as described in Fig. 7.9.   A cheap voltmeter
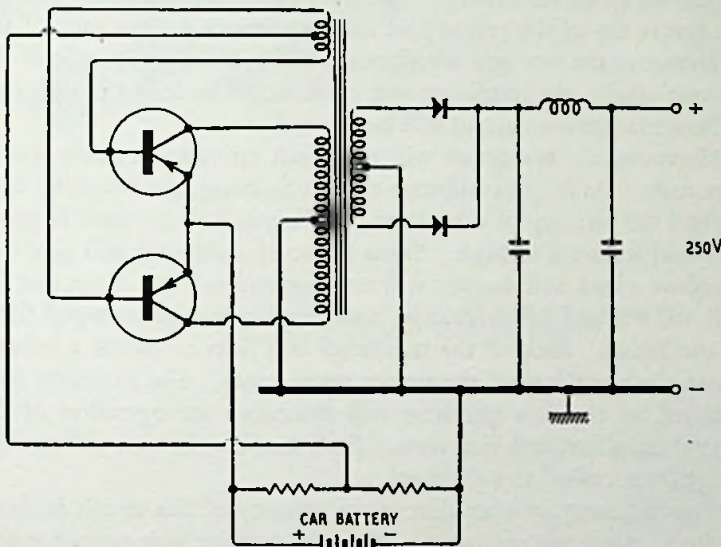
*Fig. 9.18—D.C.-to-d.c. converter changes 6-volt or 12-volt d.c. input to
250-volt d.c. output.   This arrangement is a substitute for a vibrator*

permanently connected across its output leads will confirm that it
is delivering current at the correct voltage, and it will be in circuit only
while the charging switch is off.

THE D.C.-TO-D.C. CONVERTER

As mentioned earlier, the d.c.-to-d.c. converter is found only in hybrid
car radios in which ordinary valves (those requiring anode voltages

of the order of 250) are used. Actually, the d.c.-to-d.c. converter behaves like a conventional vibrator power supply. However, it does not have any moving parts and so the noise and interference produced by a vibrator are conspicuously missing. This arrangement is not used in British receivers.

A representative American d.c.-to-d.c. converter is shown in Fig. 9.18. 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 transistor are tied together, and this common line is connected to the car battery. The return connection is made through the centre tap of the primary of the transformer. Since each of the collectors of the two pnp transistors 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. Some factor of unbalance will give one transistor a lead, and that one will reach saturation first. After that the pair will rise and fall alternately, resulting in a mutual push-pull form of oscillation. Each of the transistors will help to induce a voltage across the secondary of the power transformer. The magnetic field initiated by the first transistor will determine the operation of the second transistor, and vice versa. Each transistor in turn will run the range from cut-off to saturation.

The frequency of operation in the primary of this circuit is about 20 kc/s. Since we are using a full-wave rectifier, this operating frequency is doubled and so the ripple frequency is about 40 kc/s. As a consequence, smoothing components can be small and compact. For example, the filter capacitors may range anywhere from 0·5–1 μF, while the choke can be an air-wound coil having an inductance of about 100 mH. The voltage produced by this arrangement is about 250 volts d.c., suitable for typical valves. We can now see how the term d.c.-to-d.c. converter is obtained. The input is d.c. and so is the output.

REDUCING INTERFERENCE

There are two types of interference which can hinder the operation of the car radio. One of these comes from within the receiver itself
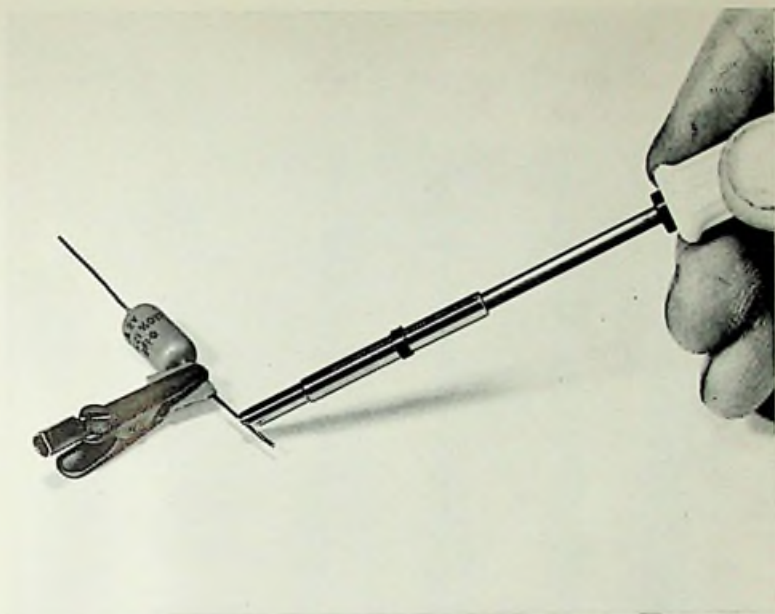
Plate 11. A piece of damp cloth held in a crocodile clip can serve as a thermal shunt in place of the more professional shunt shown below
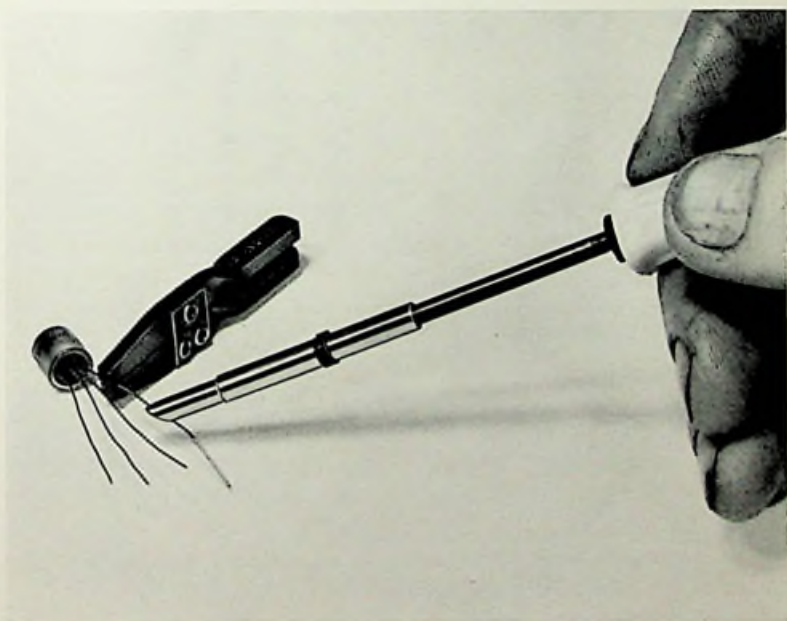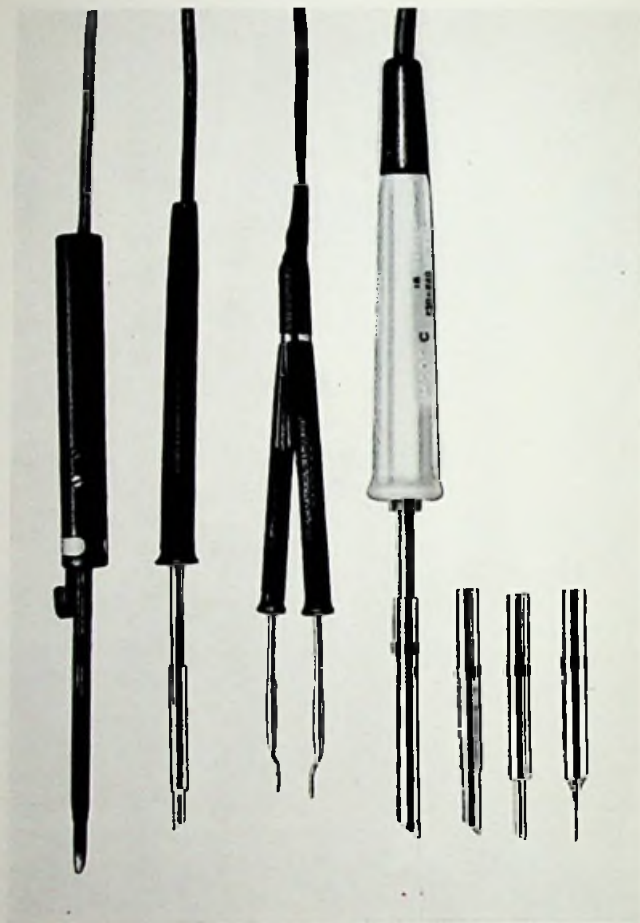
Plate 12. A selection of lightweight soldering irons. Top to bottom: Litesold; Oryx; Oryx with "tweezers" or caliper bits; A.N.T.E.X. with four interchangeable bits
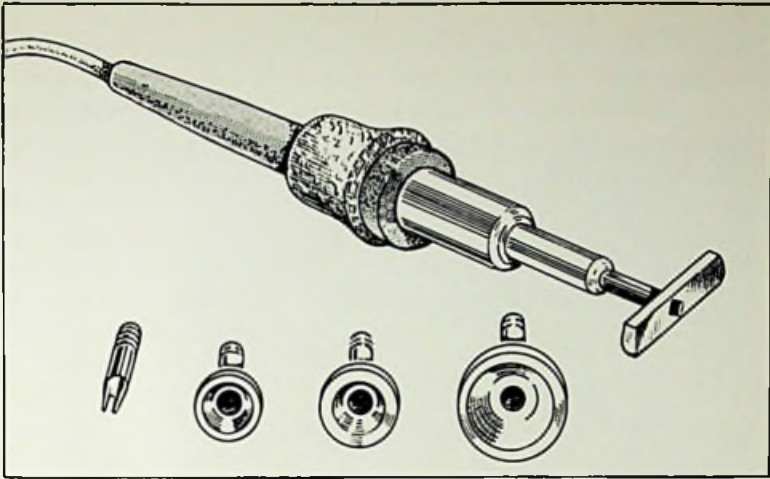
Plate 13. Interchangeable tips, or bits, have been marketed in America for unsoldering multi-tag components from printed circuit boards

Plate 14. Miniature transformers and an oscillator coil by Plessey, G.E.C. and Perdio. They are attached to the printed circuit board by terminal tags or small metal tags on their screening cans
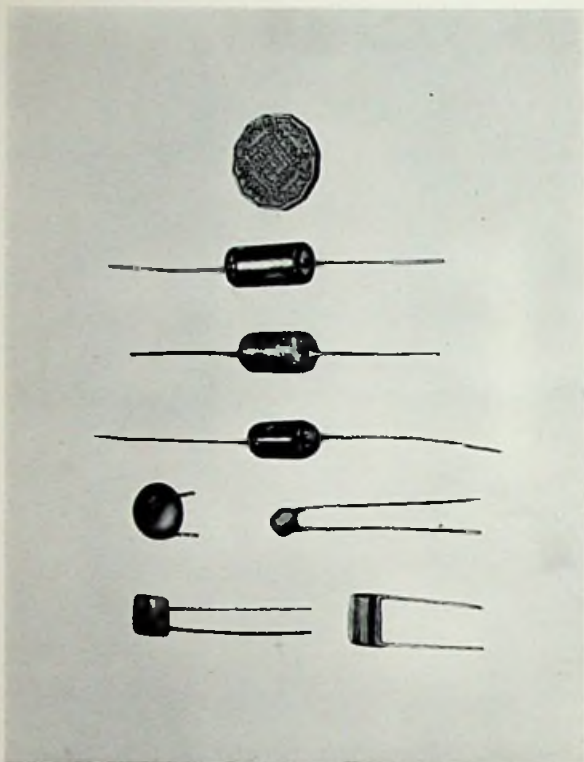
Plate 15. A group of fixed capacitors compared with a threepenny piece

and is due to a moving mechanical rectifier such as the vibrator. In the transistor car radio this has been eliminated. The other source of interference comes from the engine and equipment of the car.

Interference to a car 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 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 engine is varied. 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, and by putting a capacitor of $0\cdot1-1$ μF across the armature of the generator. This last should be done as a routine measure anyway.

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 no provision is made for a suppressor capacitor. In such instances, it may not be possible to mount the suppressor on the generator. In this case, some ingenuity is required and you may also have to run an earth lead from the capacitor to the frame of the car. When using the generator as an earth return, make sure that the earth terminal of the capacitor makes good contact. If there is any paint, oil or dirt near where the capacitor is to be mounted, scrape this away to make sure that the earth connection is a good one. If it is not you might just as well not mount the capacitor in the first place.

