SECTION II

Service Procedures and Techniques

Chapter 4

The Amplifier Signal Circuits

The first thing to do in servicing an electric guitar amplifier is to look it over carefully. Find out what it isn't doing, and, just as important, find out what it is doing. As in all electronics work, the diagnosis is the hardest part. First, look for what is working; this will give you an idea as to what is not.

Troubles in amplifiers will fall into three classes; it will be dead, weak, or sound funny. This last class covers hum, oscillation, motorboating, and similar things; in other words, the amplifier is making the noises itself when it should not. The first thing to decide is in which class this trouble falls. Make the easiest possible test: turn the instrument on and listen to it.

A normal reaction in a functioning amplifier is a slight rushing sound in the speakers called "blow" (as if you were blowing very softly into a microphone). Some slight hum is also normal, especially if the input connections are open and the volume controls are turned up. All tubes should show a little light in the top, but none of them should get red hot or show any flashing between the elements. If you see the latter, turn off the amplifier immediately; there is a short somewhere in the power supply. Also, if you hear a loud hum, smell smoke, or see smoke coming from under the chassis, turn it off.

Take the easiest problem first—the completely dead amplifier. Nothing happens when you turn it on. This means that some part has completely broken down, and it is easy to find. Simply check out all circuits in the amplifier, beginning with the power supply. It doesn't take long to find a bad component with the proper tests. These tests are listed in later paragraphs.

First, look at the statistical order of failures in this kind of electronic equipment. The author's experience in actual repair operations indicates certain troubles are more likely than others. The experienced technician checks them in the order of frequency of occurrence, and he finds the trouble faster. Likelihood of failures come in this order:

1. Tubes
2. Power supply
3. Components—resistors, capacitors, and controls
4. Cables—plugs and wiring between the guitar and the amplifier
5. Transformers—output transformers, speakers and power transformers

Remember this list, and use it; it will make the repair job a lot faster. If you find a completely dead amplifier, the first thing to look for is a bad tube. The second most likely source of failure is something in the B+ power supply, and so on in the order given.

In checking electric guitars, break the complete system down into three parts—the amplifier itself (including the speakers), the connecting cables, and the guitar (including the pickup and controls on it). Here is how to check it out. First, pull out all cables to the instruments and mikes. Turn the amplifier on, and listen for any signs of trouble. See if you can hear the normal blow or hum that means it is alive. If you do not, check at any one of the inputs. Turn its volume control all the way up, and touch the hot terminal of the jack. If the amplifier is working, you ought to hear a very loud buzz or honk noise in the speaker. There are two easy ways to make this test: One, plug in one of the cables, and touch the tip of the phone plug; this is always connected to the hot terminal on the jack. Two, make up a special test plug with the hot wire brought out to where you can touch it with a fingertip. Try this on an amplifier you know is working, and you will recognize the sound the next time you hear it.

If you hear a loud buzz, chances are the amplifier is all right, so go to the connecting cables. Plug them into the amplifier one at a time, and touch the center conductor of each cable. Again, the loud buzz says this section is functioning. Before going on, however, flex each of the cables near both connectors while touching the center conductor. Any static or break in the buzzing sound indicates there is a problem in the connector. Look over each one carefully for poorly soldered connections, broken wires, and strands of wire shorting across the connector. The section on servicing has procedures for repairing shielded cables.

When the connecting cables have been eliminated as the source of trouble, only the pickup remains. About all that can be done here is to substitute a new unit. If it is definitely established that the pickup is at fault, some effort can be made to repair it, and there are suggestions in the section on servicing as to how to proceed. Since these usually are sealed units, it is probably quickest to replace the pickup if replacements are readily available.

If you don't hear a loud buzz when you touch a hot input terminal, the amplifier is dead. Check to be sure that all volume controls are turned on in the channel you are testing. (In all servicing, you must watch out for the obvious; it is easy to overlook. For instance, if you are not careful, you may take the amplifier out of the case looking for a dead stage, and then find out that the master gain control had been turned off. Don't laugh—it has happened!)

If you can't get a sound through the amplifier from one input jack, try another one; try them all, in fact, before you pull the amplifier chassis out of the case. It may be that one channel is dead and the others are all right. If no sound is heard at all, pull the amplifier. More detailed testing will have to be performed.

Set the amplifier upside down on the bench, and make sure that the speaker is still connected. In high-powered amplifiers you can overload the output tubes and burn up a very expensive output transformer in about one minute if the amplifier is turned on without the right load (the speakers) connected. In some amplifiers you may have to rig up extension wires, but this is easy.

Transistor amplifiers are even more critical than the high-powered tube-types, on this point. There are two basic circuits used, the output transformer type and the transformerless type. Each has its own individual requirements. With the Class-A single-transistor type, do *not* turn the amplifier on with the speaker *open*. These will stand a short across the output, but operating the amplifier with the output open may blow the output transistor(s).

The output-transformerless types are exactly the opposite. They can withstand an open circuit in the output, but a short across the speaker terminals will blow both output transistors in a fraction of a second. When you hook up extension cables to the speakers or to a dummy load resistor, be very sure that there are no dangerously exposed bare wires, such as wires twisted together for extensions. Use only well-insulated test leads with insulated alligator clips, etc.

The reasons for this circuit peculiarity will be discussed in detail in the section on power-output testing.

CHECKOUT PROCEDURES

Here is a step-by-step method of testing that will show you where the trouble is in the least possible time. This is based on actual field experience in repairing these amplifiers, so follow it as closely as you can.

1. Check the B+ voltage—most of the troubles will be found in the power supply.
2. Check the amplifier, stage by stage, for voltage on plates and screen grids. Use a dc voltmeter for testing, set on a scale that is at least twice the maximum voltage you expect to find. For example, if there is about 250 to 300 volts of B+, then use a 500-volt scale to save damaging the meter.

When servicing, always start at the output—the speaker and output tubes—and work your way back toward the inputs. Why? Because this is the fastest way! No matter what you find in the early stages of the amplifier, you can't tell if the basic trouble is fixed unless the output tubes and speakers are working. So, start at the output. Check back through the circuit, fixing all troubles as you find them, and when you get to the input, the amplifier will be working.

When you make voltage measurements, watch the meter reading and listen also. When you touch the voltmeter prod to the plate of an amplifier tube, you will hear a small pop in the speaker if everything is working past that point. This pop won't be very loud when the plate of the power-output tube is touched, but it will be on the control grid. So, if you get the right voltage on the plate and screen, touch the grid with the prod. This should give you a louder pop, for you have gone through the circuitry of the tube, which amplifies the tiny disturbance you make when you touch the grid with the prod.

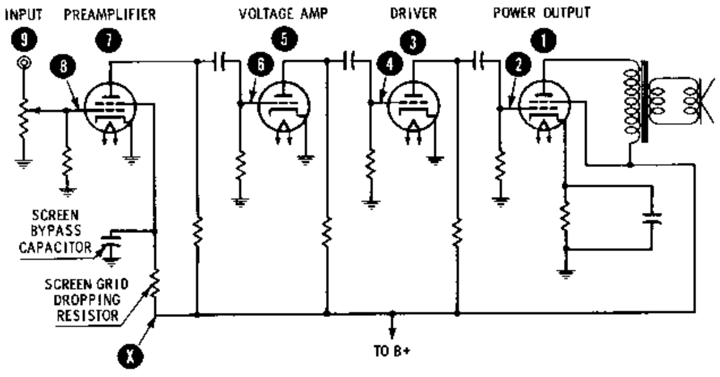


Fig. 4-1. Sequence of testing amplifiers.

Signal Tracing

As you go toward the input, you will hear louder and louder pops. This is one of the oldest methods of troubleshooting known—it was worked out back in the early days of radio where they called it the circuit disturbance test. It is still just as good as it was then, since it works every time. As you go along, watch for the stage where there is no pop. That is where the trouble is!

Fig. 4-1 shows a partial schematic of a typical amplifier. The idea is to check the signal path by listening for pops as the voltages are being checked. This path starts at the input and goes all the way through in a plain series circuit. Each time the signal passes through an amplifier stage, it gets louder (more amplification). Anything that breaks the chain will stop the signal right there. You can see the test method: Start at the output and work back toward the input. The numbers in Fig. 4-1 show the correct sequence. For this test it is assumed that the power supply has been checked and the right B+ voltage found at the filter output (X). If the output of the power supply is correct, the power supply itself must be all right, and the trouble must be somewhere in one of the amplifier circuits.

As an example, look at a typical case of trouble. Suppose you get good loud pops all the way up to and including test point No. 6. At point No. 7 you get a pretty weak pop, and hardly any at all on No. 8 (the control grid). This means that the trouble is somewhere in the preamp stage, and everything from there on is normal. The first step is replacing the tube—this is done simply because it is easiest and the problem could be a bad tube. If this doesn't help, leave the new tube in, at least until the trouble is found.

Next, measure the dc voltages around the tube—plate and screen. Assume that the plate voltage is nearly all right, but there is no screen grid voltage at all. This means that there is one of two troubles—an open screen-grid dropping resistor, or a shorted screen bypass capacitor. Either one will give the same symptom. Now you start to eliminate. (All of this work is a straight process of elimination—just keep testing until you find the bad part, once the defective stage has been isolated.)

First, measure the supply voltage at point X (the supply end of the resistor) to be sure that it is there. When you look at the schematic, it would seem that the earliest checks of the power supply output would also check out this point. Remember, however, there are wires connecting the various common points in the chassis, so these wires have to be eliminated as possible points of failure, at least indirectly. Assuming the proper voltage is present at X, the fault must be in the screen grid dropping resistor or the screen bypass capacitor. Turn the set off, and take a resistance measurement with an ohmmeter from the screen-grid tube pin to ground. If the capacitor is shorted, there will be a zero reading here—a dead short. If the capacitor is good, you will get a reading of the resistance of the screen dropping resistor plus the resistance to ground through the power supply. A normal reading here is something like one to two megohms. In this kind of circuit the screen dropping resistor is usually 820,000 ohms to 1.2 megohms.