In severe conditions where the commutator segments are badly worn or the brush holders or brushes cannot be dealt with, it may be necessary to replace the generator. Sometimes, connecting a choke in series with the lead coming from the armature terminal (terminal marked A on the generator) will help to reduce generator whine. This choke has to be the same type as that used in the d.c. line 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 car is stationary, but there is a sound like rapid firing when it is in motion, this is due to a constant build-up and discharge of voltage by the wheels and is called tyre static. This, however, can be cured in several ways. Static–collector springs can be installed, mounted on the axle locknut, thus making contact between the axle and the dust cap. Another technique is to
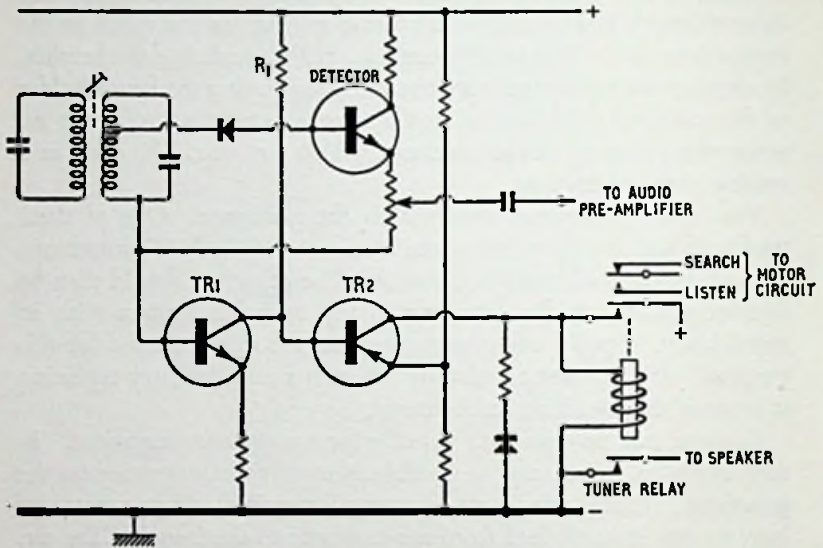
Fig. 9.19—*Automatic tuner or search system. The unit uses a pair of directly-coupled transistors, one npn and the other pnp*

inject graphite powder into the inner tube of the tyre, or you can buy a complete set of static eliminators consisting of powder and springs, available commercially in America.

A common method for eliminating ignition noise is to use a suppressor resistor connected between the distributor and the ignition coil, as close 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 one will not affect engine performance but in some modern cars the distributor is not easily accessible so there may be some difficulty in using this technique. All new British cars are fitted with them by law.

The single distributor resistive suppressor is very effective in sup-

pressing television interference, but when suppressing ignition for a car-borne radio receiver the most effective method is to fit a resistor to the top of each sparking plug, and special resistors are made for this purpose.

Sometimes interference is picked up by the battery cable coming from the dashboard to the d.c. input at the receiver. In some cars this lead is fairly long and, even though there are filter capacitors hanging from this line, and chokes in series with it, the spark pick-up is enough to get past these suppressors. In such cases, put this lead into a metal conduit, turn the receiver on and then, with a wire, probe the most logical point at which to earth the conduit. You will generally find that there is one point at which earthing 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 contact.

If the noise refuses to yield to any of these measures, it may be necessary to replace the sparking 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 sparking 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 gauges.

AUTOMATIC (SEARCH) TUNERS

The automatic tuner, which is also known as the search tuner, is not new but has already been used in conjunction with valve type car radios. However, the search tuner, as shown in Fig. 9.19, 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 TR_1, is called a trigger amplifier, and it 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 (R_1) 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 TR2, 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 signal strength of the station.

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 cut-off. 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 loudspeaker were permitted to remain connected during this operation, the transition from one station to the next would be a very noisy process. To avoid this the loudspeaker is automatically disconnected but is turned on again by the relay when the search-tuner motor is stopped 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.

Alignment and Measurements

MANY of the servicing techniques and practically all test instruments normally used in working with valve receivers can also be employed for transistor radios. However, as was mentioned earlier, a transistor receiver is not simply a valve receiver in which transistors have been substituted. Very low voltages are used with transistors and so a small shift in voltage, unimportant in a valve receiver, means the difference between working or not working for a transistor receiver. Screwdriver mechanics will not get very far with service work, and we must use a few of the more regular servicing procedures. Taking chances with the underchassis section of a transistor receiver can be an expensive practice, resulting in the loss of costly transistors.

The first thing to do with any radio receiver, whether it uses valves or transistors or both, is to give it a cursory visual examination. Sometimes just an examination of the wiring or the printed-circuit board will reveal the fault. Do not take for granted, if a receiver stops working, 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 piece of conducting element on a printed-circuit board coming apart. (Faults in printed-circuit boards are covered in the next chapter.)

SIGNAL GENERATOR

The signal generator should be capable of covering the broadcast band, the range of i.f.s of home and portable receivers and car radios. It should also be able to provide an audio singal.

There are several ways of coupling a signal generator to the receiver for alignment or tests. You can put a small capacitor (generally
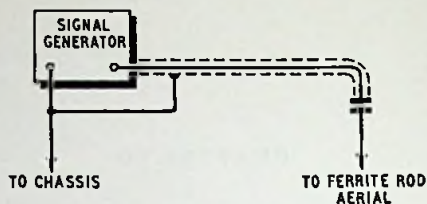
Fig. 10.1—The signal generator can be connected to the receiver input through a small coupling capacitor. Some service engineers simply clip the lead close to the aerial rod, but no actual physical connection is made. Keep signal generator level as low as possible
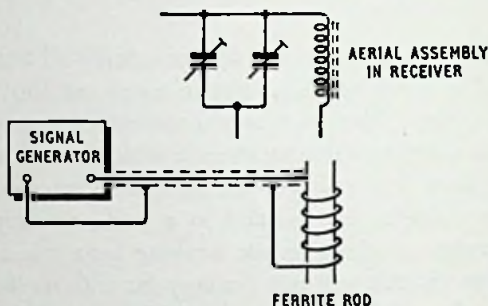
Fig. 10.2—You can use a home-made coil to couple the r.f. signal into the receiver. A spare ferrite rod aerial will do the job very nicely

300 μμF or less) (Fig. 10.1) in series with the live lead of the signal generator, or you can use a small loop of wire, as shown in Fig. 10.2, to act as a coupling coil. The loop can be about a dozen turns or more of insulated wire, either enamelled or cotton-covered. This coil can then be brought close enough to the ferrite aerial in the receiver to permit signal pick-up.

Keep the coupling between the signal generator and the receiver fairly loose, since the generator must not overload the receiver. If this happens, either the receiver will be unstable or the overloading effect will detune it. Nevertheless, transistor receivers are not as sensitive as valve sets.

Transistors, even more than valves, 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 earth connection

between the generator case and the receiver chassis is always helpful (Fig. 10.3). A good practice is to run a heavy clip lead between a contact on the generator and a contact on the chassis being serviced, in addition to the usual earth connection which is part of the test leads.

VOLTMETERS

Most valve voltmeters have input impedances ranging from about 11–25 megohms. The instrument should have a low-voltage scale—preferably as low as 1 volt on full-scale deflection.

Most technicians have an isolation probe (also known as a d.c. probe) as part of the valve voltmeter. The probe (Fig. 10.4) consists of a 1-megohm resistor located inside the probe housing. The probe resistance is counted as part of the input resistance of the valve voltmeter. Thus, if the 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 d.c. voltage measurements if maximum isolation between the receiver and the instrument is required. Also, the meter will have been calibrated for use with the probe. Thus, if it is not used, the readings will be incorrect.
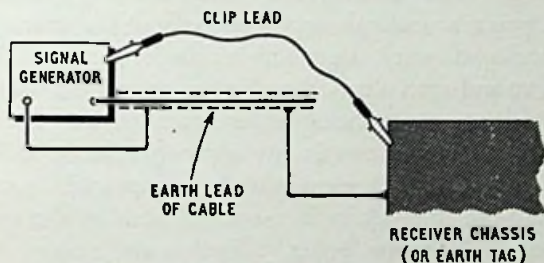
Fig. 10.3—Make sure that the receiver and signal generator have a common " earth " —that is, the chassis or metal frame of the generator is connected to the receiver chassis. Use a wire with crocodile clips at both ends. Connect one end to any metal screw on the generator, other end to chassis of receiver. It is advisable that the generator should have an isolating transformer from the mains
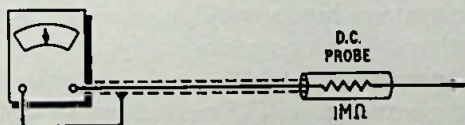
Fig. 10.4—The d.c. probe contains a 1-megohm resistor. This is part of the input resistance of the instrument

D.C. voltage measurements in transistor receivers are quite low, but care is still necessary to avoid damage from excess voltage. For example, when measuring between base and emitter, only a fraction of a volt is being checked and the 1-volt scale of the instrument will probably be used. If you then decide to make a battery test (assuming

SET TO READ
D.C. VOLTS

SET TO 10V
THEN SWITCH
TO 1V
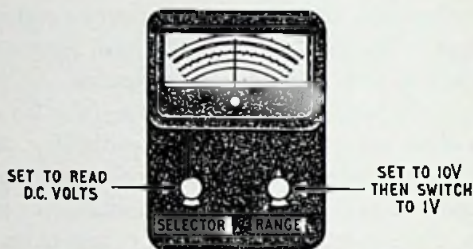
SELECTOR   RANGE

Fig. 10.5—When measuring d.c. volts, first set the selector switch to the d.c. volts position. Turn the range selector to the position for 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

a 9-volt supply) and you forget to change the range selector on the voltmeter, you may easily damage the needle of the meter (Fig. 10.5).

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

These two instruments, the signal generator and the valve voltmeter, are fundamental instruments in any service workshop and are practically indispensable. There are other instruments which are desirable because they are time-savers in servicing, such as the oscilloscope, signal tracer, substitution boxes (capacitor and resistor types) and substitute speaker.

BENCH STORAGE BATTERY

There is one piece of test apparatus that will be very helpful for transistor radios and which is not ordinarily used for valve receivers. This is a 12-volt storage battery which is required if you are going to service car receivers. Most car radios are hybrid types, using 12-volt valves (that is, approximately 12 volts on the anode) and using a power transistor for the output stage. These receivers are designed to work from a 12-volt accumulator.

A good servicing technique is to bring leads from the storage

battery up to a panel on the servicing bench so that either 12 volts or fractions of it can be tapped off. Remember, however, that storage batteries can give off corrosive fumes, so the place for the battery is not as a foot rest under the bench. The best way to make sure that the battery will have a long life is to put a trickle charger across it (as shown in Fig. 7.9) 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, which means absolutely nothing.

Some technicians prefer using low-voltage mains-operated power supplies in place of the storage battery. There is nothing wrong in this, but 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 in car receivers.

There are a few other considerations to remember. If you are used to servicing valve sets, you know that certain voltages are critical, others are less so. A difference in anode voltage of, say, 15 or 20 volts will not generally affect the operation of the set very much. But in a transistor receiver voltages are low, hence a very small change in voltage may mean a large percentage difference. If a receiver needs 9 volts to operate, a 30 per cent. drop would be 2·7 volts. Subtracting this from 9 volts gives 6·3 volts which would be about the bottom limit at which you could expect the set to work. This means that you should have a voltmeter with an easy-to-read scale shunted across the output of the low-voltage supply so that you can see what voltage you are actually getting.

If you do decide that you would prefer using a mains-powered 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 as possible pure d.c.. Also, do not use a transformerless supply but get a transformer type so that there is adequate isolation from the power line. Take care that the resistance of the smoothing components is kept low, so that the terminal voltage does not vary with the amount of current drawn.

Remember that the electrolytic filter capacitors in such supplies will not remain good forever. Every now and then, connect the output of the supply to the input of the scope and note if the ripple voltage is normal or if it has increased since the last test.

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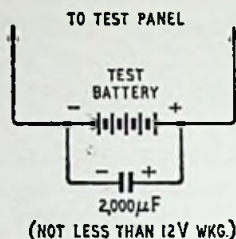
Fig. 10.6—A high value of capacitance shunted across the test storage battery keeps the overall impedance low

Now as the storage battery is used or as it gets older, its internal resistance increases. This internal resistance (or impedance) can affect readings. 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.

This can be avoided by shunting the battery with a low-voltage, high-value capacitor as shown in Fig. 10.6. The capacitor should be about 2,000 μF and have a working rating of at least 12 volts d.c. The plus side of the capacitor is connected to the plus terminal of the battery. This capacitor need not be disconnected when charging the battery but be sure that the peak ripple voltage of the charger does not exceed the working voltage rating of the capacitor.