This resistor could be open, so you take your next measurement directly across the resistor itself; the reading should be the rated value. All resistors are color coded to tell what size they are supposed to be. The ohmmeter reading must agree within 10% of this. If this resistor reads completely open, there is the trouble! Replace it with another of the same size and wattage, and turn the set on. The screen grid voltage reading will be normal. The input will now pop as loud as it should, and the input jack will give a very loud buzz or honk when touched with a fingertip—if the resistor was the only source of trouble.

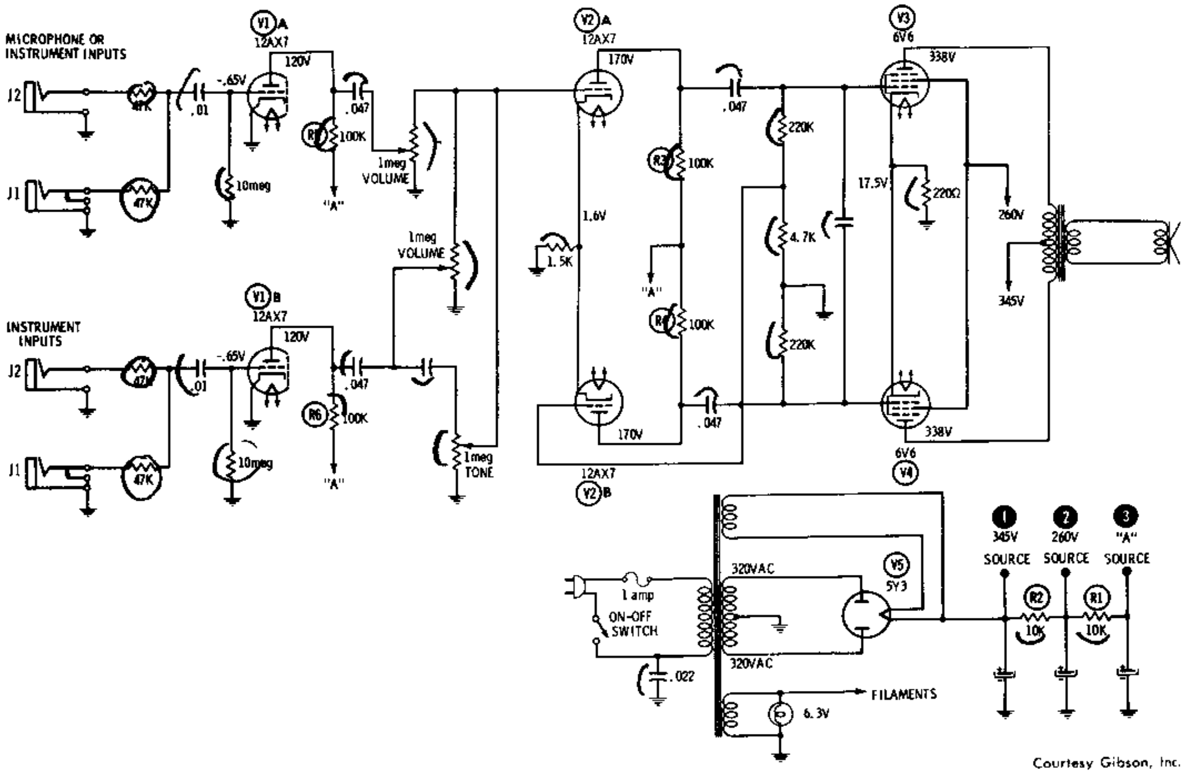
DETERMINING VOLTAGES WITHOUT SERVICE DATA

In the previous section, you made a voltage analysis of the amplifier using information gained from the schematic diagram of the amplifier. However, at times schematics are hard to find. Now see what can be done if you must test an amplifier circuit without this information. Fortunately, most of the amplifiers are conventional and since they use the same basic circuits, you can use a model amplifier for comparison. It has been done for many years. Servicing is easier if you have the service data, of course, but you can still test an amplifier and find the trouble if you know what each stage is supposed to do and how it does it. That is the reason for so much detail in the first section. How can this information be used in checking an unknown amplifier?

Fig. 4-2 shows the schematic of a commercial amplifier. This one isn't actually unknown, but it will serve as an example. What should the normal voltages be? Incidentally, there is a very valuable feature in your favor when checking voltages in vacuum-tube amplifiers—tolerance. A tube voltage can be inside a certain range, and still be all right. For example, a tube plate voltage rated at 100 volts can measure from 90 to 110 volts and still operate without affecting the performance of that stage. This is a 10% tolerance; many voltages have 20% or even slightly more. The only voltage that is really critical is the grid bias.

When you start on the unknown amplifier, the first thing, as always, is the supply voltage. Check the B+ voltage, at the filter input (point 1 on the schematic). How much should it be? A very accurate idea can be arrived at by measuring the ac voltage on the plates of the rectifier, and converting. With a normal load it can be assumed that the rectified voltage will be 10% to 20% above the rms voltage on the plates. In this one you will find about 320 volts rms on the plate, so an added 10% will give about 350 volts at the rectifier cathode for a guess.

In the circuit shown, a 10,000-ohm resistor (R2) is used as a filter choke, giving a fairly large voltage drop. The circuit indicates that the plates of the output tubes are connected directly to the rectifier output (filter input) through the primary winding of the output transformer; their plate currents will not flow through the filter resistor. This connection provides



Courtesy Gibson, Inc.

Fig. 4-2. Schematic of Gibson Model GA-6.

Table 4-1. Estimated Versus Actual Voltages

	Plate Voltage		Screen Voltage		Cathode Voltage	
Tube	Estimate	Actual	Estimate	Actual	Estimate	Actual
V1	120V	120V				
V2	160V	170V				
V3, V4	345V	345V	270V	260V		
V5					350V	345V

more voltage on the output tube plates; it also results in more hum. However, this hum is cancelled out in the push-pull output transformer, so this circuit is a practical arrangement to get a bit more plate voltage and consequently more output. Here the power-tube plate voltage will be very close to the voltage found on the rectifier cathode, or about 345 volts, since the only drop is in the output transformer.

What should the voltage be at the filter output (point 2)? The screen current for two 6V6s is being drawn through this resistor and also the plate currents of the first two tubes, 12AX7 twin-triodes. From the tube manual, screen current is about 4.0 mA for the pair of 6V6s, and 1.0 mA each should be a fair average value for the first four triodes. This gives about 8 mA current, which, by Ohm's law, is an 80-volt drop across 10,000 ohms or 270 volts at point 2.

When you examine the B+ circuits further, you will find another 10,000-ohm filter resistor (R1). This one carries only the plate currents of the preamplifier triodes (previously estimated at 4 mA for the four), so the drop across it is 40 volts. This gives an estimated 240 volts at point 3. Plate currents in voltage amplifier stages average from about 0.5 mA to 1.5 mA. The 1500-ohm cathode resistor connected to tube V2 makes the negative bias higher than on V1, and reduces the tube current. If the plate current in V2 is assumed to be 0.8 mA and 1.2 mA is assumed for V1, the drop across load resistors R3 and R4 will be 80 volts, and across R5 and R6 it will be 120 volts. Since the estimate for point 3 came out 240 volts, the plate voltage on V2 will be 160 volts, and on V1 it will be 120 volts. Thus, approximate readings for all points in the B+ circuit have been obtained.

When estimates are compared with the manufacturer's published data (Table 4-1), they turn out to be reasonably close—within 10%, in fact. Things will not always work out this well, but you see that it is possible to estimate all B+ values using some educated guesses and a tube handbook.

How do you know the size of the plate load resistors? They are color-coded so you can tell at a glance. Just find the plate connections on each socket, and look at the color coding on the resistor connected there. Any electronics handbook will tell you what the colors mean. You can also get an idea of what the normal plate voltage should be from the typical operating conditions table given for each tube in the tube manual.

Fig. 4-3 shows the complete B+ supply circuit for typical amplifier stages, beginning at the first place where dc voltage appears—the rectifier cathode or filter input. Learn this circuit; it applies to all amplifiers. If it is a bigger amplifier, there will be more; smaller ones will have less. It is always the same basic circuit. You can lift it out of the amplifier, mentally, and follow it through to see if there is any trouble in the plate voltages.

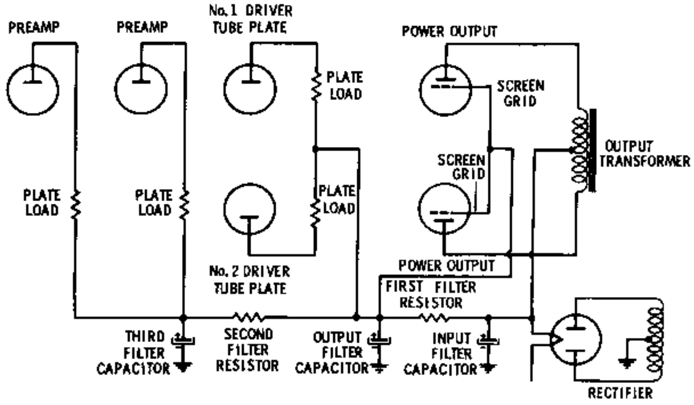


Fig. 4-3. B+ circuit of the basic amplifier.

LOCALIZING THE TROUBLE

Performance tests provide an easy way to find out just where trouble is. In other words, see just how much of the whole amplifier is working, and then concentrate on checking the part that isn't. It is easy to do. Turn the amplifier on, and make voltage and pop tests through the circuit, beginning at the output. The first time you go through a stage and it doesn't pop, there it is.