When a receiver uses Leclanché cells, discard them when they have
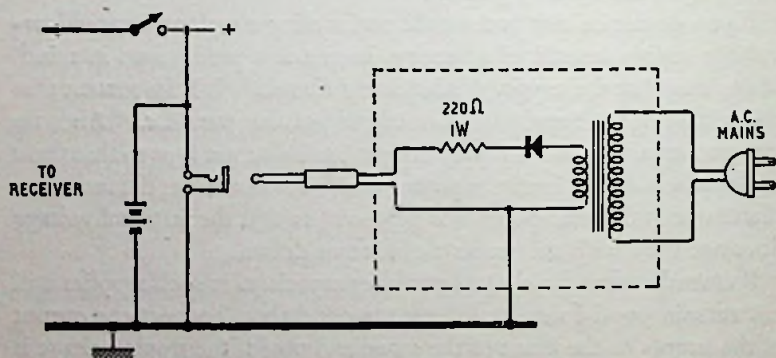
Fig. 10.7—Charging unit for use in receivers having nickel–cadmium batteries

served their purpose. Attempts may be made to recharge such cells, but they are not 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. 10.7, with a rating of 2·5–3 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 a.c. power supply.
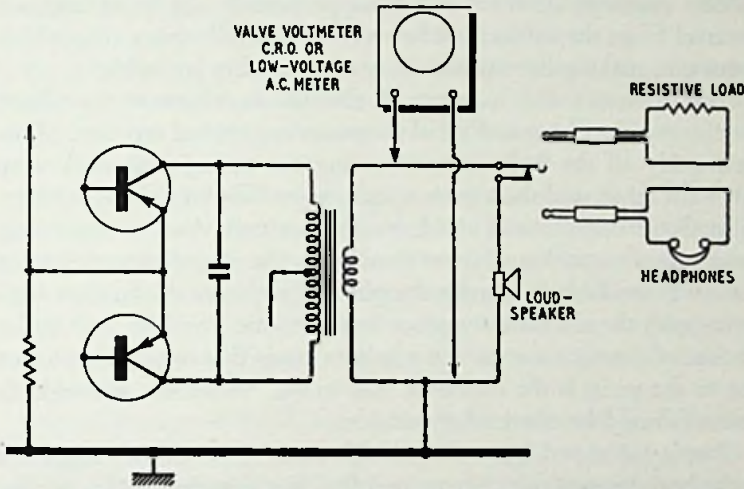
Fig. 10.8—Five types of indicators that can be used during alignment: speaker, headphones, meter, oscilloscope or low-voltage a.c. meter

The charger shown in Fig. 10.7 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, some sort of output indicator is needed to show 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. 10.8). You can use the loudspeaker in the receiver itself, and if the set is provided with an earphone socket you could plug in an earpiece or a pair of headphones; alternatively an output meter, an oscilloscope or a valve voltmeter may be connected across the speech coil leads. A plug with the load resistor connected

can be inserted in the 'phone jack if one is provided, to silence the internal speaker.

Of these indicators, the loudspeaker is the least sensitive. The meter or scope is 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. They also enable you to use a very low signal level.

Most receivers of the transistor type permit alignment without removal from the cabinet. The receiver generally has a case which opens out, making the various adjustments readily accessible.

Plate 6 shows the location of the i.f. transformers, oscillator transformer, oscillator and aerial trimmers in a typical receiver. Unfortunately all the little cans containing the tuning coils look very much the same, and there is no simple way of distinguishing between an oscillator coil unit and an i.f. transformer unit, short of examining the connections, unless a layout drawing in the manufacturer's service manual is available. Usually the physical sequence of the cans conforms with the electrical sequence in the circuit, however, and in the absence of a service manual it is a help to know that usually the nearest one to the aerial is the oscillator, and so on. However, the maker's manual should be obtained if possible.

Couple the signal generator, using one of the methods suggested at the beginning of this chapter, and feed in a suitable signal. Set the receiver volume control to maximum. The signal generator modulation control should be turned on—that is, the r.f. signal coming out of the signal generator should be modulated by the audio tone. If you use an output meter across the speech 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 loudspeaker 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 the attenuator on the signal generator has been set for maximum output, then it is possible that the i.f. section of the receiver needs realignment (assuming, of course, that there is no receiver defect).

Set the signal generator to the appropriate frequency (commonly 470 kc/s), with the modulation turned on. Rotate the tuning dial of the receiver to the high-frequency end (about 200 m) on the M.W.

band.   Starting at the output i.f. transformer, adjust the cores and, in turn, the interstage and input i.f. transformers, similarly.   As the volume increases, adjust the attenuator of the signal generator 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, a.g.c. will be either very weak or completely absent, thus permitting the receiver to be operated in its most sensitive condition.   When aligning the receiver, it is always best to use the battery in the receiver as the power supply.   That is, you should not use external batteries that do not form part of the receiver proper.   If you do, some of the settings may be upset by the presence of the battery when it is subsequently inserted.

After the i.f.s have been aligned, repeat the procedure, since the adjustment of one i.f. stage will often affect the adjustment of the preceding or adjacent stage.   After the i.f. stages have been aligned the frequency setting of the signal generator and the receiver will need to be adjusted for the " front end " alignment.   The coupling loop or coupling capacitor from the generator to the receiver need not be disturbed.

If the alignment of the i.f. section has produced a condition in which the signal is extremely loud, make the coupling between the generator and the receiver much looser.   Just move the coupling coil away from the aerial of the receiver.   Set the signal generator at approximately 600 kc/s (500 m) and tune the receiver to the same frequency.

The local oscillator of the receiver will probably have a core adjustment, and this should be adjusted for maximum volume while simultaneously rocking the tuning control slightly back and forth around this frequency.   After obtaining maximum volume, set the signal generator and the receiver to the high-frequency end of the scale, generally around 1,500 kc/s.   Having identified the oscillator and aerial trimmer capacitors, adjust them for maximum volume.

It is preferable that there should be no direct connection to the receiver while the aerial trimmer is being adjusted, unless it is to an external aerial socket.   If the coupling coil method is not being used, the signal generator lead may be clipped on to some non-conductor near the ferrite rod aerial.   If adjustment is made to the ferrite aerial coil itself, this is usually done by sliding the coil along the ferrite rod. Care should be used in freeing the coil, and it should be cemented in

position again afterwards with a touch of cellulose on the end of the former. The coil should be adjusted only when the manufacturer's instructions say so, and this might be at either end of the waveband. It is always preferable that it should not be disturbed at all.

It is generally desirable to repeat this procedure at least twice, working back and forth between the low- and high-frequency ends of the tuning scale to get the best tracking. If the receiver is provided with a L.W. band, the trimmers of this band should be adjusted afterwards, but they are usually very simple, comprising one oscillator and one aerial trimmer. These are adjusted at about 1,500 m (200 kc/s).

In many small transistor portables there is a fixed L.W. station which is tuned in by a pre-set trimmer. The trimmer is then adjusted to receive the BBC L.W. Light Programme while the receiver is switched to L.W. after the rest of the alignment procedure has been completed.

Now let us go over the alignment once again, but this time step-by-step.

1. Loosely couple the signal generator to the ferrite aerial of the receiver, by one of the methods described earlier. If via the cable and series capacitor, connect it to the insulation on a lead on the tuning capacitor (r.f. section). Set the r.f. signal generator to the intermediate frequency of the receiver. Rotate the tuning capacitor until it is completely unmeshed (open). Connect the valve voltmeter (set to read 1 volt a.c. full-scale deflection) across the speech coil of the loudspeaker. Do not disconnect the loudspeaker leads. Set the volume control to maximum.

2. Turn the receiver on. Switch the modulation control of the signal generator to the *on* position and set the attenuator control on the signal generator for small signal output. Carefully and slowly rock the signal generator cursor back and forth and you should hear a tone from the loudspeaker, and the meter needle of the valve voltmeter should give some indication. If the signal is too loud, reduce the strength of the signal (rotate the signal generator attenuator for less output or move the coupling coil farther from the receiver).

3. Examine the signal generator tuning dial and make sure that the pointer is set exactly on the intermediate frequency of the receiver. Re-adjust it if necessary even though the receiver output sounds much louder at some other frequency, provided that you know you have the correct one.

4. Starting with the last i.f. transformer (the one feeding the detector), adjust the cores or trimmers for maximum signal output. Then adjust the second i.f. transformer and finally the first i.f. transformer. After completing this job, go back and adjust the i.f. transformers once again (and in the same order) until the output cannot be improved or increased. (If the valve voltmeter reads more than about 0·5 volt, the generator output is too high; see Fig. 10.9.)

5. Note that the a.g.c. line has not been suppressed, although this procedure is quite common in the alignment of valve receivers.
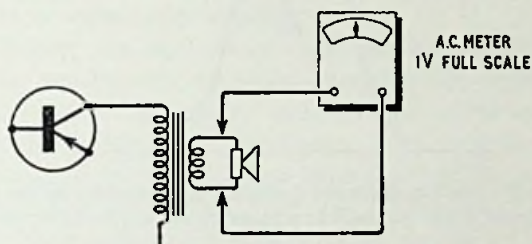
Fig. 10.9—*The maximum reading on the output meter should be about 0·5 volt. If it is more than this, your generator output is too high or one of the stages in the receiver (such as an i.f.) is oscillating*

This is the reason why it is necessary to keep the signal generator output very low; otherwise the i.f.s may tune very broadly and it will be difficult to find the peak point. Actually the best reading depends on the output circuit impedance, but 0·5 volt is a very common value. It is important to work with the lowest reading that can be used, and this may be even lower than 0·5 volt. With high-impedance speech coil circuits it may have to be higher.

6. In aligning the i.f.s, note that some transformers will give a double peak. This means that, as the adjustment screw or core is turned, the output meter will reach a peak, dip and then reach a second peak. The higher of the two peaks is the correct one (Fig. 10.10). This completes the i.f. alignment.

7. Set the receiver tuning scale to a high-frequency point such as 1,500 kc/s and adjust the signal generator to this frequency, with the modulation turned on. The valve voltmeter should remain

connected across the speech coil. Use minimum generator signal and keep the volume control of the receiver at maximum. Now adjust the oscillator trimmer, then aerial trimmer, until maximum output is shown on the voltmeter.

8. Set the receiver and the signal generator to 600 kc/s. Adjust the oscillator core for maximum signal output as shown on the
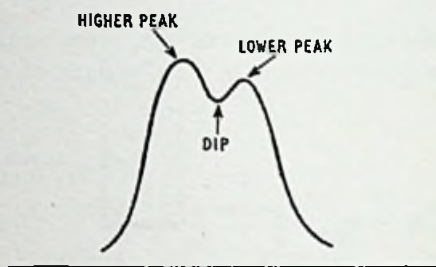
Fig. 10.10—If a double peak like this is obtained when adjusting the core of an i.f. transformer, higher gain will be achieved by selecting the higher peak

valve voltmeter. Rock the variable capacitor in the receiver back and forth on each side of 600 kc/s while adjusting the oscillator tuning core for maximum output.

9. Set the receiver and signal generator to 1,500 kc/s as described in step 7 and carefully re-adjust the oscillator trimmer. If the output cannot be increased (as indicated by the valve voltmeter) at this time, the receiver may be assumed to be aligned. If, however, an adjustment of the oscillator trimmer does increase the output, repeat steps 7, 8 and 9. It may be necessary to repeat this procedure a number of times.

It is important that the i.f. circuits are adjusted before the r.f. ones, and whereas the latter may be subsequently re-adjusted without re-adjustment of the others, the reverse should never be carried out.

There may be trouble with alignment if the first (frequency-changer) transistor has to be replaced. In some cases, the receiver will not operate at the low end of the band, due to the fact that the transistor has changed the range of the ferrite aerial in the receiver to such an extent that the tuned circuit no longer covers the broadcast band. If this does happen, another transistor can be tried until one is found that

more nearly duplicates the characteristics of the original one. Or if the ferrite aerial has an adjustable core, turn the core so that less of it is in the coil—that is, move it out of or away from the coil, or move the coil along it.

As a general rule, the inductance of the coil will need to be reduced, and pulling the iron core out will do this. After making such an adjustment, ensure that the receiver covers the entire band by tuning in stations at the bottom and top ends. If the ferrite aerial is the type that has a fixed core, it is necessary to remove turns until the stations at the bottom end (low-frequency end) of the broadcast band fall into place. This kind of difficulty is unlikely to arise with British receivers if the correct type of replacement transistor is used.

You will note that two sets of alignment instructions have been given. The step-by-step procedure does not fully agree with the earlier explanation of alignment. Similarly differences will be found in manufacturer's alignment instructions. In all instances it is best to follow the manufacturer's procedure when it is available in preference to the general instructions given here. In the absence of the maker's instructions the step-by-step procedure can be used since it is fairly well detailed.

ALIGNING THE CAR RADIO

The alignment procedure for car radio is very much the same as that for a home or portable receiver. However, the car radio receiver calls for a few special precautions.

While alignment instructions will be the same as those already outlined, remember that car radios have a radio-frequency amplifier preceding the converter. The amplifier cores 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 1,000 kc/s (300 m). If the aerial is of the telescoping type, extend it as far as it will go and then adjust the aerial trimmer until the station signal is at a maximum.

No special instruments are needed for car receivers. You can use a signal generator and valve voltmeter just as for ordinary portable sets. There is one other precaution, however. Because car radios have an r.f. amplifier stage, their overall gain and sensitivity are much higher than for ordinary receivers. For this reason, the coupling between the

signal generator and the receiver must be much looser. Otherwise the receiver may be overloaded or alignment difficult.

If you find that you cannot cut down on the gain of the 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 car receivers, be sure to take the loudspeaker along with the set. Do not forget to plug the loudspeaker leads into the l.s. sockets when testing the set. In other words, do not operate the set without its loudspeaker.

IN OR OUT OF THE SET?