Take a typical trouble and see how to pin it down. For instance, assume the output stage and the B+ supply in Fig. 4-2 are all right, but either the amplifier does not work, or it has a very bad tone. On pop tests you find that the plate of the upper driver tube (V2A) has a pretty weak pop, and the grid of the same tube has hardly any at all. Obviously, something is wrong, but what?

Check the plate voltage; instead of the normal 170 volts or so, there is about 50 volts. This pinpoints the trouble as being somewhere in the driver stage. The first thing to check is the tube, so replace it—simply because this is the easiest thing to do, and experience has shown that tubes cause a lot of troubles. However, the results are the same, so the tube must have been all right.

To proceed, look at the B+ supply circuit in Fig. 4-2. Note that the plate voltage of this tube is fed through a 100,000-ohm plate-load resistor (R3). Turn the amplifier off, and measure the resistance of this resistor. If it has opened up or increased in value, the symptoms would be exactly what have been described. However, it checks right on the nose at 100,000-ohms, so go on to consider other possibilities. The supply voltage at the bottom or line end of the resistor is all right, because it measures the same as the screen-grid voltage on the power-output tubes checked earlier.

Summarizing the situation, the load resistor is all right, the tube is all right, but still there is not enough plate voltage. The only condition that can cause these symptoms is too much plate current being drawn through the load resistor, since it will also cause too large a voltage drop. The plate voltage is dropping across the resistor instead of across the tube. A tube draws too much plate current when the grid bias is wrong, so measure the voltage on the control grid. It ought to be zero; there is no bias voltage fed to the grid from any external source, and the 1.0-megohm grid resistor goes directly to ground.

To measure grid voltages you must use a high-impedance meter—a vtvm or high-resistance vom, since this, like all grid circuits, is a very high impedance. A low-resistance meter will cause the voltage present to be incorrect, since the meter itself acts as a shunt.

Assume that there is about 5 volts positive on the grid. This is definitely wrong. No grid in this type of amplifier ever reads positive if it is in good shape. It will be either zero or slightly negative. A 5-volt positive bias on a grid will cause the tube to draw a very heavy plate current; thus, the plate voltage will drop very badly because of the excess drop across the plate-load resistor.

Where could this voltage come from? Only a one-megohm resistor and a coupling capacitor are connected to this grid. The resistor goes straight to ground, so this is not a very likely source of voltage; however, the coupling capacitor is connected to the plate of the preceding tube, and this tube has about 120 volts positive on its plate. This is a likely suspect.

In all cases a capacitor must be a completely open-circuit to dc. The capacitor is used to transfer the ac signal voltages from the plate (output) of one stage to the grid (input) of the one following; it must always block any dc from getting through. (Although the correct name for these is coupling capacitors, you will find them called blocking capacitors in some cases.)

From the symptoms that have been assumed, it looks as if the capacitor must be leaking dc onto the grid. To make sure, disconnect the grid end of the capacitor, and hook the dc volts probe of a vtvm to the open end. Now turn the amplifier on. If the capacitor is leaking you'll read a positive voltage on the open end. This should be zero, of course, since a good capacitor is a completely open circuit for dc. A normal capacitor with good insulation will give just a very slight kick of the meter needle as it charges up. Then this reading will slowly leak off through the input resistance of the meter. If you have any residual reading, any voltage showing at all after the first charge has leaked off, the capacitor is bad and must be replaced.

Fig. 4-4 shows how this test is made. With the capacitor hooked to the grid resistor as in the original circuit (Fig. 4-2), you will probably read 5 to 6 volts dc. With the capacitor disconnected, you may read as high as 35 to 40 volts positive dc on it if it is leaky. The input resistance of the vtvm (11 megohms average) is much higher than the 1-megohm grid resistor. If you use a vtvm for this test, set it on a low dc volts scale. If you use a vom, set it on a voltage scale that will carry the maximum voltage to be read. In this case it is the 120 volts on the preceding tube plate. You can't blow up a vtvm with a voltage overload, but you can damage a vom, so be careful. After the first charging kick, set the meter to a lower voltage scale. For the final test use the lowest scale available;

even one volt positive through a coupling capacitor means it must be replaced.

You cannot make a leakage test with a common ohmmeter. The actual leakage through these capacitors is very small. If you could measure it, the resistance would go up to almost 100 megohms (far above the capacity of a service ohmmeter), but the capacitor will still leak enough to cause a lot of trouble. The voltage test is sure and fast, so use it.

Capacitor leakage is a very common trouble; that is why it is used as an example. It will cause loss of volume, a very bad distortion, and even damaged tubes if the leakage is bad enough. All of these problems result from the change in the grid-bias voltage. The amplifier tubes are driven into a very nonlinear part of their operating range, and the tone suffers very severely as a result. In fact, after a little practice you will almost be able to identify the problem by listening to the amplifier. Leaking coupling capacitors give the tone a characteristic muffled sort of sound that is easy to spot.

Now examine the process that you went through and the methods you used to find the trouble. Can you see the orderly steps in the example just given? The amplifier was examined one stage at a time, until a stage that was not doing its job was located. You stopped right there, found that trouble, and fixed it, before going any farther.

You used a process of elimination to find the defective component. In electronics work there are always several things that can cause any given trouble. Did you notice that things were eliminated one at a time, until the faulty item was reached? First the tube (it is the easiest), then the plate supply voltage, next the plate load resistor, and finally the real villain, the leaky coupling capacitor were checked out. There are only a certain number of parts in any circuit that can cause any given trouble. Patiently eliminate them one at a time, and eventually you will find the right one.

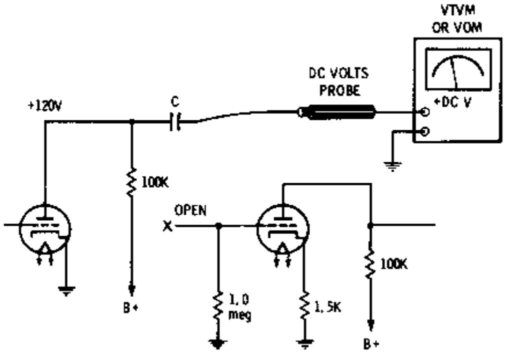


Fig. 4-4. Testing a coupling capacitor for leakage.

You may find it the first time; on the other hand, you may have to go all the way, as you did in the example. Just keep on until you find it. Later in this book there are more elaborate tests using complicated equipment. However, you will find that in this, as in all other electronics work, the majority of the troubles can be located and fixed with only very simple test equipment plus a good bit of plain old common sense. This is because a very large percentage of troubles are simple ones—a dead tube, a burned resistor, a leaky capacitor, and so on. Even the more complicated troubles will have very simple causes.

Always remember the process of elimination, and use it. If you know how each circuit works, you can quickly find the one that is not working, and start from there. There are some other tests later in this book that will help in the more difficult cases.

TRANSISTORS VERSUS TUBES

Only about 5 years ago the transistor was being hailed loudly as the answer to all the problems in electronics. Needless to say, this prediction hasn't come true. Transistors have advantages, but they're not the answer to all of our problems.

The transistor is a useful device and is ideally suited for certain applications. They do work, but there are, as usual, certain difficulties. These have led quite a few of the major amplifier manufacturers to go back to tube-type amplifiers, especially in the very high power ends of their lines. You'll see several examples of this in the Commercial-Amplifier section in the back of this book.

Among the main difficulties was the frequency of catastrophic failures or "avalanches." (One transistor blows, and it's followed in about 50 milliseconds by about five others!) Transistors with very high power ratings were difficult to obtain, without the need for stacking or paralleling, always one of the worst jobs in engineering. Finally, production transistors have a very wide "parameter-spread"; tubes, on the other hand, match one another very closely. (However, as this edition is being written, very high-power transistors, with high breakdown voltages are being perfected. These will undoubtedly show up in amplifiers very shortly.)

The wide parameter spread makes precisely matched pairs hard to find, and expensive. Contrary to some ideas, transistors aren't cheap, especially in the high-power types. A very high-power transistor can cost up to two or three times as much as a vacuum tube with approximately the same power rating.

The "immortal transistor" is another fallacy. At first, we were told seriously that the transistor would "last forever" in actual service. It has no filament to create heat, no cathode to become exhausted, it was perfectly sealed against environmental contamination, and so on. So, it could be soldered into the circuit as a permanent part. That statement must be amended to fit the truth as it is today.

Transistors do not "get weak" and lose amplification, as tubes do. But, they can develop quite a few other defects that cause a loss of gain, such as leakage, etc. So, they must be tested just like any other part. In fact, from my experiments and experience in actual bench-servicing of guitar amplifiers, the first think I look for, now, is a bad transistor—exactly the same technique we used in the servicing of tube amplifiers.

Before we go any further, let me say this: the modern, *well-built*, correctly designed transistor amplifier is a *very* good piece of equipment. If the transistors operate within their safety factors, run cool, and the unit is properly serviced, a transistor amplifier will give just as good service as any other. If you understand the operation of transistors, you'll have no real problems in servicing transistorized amplifiers, and keeping them up to par.

Incidentally, there has been a great deal of material published on transistors. Much of this, quite frankly, is useless to the service technician. You do not need to know all about how a transistor is *built*. All you have to know is how it works! It is the *function* of the device, and not its detailed structure, that matters. So, if you know how a transistor amplifier stage works, and what dc voltages to expect on any element, and that sort of thing, you will be able to service this type of equipment just as quickly and easily as you do tube amplifiers.