Transistor receivers are so constructed that they can be aligned without taking the receiver out of its case. Do not remove the set from the
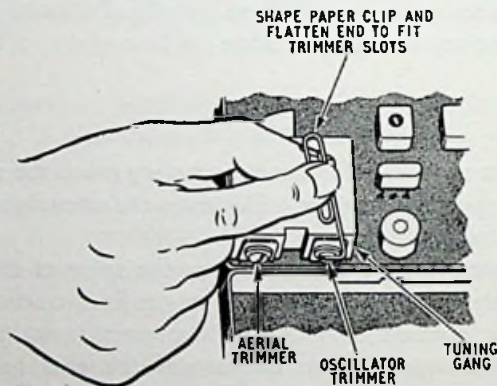
Fig. 10.11—Provided that the adjustment head is metallic a paper clip with a flattened end can be used as a trimming tool

case unless, for some reason, there is no alternative. 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 its cabinet does not behave as though it is aligned when it has been put back in again.

There may be cases where you need a special tool. For example,

even your smallest screwdriver may not be small enough to reach the core adjustment in some of the very small tuning coils; or the adjustment head, whether it be a core or a capacitor screw, may be inaccessible with a straight-bladed tool.

The answer in the first case is simply to shape up a short length of small-diameter rod of insulating material (a knitting needle of the correct gauge to fit the coil former is the simplest solution), carefully filing the end to obtain an accurate fit in the slot in the adjustment head.

In the second case, where the adjustment head is inaccessible with a straight tool, the end of the blade can be turned at an angle to reach the head. When the presence of metal is permissible without affecting the setting, a small strip of metal can be bent to the required shape, or at a pinch, where a very small adjustment head is encountered, a suitable tool can be formed with an ordinary paper clip, as shown in Fig. 10.11. When metal cannot be used, as for instance in a coil core, a right-angle bend can easily be made in a plastics knitting needle if softened in a jet of steam from a boiling kettle. The end can be cut and filed to shape afterwards.

SERVICING PRECAUTIONS

There are a few precautions to follow in servicing or aligning transistor receivers. Do not if you can help it use test instruments which are a.c./d.c. 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 the bench, or away from it. (This refers to mains isolating transformers connected between the instrument and the power supply line.) Transistorized test instruments are the best ones to use with transistor receivers.

Be very careful not to earth the base lead of any transistor, since this can result 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 the signal generator, always make sure that the attenuator control is so set that minimum signal comes out of the generator. If you do not want to be bothered using the series capacitor or loop

mentioned earlier, then clip the live lead (that is, the crocodile clip) to any nearby component sleeve and you will get enough leakage signal in the aerial of the receiver. Alternatively it may be clipped on to any piece 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. The battery should preferably be new, and proper alignment may not be possible if battery voltage has dropped much more than 20 per cent. below normal.

MEASUREMENT OF LOCAL-OSCILLATOR VOLTAGE

In valve receivers, local-oscillator voltage can be measured by connecting a valve voltmeter across the oscillator grid leak. This cannot be done in a transistor receiver but a similar check can be made by measuring the d.c. voltage across the emitter resistor, where a change of voltage should be seen upon stopping oscillation, say by short-circuiting the reaction coil.

Another check can be made by using an oscilloscope connected between the base of the frequency-changer transistor and the chassis. A calibrated oscilloscope 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 core. As a general rule, when the receiver is tuned to 1,500 kc/s, there should be approximately 0·5 volt peak-to-peak.

REGENERATION

The process of alignment increases the sensitivity of the receiver, and it is possible for the i.f. stages to break into oscillation after alignment has been completed. If such is the case, a small amount of mis-alignment may cure the trouble. If not, it may be necessary to check any feedback resistors or capacitors that may be present in the receiver, so as to make sure that the decoupling is efficient. Detuning to avoid instability is " bodging " a job.

TRANSISTOR BASE CONNECTIONS

Transistors come in quite a variety of packages (this is a name for the case around the body of the transistor). Here are a few techniques for identifying the leads of a transistor, depending upon the type and the manufacturer. One type, shown in Fig. 10.12(a), has what is known
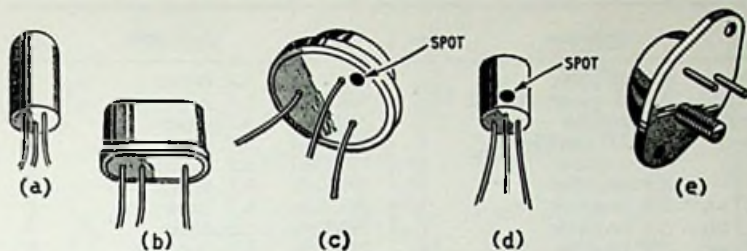
Fig. 10.12—These drawings represent some examples of transistor pin arrangements, but others are also used

as an asymmetrical pin arrangement, which is the commonest. The centre pin is the base lead. The pin closer to the centre pin is the emitter and the remaining pin is the collector lead. Another view of an asymmetrical pin arrangement is shown in Fig. 10.12(b).

From the sketch at (b) it can be seen that this type of transistor has a flat-sided case, giving the underside an elongated form that becomes lozenge-shaped if the ends are rounded, as they often are. The same asymmetrical arrangement of lead-out wires is sometimes used with a circular case. If a fourth lead is present it will be a shield or screen lead, which should be earthed, and it will be situated between the base and collector leads, usually closer to the latter.

Another circular shape is shown at Fig. 10.12(c) in which the three (or four) leads are disposed at equal intervals round a circle. The only identifying mark is a spot of paint beside the collector lead. There is no safe method of identifying the other two (or three) leads apart from measurement except by reference to the maker's data sheets, because in one type the sequence is clockwise, and in the other it is anti-clockwise. Always, however, irrespective of the shape or type, it may be taken that if there is a spot mark it is there to identify the collector. Another case of this type is illustrated at Fig. 10.12(d).

A typical power transistor arrangement is shown in Fig. 10.12(e). The shell of the transistor is the collector connection. Holding the transistor so that the ends of the pins face you, with the large fixing bolt away from you, the emitter pin will usually be the one to the left, but it varies. It can be confirmed from the diagrams in Fig. 10.13.

A number of commonly used transistors is shown in Plate 2, with a few power transistors. Table 10.1 shows the base connections of a fairly wide and representative range of British domestic transistors.

TABLE 10.1—Transistor types and connections.   (The letters refer to Fig. 10.13.)

Type	Application	Base	Type	Application	Base
AF114	R.F. amplifier	C	NKT252	A.F. driver	A
AF115	R.F. frequency changer	C	NKT253	A.F. output	A
AF116	I.F. amplifier	C	NKT254	A.F. driver	A
AF117	R.F./I.F. amplifier	C	NKT255	A.F. amplifier	A
GET3	A.F. amplifier	H	NKT261	A.F. output	F
GET6	A.F. amplifier	H	NKT262	A.F. driver	F
GET102	A.F. amplifier	G	NKT263	A.F. output	F
GET103	A.F. amplifier	G	NKT264	A.F. driver	F
GET106	A.F. amplifier	G	NKT265	A.F. amplifier	F
GET113	A.F. amplifier	G	NKT401, 402 Relay driver		B
GET114	A.F. amplifier	G	NKT451	A.F. output	B
GET115	A.F. output	G	NKT452	A.F. output	B
GET116	A.F. output	G	NKT453	A.F. output	B
GET571	A.F. output	B	NKT454	TV line output trans.	B
GET572	A.F. output	B	V6/2R	I.F. amplifier	A
GET691	R.F. amplifier	G	V6/4R	R.F. frequency changer	A
GET692	R.F. amplifier	G	V6/8R	R.F. amplifier	A
GET873	I.F. amplifier	G	V10/15A	A.F. amplifier	A
GET874	R.F. frequency changer	G	V10/30A	A.F. driver	A
OC16W	A.F. Output	B	V10/50A	A.F. output	A
OC19	A.F. output	B	V15/201P	A.F. output	★
OC26	A.F. output	B	V15/20P	A.F. output	K
OC44	R.F. frequency changer	A	V15/20R	R.F. frequency changer	J
OC45	I.F. amplifier	A	V15/30P	A.F. output	K
OC65	A.F. amplifier	A	V30/201P	A.F. output	★
OC66	A.F. amplifier	A	V30/20P	A.F. output	K
OC70	A.F. hearing aid	A	V30/30P	A.F. output	K
OC71	A.F. hearing aid	A	V60/201P	A.F. output	★
OC72	A.F. amplifier	A	V60/20P	A.F. output	K
OC78	A.F. output	D	V60/30P	A.F. output	K
OC81	General purpose	D	XA101	I.F. amplifier	D
OC81D	OC81 driver	D	XA102	R.F. frequency changer	D
OC170	R.F./I.F. amplifier	C	XA103	I.F. amplifier	D
OC171	R.F. frequency changer	C	XA104	R.F. frequency changer	D
TK30C	I.F. amplifier	L	XA111	I.F. amplifier	E
TK31C	R.F. frequency changer	L	XA112	R.F. frequency changer	E
TK40C	A.F. output	L	XA121	I.F. amplifier	C
TK41C	A.F. amplifier	L	XA122	R.F. frequency changer	C
TK42C	A.F. amplifier	L	XA123	R.F. frequency changer	C
TK1000C	I.F. frequency changer	L	XA124	R.F. frequency changer	C
TK1001C	A.F. output pair	L	XA126	R.F. amplifier	C
TK1002C	A.F. output pair	L	XB102	A.F. amplifier	D
NKT151	R.F. frequency changer	A	XB103	A.F. amplifier	D
NKT152	Mixer	A	XB104	A.F. amplifier	D
NKT153	I.F. amplifier	A	XB112	A.F. amplifier	E
NKT154	I.F. amplifier	A	XB113	A.F. amplifier	E
NKT155	Detector	A	XC101	Class B output	D
NKT161	R.F. frequency changer	F	XC121	Class B output	E
NKT162	Mixer	F	XC131	Class B output	E
NKT163	I.F. amplifier	F	XC141	A.F. output	B
NKT164	I.F. amplifier	F	XC142	A.F. output	B
NKT165	Detector	F	XC155	A.F. output	B
NKT251	A.F. output	F	XC156	A.F. output	B

★ Coloured leads: Emitter, violet; Base, orange; Collector, white.
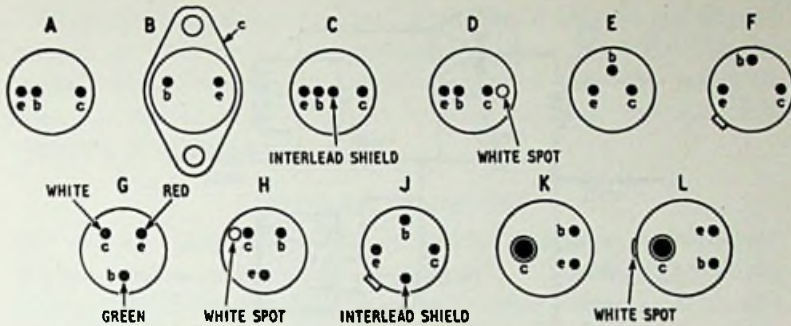
Fig. 10.13—Key to the letters used in Table 10.1

EMITTER VOLTAGES

By making voltage measurements across the emitter resistor, as shown in Fig. 10.14, it can be determined if the associated transistor and its circuit are working properly. But before deciding to make such tests, there are a few things to check.

First, these tests are of no value if the battery is run-down or if it is on the borderline of replacement. The next step, if the battery is good, is to determine if you are dealing with an npn or pnp transistor. Although practically all British receivers use pnp's it should not be assumed that pnp units are used throughout because you notice that one of them is such a type. Both types can be used in one receiver, and foreign receivers, particularly American and Japanese models, often use npn's.

Finally, the only instrument you can use to make such measurements is a high-impedance valve voltmeter. If you have an isolation probe, use it. Do not try to make this test with an ordinary multi-range meter.

When checking the emitter resistor of an npn transistor, touch the positive lead to the emitter and the negative lead to the earthed end of the emitter resistor as shown in Fig. 10.15(a). Of course, for pnp transistors, the test leads should be transposed—the negative lead should go to the emitter, and the positive lead to earth as shown in Fig. 10.15(b). In the npn transistor current flows through the emitter resistor in one direction, and in the pnp, in the opposite direction.

If you have ever measured voltages across cathode resistors in a valve radio, you know that the voltage range is considerable. Every receiver has its own set of bias voltages and it would be physically impossible to prepare a list of voltages to use as a guide which could
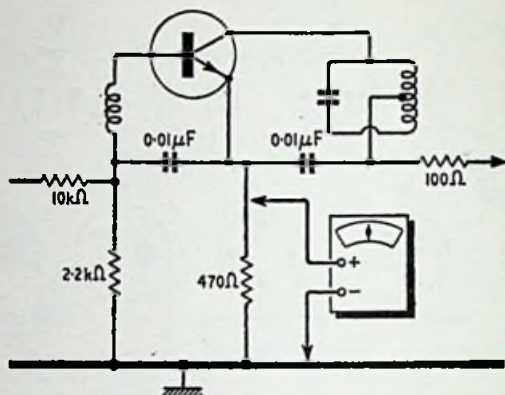
Fig. 10.14—Method for making voltage measurements
across the emitter resistor (of an npn transistor in this case)

always be consulted. The same is true of transistor receivers, but the following list shows average voltages (across the emitter resistors) for a typical receiver. These may not necessarily be correct for any particular set, but at least they give some idea of the readings to expect. These values are for no signal input, except where otherwise indicated:

Frequency changer: 1–2 volts
First i.f.: 0·22 volt
Second i.f.: 0·7 volt
Audio driver: 0·28 volt
Push-pull: 0·25 volt (with large signal input).