One of the bigger headaches is finding suitable replacement transistors, In too many cases, we cannot get exact duplicates, of the same type number, without too much delay. However, the replacement transistor manufacturers—Motorola, RCA, Sylvania, etc.—do have general replacement types which will work in practically all circuits. There is a method of selecting replacement transistors—we'll take this up in detail in just a little while. Used properly, this will let you choose a suitable replacement for any kind of transistor. This has been verified by several years of actual experience in commercial amplifier servicing.

THE NUMBERS GAME

Unlike tubes, the numbers on an original equipment transistor are often entirely meaningless. Every amplifier you open up for service will probably have different transistor numbers. This is almost universally true in import amplifiers, and often in U.S. built units. A few of the better companies do use standard-numbered replacement types, but I am afraid that you'll find a great many with what are called "in-house numbers."

In other words, the manufacturer buys a batch of transistors to meet his specifications. Then, he assigns his own type numbers to these, meaningless to anyone but his own stock clerks.

At regular (and quite frequent) intervals, the replacement transistor manufacturers publish listings of all the transistor numbers they can find. In quite a few cases, you'll even be able to find a listing of the number on the original part, and a recommended substitute. These lists are long—one manufacturer lists something over 38,000 different types of transistors! However, something like 35 to 40 replacement transistor types can be used to replace any of these. These replacements will work. In practically all cases, the transistor makers have run tests to make sure that they will.

Being skeptical by nature, I ran my own test series not too long ago, to find out if this was really true. It was! In no case did I find a replacement transistor listed that would not give service equal to or better than the original. However, if you should run into any difficulties, you can use the method to be given, to cross-check the specs of the original against the recommended replacement.

SERVICING TRANSISTOR AMPLIFIERS

What's the difference between transistor amplifiers and tube amplifiers? What different service methods must you use to work on solid-state equipment? The answer to both of these questions is the same—none. You use exactly the same methods, test equipment, and service procedures that you'd use on a tube type to check out a transistor amplifier. Why? Because all amplifiers do exactly the same thing—amplify a signal. So, if you use the *signal* as your reference, you can check out any amplifier and find the trouble in the shortest possible time. All of these amplifiers have a normal input signal of about 50 millivolts, and they amplify this to about 50 watts (100, 200, makes no difference!)

So, you'll see that while there is apparently a big difference in the appearance of the two types, there is absolutely no difference in their *action*. You'll still be able to use dc voltage readings, resistance readings, and, fastest of all, signal-tracing tests. The basic method is very simple. Feed in a known input signal, follow it through the amplifier with a scope, until you find out where it stops. Then, take dc voltage readings, and make resistance tests, and you'll find the defective part.

Things will look different, of course. Instead of working with +200-300 volts, you'll be reading lower dc voltages, say from about 16 volts of either polarity up to maybe 60-75 volts. Sometimes, dc voltages of both polarities will be found in the output stages. Instead of plate currents around 100-150 milliamperes, you'll have collector currents of up to 3-5 amperes, and so on. These are "differences of degree" only. The schematic diagram will tell you what the normal voltage readings should be. The basic test procedures will still be the same. Now, let's look at some transistor circuits in detail, and see how they're made. Just as in tube amplifiers, the circuitry has become pretty well standardized. If you know the few basic circuits, you're in good shape. You'll find them used in all amplifiers.

THE "HOT TRANSISTOR"

The transistor has several advantages over tube-type amplifiers. For one, less heat is generated inside the cabinet. Contrary to what you might think, transistors do *not* run cold. If you think so, carefully touch one of the big power transistors in an amplifier after it has been running for a while. Heat dissipation is a major problem in power transistors of all sizes. While they do not run as hot as tubes, heat is generated due to the normal power loss in the transistor, and this must be carried away to keep it cool, or as cool as possible.

A good deal of heat is generated in the collector-emitter junction of a power transistor. The early germanium transistors had a bad habit of getting hot, then developing some leakage, which in turn made the junction run even hotter, which caused more leakage, and so on and on until the transistor went into what was called *thermal runaway* and destroyed itself. The silicon power transistors now used almost universally aren't quite so bad about this; in fact, they will not go into thermal runaway, if kept anywhere within reasonable limits. They can withstand temperatures almost double those of the older germanium types.

The collector is internally connected to the case of the transistor, electrically and "thermally." This helps to get the heat away from the junction and outside of the transistor, where it can be radiated away. The cases of larger power transistors are mounted on big flat sheets of metal, called *heat sinks*. Due to their larger area, they radiate the heat away into the air.

This brings up another problem. The heat sink must make a good thermal contact to the transistor case. Yet, it must be electrically insulated from the chassis so that the collector voltage won't be shorted. This is accomplished by using very thin mica insulators between the case and heat sink. These insulators are coated on both sides with a special *silicone* grease. This grease helps the heat transfer between case and heat sink, but gives good electrical insulation. When replacing power transistors, you must be sure that the case is perfectly insulated from the heat sink, and that the mica insulator isn't cracked or damaged. Be sure to coat both sides of the insulator with the silicone grease. Leaving this "dry" will reduce the heat transfer by a surprisingly large amount.