(a)   (b)
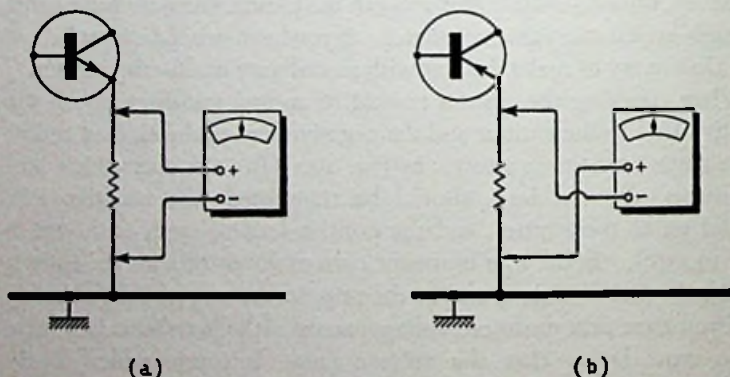
Fig. 10.15—Methods of connecting a valve voltmeter
across the emitter resistor for npn (a) and pnp (b) transistors

Whether these values of voltage are positive or negative will depend entirely on whether they are pnp or npn units. Note also that the voltages are quite small, so a suitable range on the valve voltmeter must be used to enable them to be read. Be sure that the valve voltmeter is set to read d.c. volts.

FREQUENCY CHANGER

The current flowing through the emitter resistor of a frequency-changer transistor will average about 0·5 mA. This will vary with the setting of the tuning capacitor, and usually 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, although the difference will be quite small. For example, the current might be 0·5 mA with the tuning set to 600 kc/s, increasing to 0·55 mA when the set is tuned to 1,400 kc/s. With a valve voltmeter of course we would not be reading the current, but the voltage reading would vary in direct proportion to the change in current.

There is one peculiarity of the frequency-changer stage that was mentioned in an earlier chapter, and it is important enough to bear repetition. Normally, in a pnp unit, the base is negative with respect to the emitter. In the case of a frequency changer, 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 transistor circuit is not working. The same thing applies to an npn transistor but with the polarity signs reversed.

This voltage which appears across the emitter resistor can give a clue as to the possible cause of trouble in that stage. If you want to check local oscillator operation quickly, connect the valve voltmeter across the emitter resistor and observe the needle position carefully. Now short the oscillator tuning capacitor plates and note the reading. If the needle kicks back, the oscillator is functioning. Make sure, first, that there is no battery voltage between the tuning capacitor plates.

To determine the actual amount of emitter current flowing, one of two things must be done—you can measure the current by inserting a 0-1 d.c. milliammeter in series between the emitter resistor and the emitter. To do this disconnect the end of the emitter resistor that is connected to earth and insert the meter between earth and the resistor. If the meter needle swings backward, transpose the meter leads.

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If you do not want to bother with a milliammeter, use the voltmeter and calculate the amount of emitter current by doing a bit of arithmetic. Current (I) is equal to voltage (E) divided by resistance (R). The value of emitter resistance is known or can be measured. The voltage is known simply by looking at the valve voltmeter when making the emitter voltage measurement. Dividing the voltage by the resistance gives the amount of current. There is just one precaution; an error which we all sometimes make. All units must be basic—if the resistance is in ohms and the voltage is in volts, the answer will be in amperes. This will usually be a very small fraction. To change your answer to milliamperes, multiply it by 1,000.

Arithmetic does not appeal to many technicians and so, if you are one of this group, inexpensive, easy-to-understand Ohm's Law slide rules are available which will do practically all the arithmetic for you. These rules can usually be purchased at the type of shop that sells radio components.

In making voltage checks across the emitter resistor, remember that the amount of voltage read is an indication of the condition in which the stage is operating. For example, if you read a high 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 and test the resistor. If the resistor is good but you 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 be misled. You may imagine that you are reading near-zero voltage, but there is actually a small e.m.f. across the emitter resistor. Make sure you are on the correct range of the valve voltmeter. 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 the voltmeter, 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 what to expect in the way of voltages across the emitter resistor, let us see what currents produce these

voltages.   Here is a useful check list:

Frequency changer: average current about 0·5 mA
First i.f. amplifier: average current about 0·5 mA (no signal)
Second i.f. amplifier: average current about 1 mA (with signal)
Audio pre-amplifier or driver: average current about 2 mA.

Considerable variety will be found in 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 (assuming a typical class B stage) and whether the signal is weak or strong.

Printed Circuits

IF you ever get the opportunity to examine a really old-fashioned radio set—preferably one manufactured around 1931—it is quite revealing to do so. Some of these " antiques ", especially those that had more than one tuned r.f. stage, were constructed like battleships. Some of them weighed more than a modern television receiver. The underside of the chassis was especially interesting since it was a tangle of wires and parts; a sight that frightened many a potential servicing student from continuing with his trade.

By comparison, modern radio receivers (and some television sets) look as though they have practically no components whatsoever. This is especially so if the receiver has a printed-circuit board. A printed circuit is nothing more than a sort of pre-wired arrangement consisting 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 of the conventional kind 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 appearance. The connections from one part to the next are the same, but because the " jungle look " has been removed, servicing is considered to be easier, although many service engineers do not think so.

Printed-circuit boards lend themselves very nicely to transistor receivers. Transistors are compact 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. In keeping with this all the other parts are made proportionately smaller.

THE PRINTED-CIRCUIT BOARD

There is quite a number of techniques for making printed-circuit boards. The conductors can be put on by spraying, plating, hot-die stamping, printing, painting, embossing, etching, etc. The board itself is generally a sheet of laminated plastics 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 above. Holes are drilled in the board—usually four, one at each corner—for mounting. Holes are also drilled 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 in one operation, although other manufacturing methods are also used.

WORKING WITH PRINTED-CIRCUIT BOARDS

Every radio part requires its own special handling and a printed circuit is no exception.

In almost all cases, some of the printed-circuit wiring goes directly to the mounting holes, so that in mounting the printed circuit on the metal chassis, there is an electrical connection between the chassis and the conductors on the board. The board should drop easily over the mounting screws. If it does not do so and you try to force the board into place, tightening the nuts on the holding screws for the board will crack it. Tightening the mounting or holding screws and nuts should not put any stress on the board itself. In replacing a board, it may be helpful to hold it 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 dealt with by using some thought and care. For

example, the conductors on the board are generally cemented fairly securely to it, but they can be lifted off by improper handling. They can become scored, broken, raised or severed, producing an open-circuit condition. Dropping solder blobs, using too much solder or a sloppy soldering technique can cause short-circuits—and quite easily at that. On most boards the conductors are fairly close together and any excess solder will run between them, probably fusing them beautifully. If this happens use the soldering iron and a sharp-pointed tool to clear the short.

If you find that one of the printed conductors is broken, you should not make a repair by bridging the break with a piece of copper wire as shown in Fig. 11.1. Run a new piece of wire to replace the conductor from end to end. If soldering operations are made along the run of a printed conductor it is likely to " lift " off the board. Use a length of 22 gauge solid tinned copper—not stranded wire.

It is inadvisable to remove the board from the receiver unless you feel that you will save much time and trouble by doing so. Having done so you can mount the board in a vice leaving your hands free to work, but remember that a vice can exert a tremendous pressure. Some technicians use a soft copper covering for the vice to prevent damaging the printed-circuit boards. This is good practice, because it prevents the serrated jaws of the vice from tearing the conductors on the board, but you must still be careful not to use excessive pressure.

Finally, remember that brute force is not required. Use one of the lighter irons, rated anywhere between 20 and 30 watts. A pencil iron, light in weight, will give the necessary hand control for working in confined spaces. A heavy iron is not only difficult to control,

WIRE SOLDERED
OVER BREAK
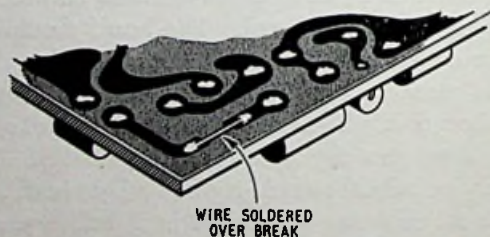
*Fig. 11.1—How not to repair a break in a printed-circuit conductor.
To repair a break solder a length of tinned wire between the ends
of the faulty conductor. Do not attempt to bridge the gap*
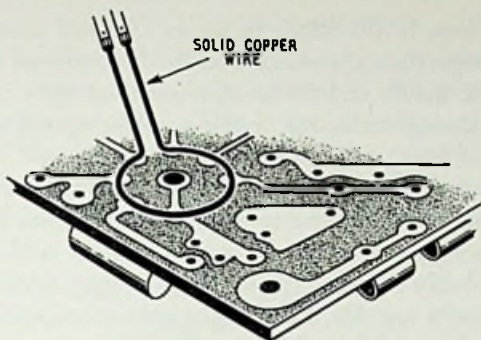
SOLID COPPER WIRE

*Fig. 11.2—Some No. 14 or 16 s.w.g. tinned copper wire
can be used as a special tip with a solder gun*

especially for fine work, but the heat it 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 it. Keep a cloth handy so you
can wipe the tip frequently to keep it clean and shiny.

If you have a soldering gun, you can make a special tip for work on
multi-tag components on printed-circuit boards. Remove the
existing tip by loosening the holding screws and get some 14 or
16 s.w.g. solid copper wire and fashion it into the shape shown in
Fig. 11.2. Tinned wire should be used but if the wire is not pre-
tinned, tin the circular loop portion of the new tip. Insert it into the
soldering gun and you are ready to go to work, first making certain
that transistors have been removed from their sockets.

If you have only a high-wattage iron, take some 14 or 16 s.w.g.
wire and wrap it round the iron as shown in Fig. 11.3. Make a good
tight wrap-round so that the wire does not slide off the iron and the
copper wire will now form the new tip. Sharpen the end of the
wire to a point by rubbing it against a fine-toothed file with a circular
motion. Tin the end of the tip, just as you would an ordinary
soldering iron.

By this means it is possible to use a heavy iron instead of the lighter-
weight iron just recommended, but it is not advisable. It is not always
the iron that produces the damage but the man behind it. Using
even a lightweight iron, you can damage the wiring if you keep the
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, but it is heavy to handle and the heat from it alone can cause damage. A different soldering technique, using a soldering pot or crucible, will be described later.

Some technicians have the idea that solder is solder and that is that. Why make your work any more difficult than it need be? If you were skilful enough you might be able to use bar solder, but then you would probably be better off connecting heavy telephone cables. For printed circuits use thin, lightweight resin-cored solder having a low melting-point. High-melting-point solder and pencil-bit irons belong together as much as pickles and ice cream. Use 22 s.w.g. resin-cored solder containing 60 per cent. tin and 40 per cent. lead. Avoid acid-cored solder.

A small wire brush will also be of great help to clean away very fine dots of solder that conceivably could cause trouble. But use it gently! The idea is to remove unwanted solder and resin, and not to buff the printed board to a high gloss. Careless handling of the brush can also remove some of the printed circuit board conductors.

Other tools you will find extremely helpful include a wire pick and a pocket knife. If you do not have a wire brush, use a stiff bristled toothbrush in its place. Also, the long-nose pliers and side cutters used for other servicing work can be very helpful for printed circuits.

Either before soldering or in the process of soldering, the protective varnish has to be removed from the area of the work, and this must be replaced. Suitable materials to seal the area are a silicone spray, made specially for the purpose in a pressurized can, or an epoxy resin varnish that can be brushed on. Suitable materials are marketed by Midland Silicones Ltd., and Hellermann Ltd. The makers' instructions for using them should be followed implicitly.

Various solvents are made for cleaning off the area of a printed-circuit board after working on it, but ordinary denatured alcohol (such as that used to thin shellac) can be used. Put some of the alcohol on the brush and dab the board around the area where you have soldered. This will remove excessive resin. Take care not to remove more of the protective varnish that covers the whole board than is necessary to perform your soldering job. Afterwards coat the area with a silicone varnish or epoxy resin.

COMPONENT REPLACEMENT

Much time can be saved by not removing defective components completely. If you try to do so, you may pull away some of the printed-circuit conductors. The better technique is to cut away the body of the defective part (resistor or capacitor) and allow the leads to remain (Fig. 11.4). You will now have two moderately stiff wires sticking up out of the board, to which the leads of the new
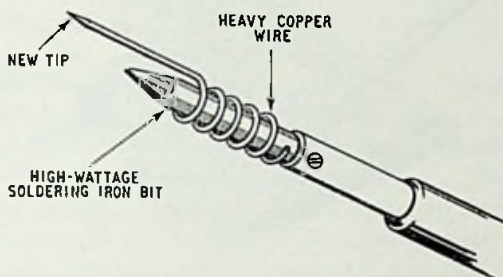
Fig. 11.3—Wrap some heavy tinned copper wire (such as No. 14 or 16 s.w.g.) around the bit of a heavy-wattage iron to convert it into the equivalent of a low-power iron

part can be looped and soldered. Since you will not be soldering to the board itself, the job will be that much easier (Fig. 11.5(a)) and damage to the board itself will be avoided.

However, there will be times when it will be necessary to remove 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 gently to remove some of the solder. If the ends of the wire are bent
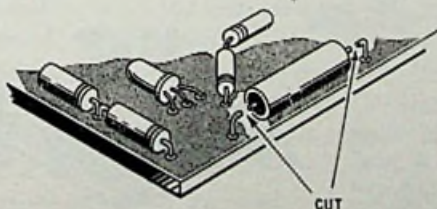
Fig. 11.4—To remove a resistor or capacitor, cut the leads as close as possible to the body of the component
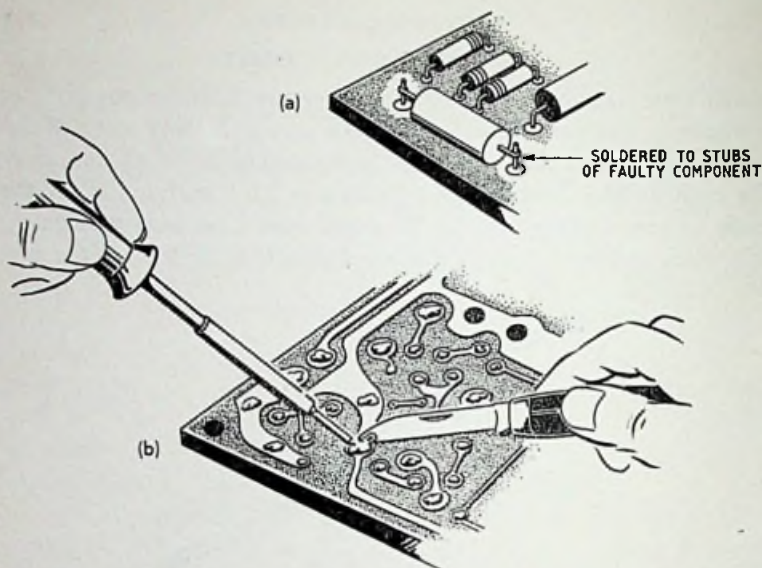
Fig. 11.5—(a) If the old component is cut away from its connecting wires, the stubs that are left can be used, as shown, for the connection of the new component. This avoids disturbance of the printed circuit. (b) With care the bent-over wire of a component can be " lifted " as shown from the printed circuit while applying a soldering iron. Thus the wire can be withdrawn to disconnect one end of the component
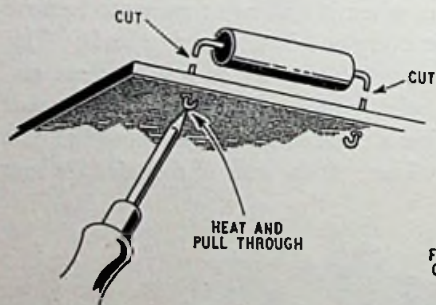
Fig. 11.6—To remove a component such as a resistor or capacitor, cut the ends as shown. If the remaining leads are then heated, they can be pulled through the board

Fig. 11.7—If the break in the conductor is small enough as shown at (a), you can repair it by flowing some solder between the two open ends. This method might cause the conductor to " lift ", however, and the correct method is to replace it as shown in Fig. 11.8
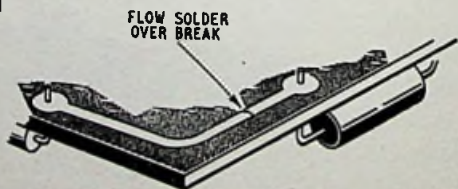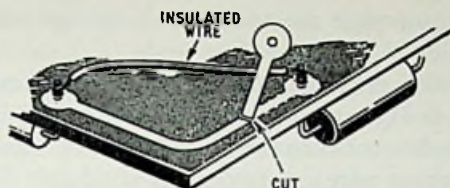
Fig. 11.8—If a small piece of the printed-circuit conductor lifts up, replace the whole conductor with a length of insulated wire

over, prise them up with the edge of a pen-knife and straighten them as shown in Fig. 11.5(b).

With most of the solder removed, you should now be able to apply the iron and wiggle the component loose. Then it should come out with its leads. You must be careful since it is easily possible to lift up some of the conductor when removing a part. After the part is removed, clean the mounting holes of any solder threads.

Another technique, as shown in Fig. 11.6, 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. This method is deprecated in some quarters as it may cause the conductor to " lift " off the board.

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, do not assume immediately that it will have to be removed completely (if a replacement is to be made). Instead, cut the part in half with a pair of side 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. Having done this, you will find that there is enough lead left at each end to solder the new leads to. Of course, they will have to be cleaned to make a good soldered connection.

Whenever you have made a repair on a board, always be sure to examine it after you have finished, to make sure that there are no 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 are practically touching, you can make a connection by running some solder across the crack between the ends (Fig. 11.7). This is one method, but it is deprecated in responsible quarters. A

better method is to replace the whole conductor unit with a piece of wire.

If, for some reason, the printed-circuit conductor lifts away from the board, as shown in Fig. 11.8, cut away the section that has lifted and replace the complete conductor with a length of wire. Use solid tinned-copper sleeved wire and replace the conductor for the whole of its length, as just described. A break may occur along the length of the conductor, which is such a fine hair-line crack as to be difficult to see without a lens. This is repaired in the same way.

After repairs are finished, use a toothbrush (or any stiff bristle brush) and a solvent to clean the area round the repaired part of the board. Denatured alcohol is cheap and is a good cleaning solvent. Apply a small amount of alcohol to 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 little pieces of lint. If you have carbon tetrachloride available, it can be used in place of the alcohol, but remember that the fumes are poisonous. Work in a ventilated room and, if possible, use a small fan to blow the fumes away.

After cleaning an area with the solvent, cover the underside of the board (the foil side) with a silicone resin spray. If you can get this in a pressurized can 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. If you cannot obtain a spray can, apply a silicone varnish with a brush.

REPLACING R.F. AND I.F. TRANSFORMERS

If you intend to replace a defective r.f. or i.f. transformer, cut away the transformer soldering lugs. These lugs come through holes in the board. Remove the solder from each of the lugs by heating and brushing, then cut them with diagonal cutters. You should then be able to remove the transformer, being careful when pulling the transformer can. Work it 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 soldering the job.

If the transformer is to be repaired (instead of being replaced), more care is needed. Remove all solder from the soldering terminals and then straighten them out. You may have to file the terminals to remove the last bit of solder and to remove the transformer.

I.F. transformers are symmetrical—that is, they usually have as many terminals on one side as on the other. For this reason, when removing one for repair, make sure that you do not turn it round when putting it back. There is any number of identifying methods that can be used, such as a scratch mark or a dab of ink. It makes no difference which technique is used, so long as the transformer is inserted right way round.

Some i.f. transformers will have a colour dot on one of the lugs. The idea of this colour dot is exactly the same as the dot found on the side of the package (or case) of a transistor having a symmetrical lead arrangement. You must remember the position of the lug with the dot on it and then insert the new transformer in the same position Sometimes the manufacturer puts 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 for identification only and not as a positioning aid.

One final caution: in soldering, as in almost everything else, use restraint. Do not 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 i.f. transformer and to damage it in the process.

FAULT TRACING

Resistance and voltage measurements can be made with printed circuits in the same way and using the same techniques as with conventional wiring. However, all components are usually mounted on one side of the board. 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 to 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 helpful. If a continuity check shows a break in the conductor it may be necessary to use a magnifier to find it.

In ordinary servicing, one of the test leads is equipped with a fastener of some kind, such as a crocodile clip. For circuit-board work, it would be helpful to fill the jaws of one of the clips with solder. After the jaws are filled, file them down until they are fairly smooth. The teeth of the jaws will then be unable to damage the board, while the larger 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 FAULTS

A printed-circuit board should be regarded as a radio component. It might be considered as a resistor or a capacitor or a valve (in the sense that these are also wireless parts). And, like all components, the printed-circuit board has a few ailments of its own. A printed board may look all right, but then a valve or transistor might also appear to be in working condition only to prove defective when tested.

LEAKAGE RESISTANCE

Leakage resistance is a fault that might occur anywhere. It is found in capacitors (especially electrolytics), in high-voltage circuits, and it can cause trouble in transistor receivers using printed-circuit boards.

Leakage can be checked with a valve voltmeter, which must be able to read high values of resistance, up to 1,000 megohms. It can be caused by dirt, by a defect in the plastics plate or by resin between conductors on the board, and particularly by dampness. 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 valve voltmeter. If there is 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 embed themselves between the conductors but the brush will remove them quite readily.

POOR CONNECTIONS

Printed-circuit boards are mass-produced and, as in any mass-production system, a few defects will always get through. It is possible

for a connection to be poor, 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 this is to use an ohmmeter.

INTERMITTENT FAULTS

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 and 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 which may look sound 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 (virtually zero) connection between radio components. However, while the conductor may look sound enough 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 which do not cause an open circuit, but since they reduce the amount of conductor material, result in increased resistance. If this happens, when the circuit shows that there should be a direct connection (zero resistance), then there might be a high-resistance conductor on the board—although care must be taken that there is no other component between the two measured points. This can be found by measuring the resistance between points on the board.

READING PRINTED-CIRCUIT DIAGRAMS

A printed-circuit diagram shows the various parts in schematic or symbolic form with the printed-circuit conductors drawn as a solid or shadowy outline, or both, as shown in Fig. 11.9. The diagram is unusual in some respects—it shows the location of parts with respect to each other, 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. 11.9 is of considerable help in servicing.

REPLACING VALVE SOCKETS

Sometimes a valve 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. The decision may depend upon the type and size of the board, but if a new board is
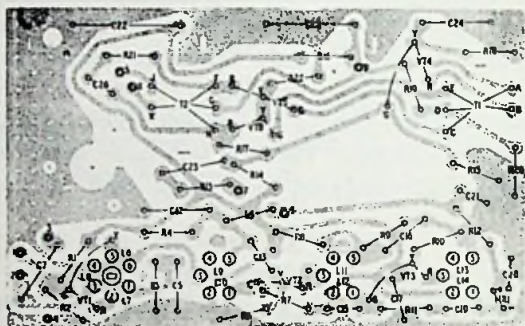
Fig. 11.9—A printed circuit diagram indicating the location of parts. The conductors are shown tinted

put in it will either have to be bought, in which case the repair would be expensive, or you might decide to salvage the parts, in which case the repair would be time-consuming. While putting in a new socket is not a quick job, therefore, it is often the least bothersome of a number of possible procedures.

To put in a new socket, first get rid of the old one. Cut it with a pair of side cutters but do not be too ambitious. Cut away a small bit at a time, otherwise you will find 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 cutters at these points. The pins may be removed by heating the lugs on the printed side of the panel and then gently pulling the pins through the hole from the component side.

Do not try to do this job holding the printed-circuit board, the soldering iron and a pair of long-nose pliers in your hands. Mount

the board in a small vice, putting two pieces of cardboard over its jaws so that the serrated edges do not cut into the board. And remember that the purpose of the vice is to hold the printed-circuit board, and not to crush it. Go easy on the pressure you put on the vice.

After the pins are out, remove the centre spigot if fitted, in the same way. Heat the soldered point and push it through from the component side. A replacement socket can then be inserted in the openings.

You may be wondering why you are being told about valve sockets in a book dealing with transistors. The answer is quite simple. First, some receivers (such as car sets) use both valves and transistors. Second, with an eye to the future, no one knows as yet whether valves or transistors will ultimately take the lead in electronics equipment. More likely, however, both will be used side by side in test equipment, receivers, transmitters, industrial apparatus, etc. Transistors are remarkable—but so are valves. Taken together, they can make a good team.

VOLTAGE MEASUREMENTS

Once you become experienced in working with receivers that use printed-circuit boards, you will find they have a number of advantages over ordinary wiring. There is a flat surface with all connections readily visible. There is no need to worry about " dressing " the leads, because the conductors are fixed in place and voltage test points are easily accessible—no need to probe around trying to find a suitable spot for a voltage check.

There will be some disadvantages too, especially if you have been used to working with ordinary wired circuits. The conductors on printed boards are close together, and as components are usually on one side and conductors on the other, it is not 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, voltage readings can be taken at the pins of the transistor or valve sockets. Most boards have components on one side only and you can use the exposed lead of a component, such as a resistor or capacitor, as a test point. Do not jab a test prod

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—even if it is a needle point—into any of the conductors on the board. Trace the conductor to the nearest component lead and make that the test point. The conductors on a printed-circuit board will not take the punishment that copper wires in an ordinary receiver will.

Another reason for testing in this way is that the printed board will be covered with resin. Because the conductors are so close together it does not 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 test directly on the conductor, using a needle-point test prod, the resin seal will be broken. You may be able to make the measurement but the small puncture in the resin may lead to trouble later on.

ADVANTAGES OF PRINTED CIRCUITS

Printed circuits have quite a number of advantages in manufacture. 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 an exact copy of the original, you can be quite certain that all of the " bugs " have been taken out of the original design, because the manufacturer must make sure that his design is a good one. Changes based upon experience in the field are not so easy to make when using printed circuits.

With the printed-circuit board there is not a confusing jungle of wires. All the leads (or conductors) can be seen and all the capacitors and resistors mounted on the board can be reached easily. It is just like a miniature chassis but, instead of being made of metal, it is made of insulating material. You cannot look through a board but, if you want to work on the top side of the board, put an electric light behind it, and you will be able to see all the wiring. Use a 60–75-watt bulb, preferably a clear type.

SOLDERING POT OR CRUCIBLE

A dip soldering pot is simply a small cylinder having a diameter of about $1\frac{1}{2}$ inches. Larger than a thimble (but having smooth walls), the solder pot holds enough molten solder to make quick repairs on printed-circuit boards. The heat of the solder is regulated by a temperature control device to give a solder temperature range of

300–600°F.   Actually it is no more complicated than a rather elaborate soldering iron, but their use is usually confined to factories.

The soldering pot is extremely useful since with its help components having several tags can be removed easily, much more quickly and professionally.   To remove a part, put the soldered connections of the part right over the solder pot, so that the connections 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, it is very easy to slide the component right out of its mounting holes.

Of course, when working with a soldering pot do not keep the printed circuit board dipped into it any longer than necessary.   If you do, you may damage the board.   The job should be done as quickly as possible.

The pot can be used for replacing a part such as a resistor or a capacitor.   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.

Having got 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 touching up.

You may ask whether a soldering pot has any advantage over a soldering iron.   To answer this question you would have to remove a component (such as a resistor) by the soldering-iron method and then try a soldering pot, and many technicians would probably prefer the light soldering iron for small components.   The pot is of great assistance in removing multi-lag components like valve holders and transformers.

When using a soldering iron, a certain amount of common sense and caution are needed.   You should never dip a soldering iron into water to cool it.   To do so is dangerous and might also damage the

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iron. A soldering pot must also be handled with respect—if you use one, 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 and 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 and throw it 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 resin-cored solder.

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

MOUNTING OF BOARDS

Printed-circuit boards are mounted in every possible way. In some receivers there is the usual metal chassis with a rectangular cut-out. The printed circuit board is mounted in this cut-out and will generally be 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 which form mounting fixtures and connecting tags at the same time.

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 components in another part of the receiver. Sometimes there will be no supplementary connecting wires, the only connections being made automatically as 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.

Transistor Types

History has a habit of going around in circles. If you want to know what is 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 valve between 1920 and 1930 was the triode. It was not until the early 1930s that multi-electrode valves came into use. Today, the most widely used transistor in receivers is a triode. However, " multi-element " transistors are being made and it would not be surprising to find the equivalent of the pentode at work in future transistor receivers. However, we are less concerned with the future than with the present. We have spent a long time studying transistor radios, but there are many opportunities in the electronics industry for those who know more than routine repair work. It is impossible to cover all of the new kinds of transistors (that would take a book in itself) but it is useful to become acquainted with a few of the more important developments.

In the appendix there is a list covering many of the faults met with in transistor radios. Listing symptoms and their cures, this serves as a ready reference helping to cut down on servicing time. Theory references, by chapter, are also given to avoid a " rule of thumb " approach. We want to be able to service transistor receivers, but we should also know why the receiver behaves as it does.

THE PHOTOTRANSISTOR

If you are familiar with the photocell you know that it is somewhat like a wireless valve except that current flow is caused by a beam of light instead of heat. We say that the valve is light-sensitive. Photo-

cells are widely used in industry on automatic door openers, light dimmers, as silent guardians where valuables are stored, or in any circuit where flashing a light will cause some circuit to go into operation. A drawback with a photocell, though, is that it delivers a very small amount of current and hence it must be accompanied by a suitable amplifier. The output of the amplifier is then large enough to operate a relay. This is shown in block form in Fig. 12.1.
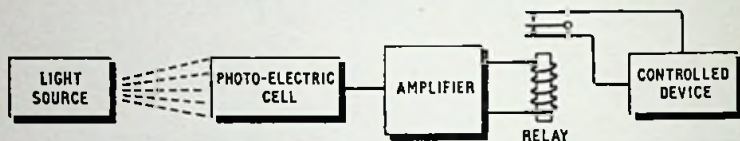
Fig. 12.1—An ordinary photocell is usually followed by an amplifier to build up the current until it is strong enough to operate a relay

Fig. 12.2—Because the phototransistor supplies more output current, it can operate the relay directly, without the necessity of using an amplifier stage

The phototransistor does the same job as the photocell, but it has the important advantage of supplying more output current than the photocell, enough to operate a relay without an amplifier, as shown in Fig. 12.2.

A drawing of the phototransistor appears in Fig. 12.3. 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 pnp 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 (photo-sensitive) material. When a beam of light shines on the photo-sensitive 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, enough current is caused to flow in the collector circuit to operate the relay. The relay, of course, is nothing more than a magnetically operated switch and can be used to turn a circuit on or 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 valves and transistors are similar, but they also have certain characteristics of their own that make them different. For instance, some transistors work well at low frequencies and others 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 one of this type is shown in Fig. 12.4. The difference between this
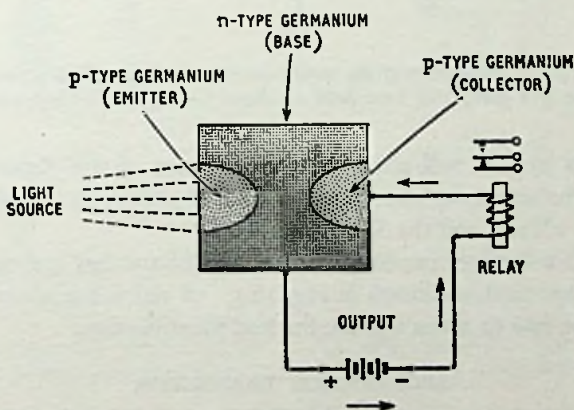
Fig. 12.3—Cross-section of the phototransistor

transistor and those studied so far is in the method of construction. It is a triode, with an emitter, collector and base, and it 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, so the drawing is enlarged to show its cross-section. 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 American types of surface-barrier transistors are identified by the prefix SB. Thus there are types such as the SB101, SB102, etc. However, other type numbers have been assigned to these
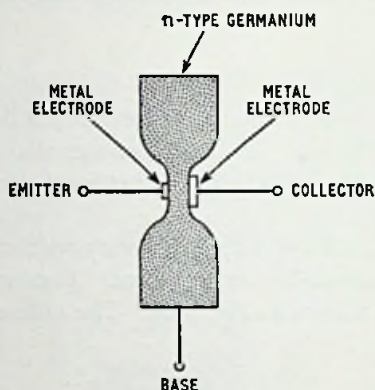
Fig. 12.4—Cross-section of the surface-barrier transistor. This is just one type of a group that have been developed for high-frequency operation

transistors so you will also find them as part of the American 2N series. For example, the SB101 is also identified as a 2N344, the SB102 as 2N345, and the SB103 as 2N346.

A surface-barrier transistor such as the SB101 has a symmetrical lead arrangement, as shown in Fig. 12.5. A red dot is placed on the side of the case 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 semi-conductor. After purification, as in the case of germanium, controlled amounts of impurities are added to give the silicon the required properties for use in a transistor.

Silicon transistors have a number of advantages over germanium ones. They are capable of working in higher temperature ranges and in addition, have lower leakage currents.

The circuit arrangements for silicon units are the same as for germanium transistors, but the values of associated resistors and capacitors may be slightly different.

Silicon transistors are used in many industrial applications, such as servo-motor control, magnetic core switching, solenoid operation,
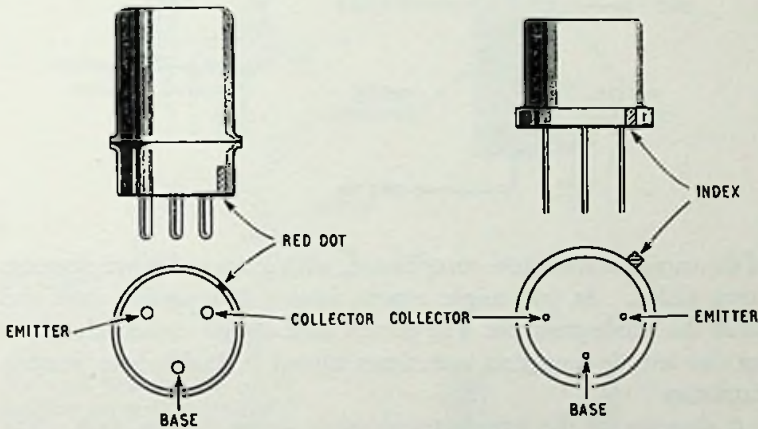
Fig. 12.5 (left)—One type of surface-barrier transistor encapsulation

Fig. 12.6 (right)—One type of silicon transistor encapsulation

d.c.-to-d.c. converters and low- to medium-power oscillators in transmitters. In receivers they can be used in single-ended or push-pull output stages.

One type of silicon transistor is shown in Fig. 12.6. This is a medium-power npn unit for switching applications, or it can be used as an amplifier. A mark on the covering of the transistor serves to show the position of the emitter lead. The centre 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. In some kinds of circuit this means that the case will have to be insulated from its mounting.

TETRODE TRANSISTOR

The very first valve was the simplest type—a diode. A big forward step was made when the control grid was added, and in time the inside
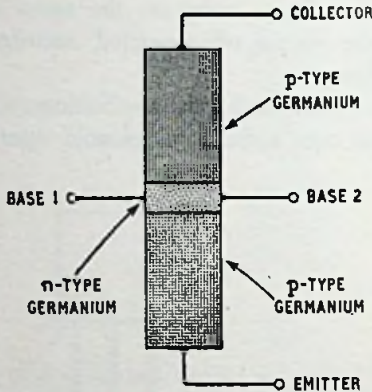
Fig. 12.7—Cross-section of a tetrode transistor

of the valve became quite complicated, with more and more elements being added. As you might expect, history is repeating itself and while the triode transistor is at present used almost exclusively, there are also tetrode transistors sometimes known as double-base junction transistors.

A diagram of the tetrode transistor is shown in Fig. 12.7. The transistor has the usual emitter, base and collector, but two connections are made to the base. This transistor is a pnp type, the base being made of an extremely thin layer of n-type germanium, but npn types are also made. The advantage of the tetrode transistor is that it can work at much higher frequencies than the usual triode transistor. Fig. 12.8 shows the bottom and side views and the electronic symbol for a tetrode.

DIFFUSED-JUNCTION TRANSISTOR

The diffused-junction transistor in itself is not a specialized type. The name refers to the technique by which it is manufactured.

Briefly, a diffused-junction transistor is made by melting an impurity 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 pn junction.

A diffused emitter-collector transistor is one in which both the 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 has been said it can be seen that the diffused-base transistor and the diffused-emitter transistor come under the general heading of diffused-junction transistors.
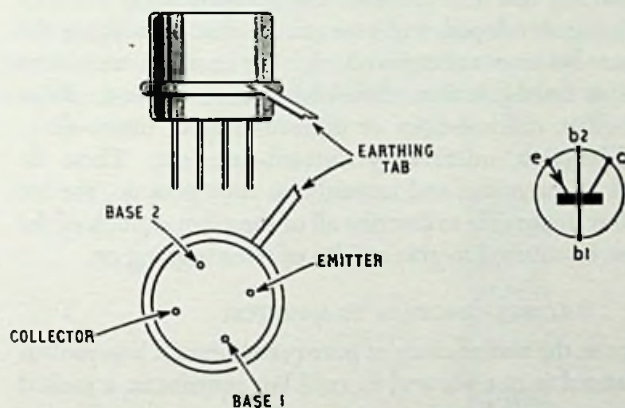
Fig. 12.8 (above)—The tetrode transistor and its electronic symbol
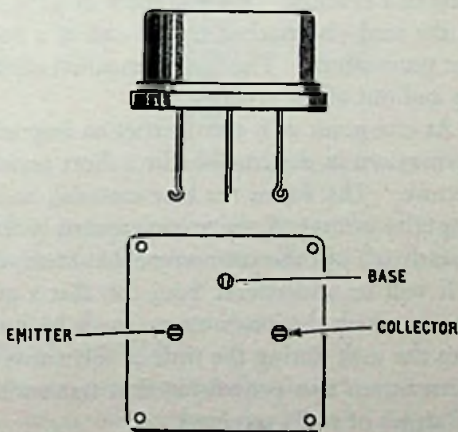
Fig. 12.9 (right)—External appearance of an npn diffused-junction silicon power transistor

Fig. 12.9 shows the external appearance of an npn diffused-junction silicon power transistor, which 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.

Transistors can be made in many different ways and thus there may be slight differences in manufacturing techniques between transistor types. In some cases the manufacturers have named the transistor after the technique used in its production, and in others manufacturers have identified their transistors from the way in which the transistor operates, or in some cases the transistor is named after both its production method and its operating technique.

Add to this the fact that new processes and manufacturing methods are constantly being developed, and you can see that identifying the transistor by name becomes rather involved. 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. It is impossible to describe all of these but enough of the various types can be covered to give an idea of what is going on.

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 piece 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.

At one point as it slowly rises an impurity is added to the molten germanium in the crucible for a short period, causing a change in the texture. This forms the base material, and when the addition of the impurity is stopped, the texture reverts to its former condition, leaving a sandwich of different texture that forms the base.

It will be understood from this that 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 npn grown-junction transistors supply high gain in the i.f. stages of radio receivers.

THE INTRINSIC SEMICONDUCTOR

In the first chapter of this book, we learned that by using acceptor or donor impurities, either p-type or n-type germanium could be made and that the 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 holes and electrons. Germanium treated in this way cannot be called either p-type or n-type since it is actually neither. This type of semiconductor is called an intrinsic semiconductor. Thus, we now have three types of semiconductors available—p-type, n-type, and intrinsic.

INTRINSIC-JUNCTION TRANSISTOR

The i-type semiconductor was developed for use in the intrinsic-junction transistor, illustrated in Fig. 12.10. This is really a pnp transistor with a layer of intrinsic material sandwiched between the
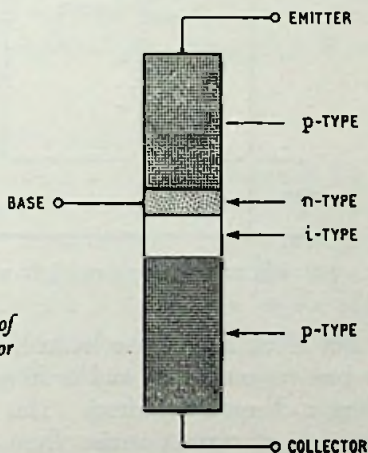
Fig. 12.10—Cross-section of intrinsic junction transistor

base and the collector, and thus it makes a four-layer transistor or a pnip type. Intrinsic-junction transistors are also made in the form of npin.

DRIFT TRANSISTORS

One of the big problems confronting transistor designers and engineers has been the need for transistors to work at higher and higher

frequencies. The surface-barrier transistor and the intrinsic-junction transistor are 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 earlier descriptions that transistors are made to conduct by doping them with selected impurities. In the drift transistor, an impurity is added to the base. The amount of this impurity is carefully controlled so that the maximum amount is close to the emitter, gradually decreasing so there is only a small amount near the collector.

The particular kind of impurity material that is added is of the type that has excess electrons, and when these move away they leave
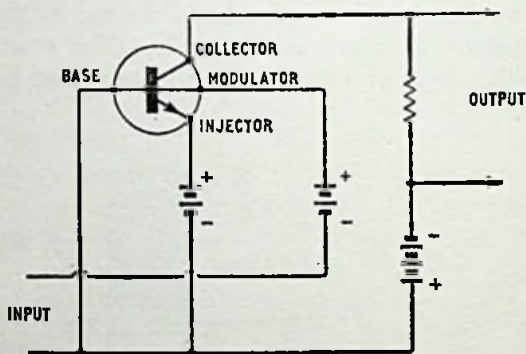
Fig. 12.11—Simple circuit for a spacistor amplifier

holes. But holes, as we have learned, represent positive charges so that the base region is then said to have 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 then ordinary types. At high frequencies the movement of current carriers must be fast— in technical language the " transit time " has been reduced.

SPACISTOR AMPLIFIER

A simple circuit arrangement for a spacistor amplifier is shown in Fig. 12.11. The spacistor is a rather special type of tetrode transistor,
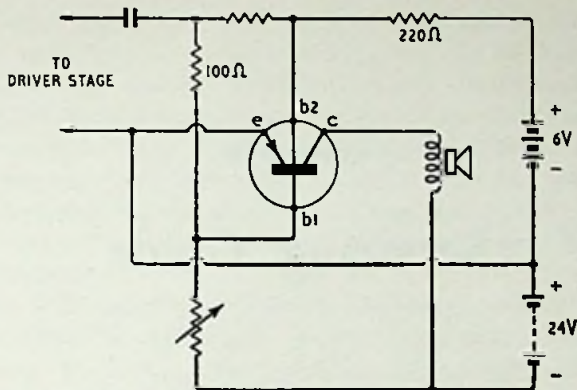
Fig. 12.12—Amplifier circuit using a tetrode transistor

unlikely to be found in domestic receivers. 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. 12.12. The transistor is a pnp 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 loudspeaker as shown and has the advantage that no output transformer is required. The circuit can also be used as a modulator in transmitting circuits.

Servicing Guide

A SERVICE technician is an electronic detective. A competent service technician does not need many clues to help him find the defective component. In this book many clues have been given as to why a transistor receiver may become faulty. But all this cannot possibly be remembered. You will perhaps want to refer to this book from time to time and in order to provide a quick reference to the appropriate section this servicing guide has been compiled.

A.G.C. Voltage Absent (Chapters 4, 5 and 9). Make sure that the receiver is tuned to a station. If you are using an output meter but have the loudspeaker disconnected, a meter reading does not necessarily indicate the presence of a station. The receiver may be oscillating (one of the i.f. stages may be regenerative).

If, however, you do have a station but no a.g.c. voltage, check the a.g.c. filter resistors and capacitors. If the set seems unusually sensitive, overloads easily and distorts, but a.g.c. voltage is missing, trouble is definitely caused by some defect in the a.g.c. network. The crystal diode will sometimes pass enough audio signal to make you think that it is good, but, if a check of the a.g.c. system does not reveal the trouble, try replacing the diode.

Missing a.g.c. voltage may not necessarily indicate a defect. The set may be using delayed a.g.c., in which case no a.g.c. voltage would appear until the signal level is strong enough to overcome the amount of delay voltage.

Audio Instability (Chapter 8). Refer to the section on motorboating.

Audio Output Low (Chapters 3, 5, 6 and 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 output 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 loudspeaker. Earphones, sometimes used, may have defective jack. Put on earphones. If volume is good but sound of loudspeaker is weak, then check the loudspeaker.

Transistors are usually the last item to check.

Battery Life Too Short (Chapter 7). The battery in portable transistor receivers is usually shunted by an electrolytic. If excessively leaky, this could cause a severe drain on the battery.

The on/off switch might be defective. These switches are small devices and sometimes have mechanical faults. 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 loudspeaker. 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 d.c. 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 may rise to about 40 mA (or more) with signal.

If the total quiescent current of the complete receiver exceeds 15 mA either there is a fault or the battery consumption is excessive in that type of receiver. The makers' manual should be consulted to determine the correct current.

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 repeatedly recharged.

Remember also that torch type cells will not last as long as mercury batteries. Mercury batteries should have a life expectancy several times as long as Leclanché torch cells.

When making voltage checks on mercury or nickel-cadmium batteries (where these have been used to replace torch cells), keep in mind that mercury and nickel-cadmium types supply about 15 per cent. lower voltage per cell.

Every receiver will show a certain amount of resistance across the battery clips. To check, remove the battery. Connect your valve voltmeter (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, 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 short-circuit in the set.

The trouble may be caused by an open or shorted 'phone jack.

Dead Receiver (Chapters 7 and 8). Refer to the section on inoperative receiver.

Distortion (Chapters 3, 5, 6, 7 and 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 replacement value of emitter resistor or by a shorted emitter by-pass 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 motor-boating. 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 a.g.c. filter capacitor with a similar unit. If the distortion clears, then the original capacitor is at fault.

If the detector also supplies a.g.c., try replacing the detector. Make sure the detector has not been inserted with reverse polarity.

Distortion can also be caused by a battery which needs replacement. If the receiver uses earphones and the signal as heard in the earphones sounds normal, but is distorted when the loudspeaker is used, check by using a substitute loudspeaker.

Check the base bias of each transistor. A small change in bias can 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 r.f. by-pass capacitor at the detector output is open. This causes overloading of the first audio amplifier stage.

Electrolytic capacitors are often used for coupling. 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 are found to be correct.

Distortion can be caused by the loudspeaker. The cone may be torn, or the voice coil can be rubbing against its pole piece. Cones have a habit of drying out. If this happens to 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 deceptive, because 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.

Do not confuse atmospheric 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.

Inoperative Receiver (Chapters 4, 7, 8 and 10).   Check the battery. If it has dropped below 30 per cent. of its full-load voltage, replace it.   There is sometimes a critical battery voltage at which the oscillator in a superhet stops oscillating.

Check to make sure that the entire receiver is not 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 does not pass the signal is at fault.

Always remember the oscillator.   If the local oscillator is not 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 i.f. transformer winding (or a short in the i.f.).

Check the ferrite-core aerial.   It may be open-circuited, or the connections to it may be broken.   There may be a short-circuited turn (which will kill the signal) or the ferrite rod itself may be fractured.

Interference (Chapter 9).   Interference in a car 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 or wheels.   Noise voltages are often radiated by the wiring of the car.

Since car 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 inter-

ference.   If this is due to the design of the receiver, there is not much you can do about it.   Try turning the portable in one direction or the other to favour 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 favour those stations at the expense of others.

Intermittents (Chapter 11).   Rotate the volume control.   If the set operates best at one particular spot on the control, the control is dirty or worn.   Clean with carbon tetrachloride or commercial lubricant cleaner.   If pressing hard on the volume control knob removes the trouble, the wiper arm inside the potentiometer has pulled away from the resistance element.   It may be easier to replace than to repair.   Another cause of intermittent operation can be poor contact between the volume control spindle and its bush.

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, but make sure no fragments of the steel wool drop into the set.

Intermittents can also be due to poorly soldered connections, produced either during the original manufacturing of the set or in previous servicing.

Spot-solder any doubtful connections.

With the receiver turned on and the volume partially turned down, put your ear near the loudspeaker and 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 is simply due to dirt or metallic dust or particles that have become embedded between the stator and rotor plates.   Examine both the oscillator and r.f. 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.

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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 (Chapters 6 and 8). This is a slow rhythmic sound, often accompanied by a howl. Check for an open decoupling capacitor. Also check the electrolytic capacitor 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 (Chapter 8). Refer to the section on inoperative receiver.

Noise (Chapter 9). *See* Interference.

Noise but No Signal (Chapters 8 and 10). The local oscillator may not be functioning. This can be checked by any of the techniques previously described in detail in these chapters. If the oscillator is not working, check the voltages at the base and emitter of the frequency changer transistor. Also check the voltage at the collector. If any of these voltages are missing or are incorrect, check the voltage-divider and dropping resistors which are 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 probably shorting. If the reverse is true—that is, if the set works for low-frequency stations but not for the higher-frequency ones—then the rotor plates of the oscillator tuning capacitor may be shorting against some metal component.

One Station Only Over Entire Tuning Range (Chapters 8 and 10).

The i.f. stages may be severely misaligned. Someone may have tampered with all alignment cores and screws.

This condition can sometimes happen when the local oscillator is not working. The misaligned i.f. can pick up a broadcast station, with the entire receiver acting as a fixed-tuned i.f. receiver. Check the local oscillator.

Oscillation (Chapters 4 and 8). The symptom in this case will be a continuous howl and the set may be very touchy and sensitive. Look for an open-circuit in the neutralizing network (resistor or capacitor, or both), if the set has such a network.

The fault may be in the a.g.c. system. Make sure that the detector diode is not reversed. Check all a.g.c. filter capacitors.

This trouble may be caused by a weak battery whose internal resistance is high.

Oscillation can be caused if the earth connection of the printed circuit does not make good physical contact with the earth of the receiver.

Poor Sensitivity at Low End of Broadcast Band (Chapter 10). This may be caused by misalignment of the oscillator or r.f. section. It also may happen when the frequency changer transistor is replaced.

Poor Sensitivity at High End of Broadcast Band (Chapter 10). This trouble may be caused by poor alignment in the front end of the receiver. It can be caused when the f.c. transistor is replaced.

Power Supply Voltage Too Low (Chapters 2 and 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 per cent. 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 get weak very rapidly, look for defective component that puts heavy load across the battery.

Low supply voltage can also be caused by a short in the receiver or leaky electrolytics. If the voltage across the battery terminals is good but there is 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, check resistance from each winding to the transformer shield. A high-resistance leak here will put a drain on the battery.

In car receivers, if supply is too low, check the storage battery. In hybrid sets check the d.c.-to-d.c. converter, if one is used.

Regeneration (Chapter 8). Refer to the section on oscillation.

Scratching Sound (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 are used less than 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. So can a " dry joint " in any component.

Sound Distortion (Chapter 6). Refer to the section on distortion.

Sparking (Chapter 9). Refer to the section on whine.

Squealing (Chapter 8). Refer to the section on motorboating.

Static in Car Sets (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 (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.

Volume Changes Considerably as Receiver is Tuned from One Station to Next (Chapter 5). Check the a.g.c. system, including all filter resistors and capacitors. Try replacing the detector.

Weak Signal. Refer to the section on low audio output.

Whine (Chapter 9). This is a condition in car radios. It is generally noticed as a change of pitch as the speed of the engine is varied.

In this case the trouble is caused by the generator and 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 earth 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 wire connecting the armature of the generator to the regulator is kept away from the aerial 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 a.g.c. circuit. It can also result from one station " beating " with another whose frequency is too close. Unless the whistle can be reduced by turning the aerial to a direction that is unfavourable to the interfering station, there is nothing that can be done.

Examine the aerial coil. If the ferrite rod is cracked, replace it or put in a new aerial coil.

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