SMALL-SIGNAL AMPLIFIER STAGES—CIRCUITS

Practically all of the "small-signal" stages in transistor guitar amplifiers will use a common-emitter circuit. This is exactly the same as the grounded-cathode circuit found in tube amplifiers. The base is the input, the collector is the output, and the emitter is common to both, thus the name. These are the stages known as voltage amplifiers in tube circuits. In the transistor amplifiers, they're usually called small-signal stages. Voltages will be much lower and currents will be slighter larger than in tube types. However, there will be enough *voltage* amplification to let us use our fastest test methods. These stages do the same thing—build up the very small input signal to a voltage (and power) level high enough to drive the power-output stages to full rated output.

So, we can use exactly the same tests as before. Fig. 4-5 shows a basic circuit of a typical transistor amplifier. (A lot of components have been left out, but this is the complete *signal path.*) You can make your tests in the same way as before—either "back to front" as shown in Fig. 4-1, or you can use the signal-tracing method shown here.

SIGNAL-TRACING TESTS

Let's assume that the amplifier is dead. It won't pass a signal from the input to the output. Dc voltage supply is assumed normal. So, we have our first fact; the signal path is broken somewhere between the input and output. To locate this break, in the least possible time, is the object of all troubleshooting methods. With signal tracing, it can be faster.

Refer to Fig. 4-5. Feed in a known input signal, say 400 Hz at about 50 millivolts. With a scope, check this level at Point 1, then at Point 2, and so on, going from base to collector of each stage. Normally, you'll see a good deal of voltage gain from input to output of

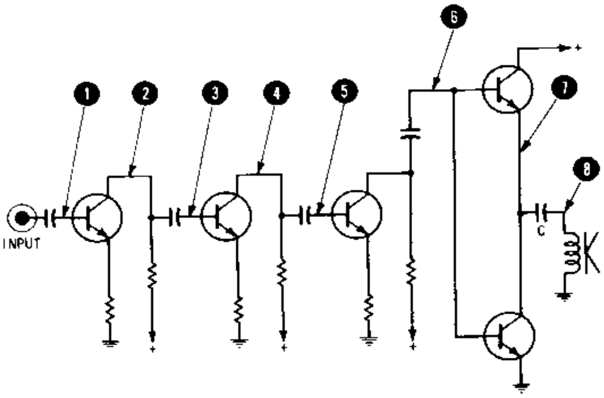


Fig. 4-5. Basic circuit of transistor amplifier showing the signal path.

each stage. In certain stages, you may only "break even." This is a typical characteristic of current-amplifier stages; the signal *voltage* will be almost the same at input and output. However, this is all right. What you're looking for is a stage which has input, but no output at all.

Since this amplifier will not pass a signal from input to output, there's a stage like this in there somewhere. When you find it, stop. You've found the trouble. Now, lay down the scope probe, and use the vtvm. (Here, and from now on, vtvm means any very high-impedance voltmeter, whether tube or transistor type.) Read the dc voltages around the dead stage. These will point out the type and location of the fault. Each one will have its own peculiar reactions on the dc voltages, as you'll see very soon.

TRANSISTOR PECULIARITIES

Transistors differ from tubes in one important way. A vacuum tube, with plate voltage applied, but no bias (same voltage on grid and cathode, or "zero bias") conducts a pretty heavy current. A high negative voltage must be applied to the grid to make the tube stop conducting. A transistor is different. With zero bias (same voltage on both base and emitter) it will not conduct current at all. This is one thing you must remember, for it is a very important clue to trouble.

This applies to all transistors, of any size, polarity, or type. A small bias voltage must be applied to the base, in a *forward* polarity. This is usually 0.2 volt for germanium transistors, and 0.6 volt for silicons. If this minimum bias isn't there, the transistor will be cut off.

You will seldom find transistors in audio amplifiers, such as guitar amplifiers, with only "cutoff bias" applied. In applications such as transistor TV, yes, in certain circuits. However, all small-signal stages in guitar amplifiers must work in Class-A, and this means a bias slightly greater than cutoff, for distortion-free operation of the stage. (In the output stages, working in Class-B, you'll find power transistors biased *almost* to cutoff, but not completely, for reasons which will be explained later.)

A transistor which is cut off is not conducting. So, there is no current through the load resistor, and there is no signal to pass along to the next stage. Also, there is no current through its emitter resistor. Remember these two facts; they're very important clues in testing for faults. Like the plate-cathode current path in tubes, the collector-emitter path in transistors is the important one. The lack of current flow here will cause two symptoms; the collector will read the full dc supply voltage, and there will be no voltage on the emitter at all.

This condition can be due to one of two things: incorrect bias (zero) due to trouble in the bias network, or to an internal open-circuit in the emitter-collector circuit (base-emitter or collector-base since the base is a part of both circuits.)

Transistors can short internally, also. In the basic circuit of Fig. 4-5, an emitter-collector short will probably burn up the emitter resistor, due to the high fault-currents. In circuits with higher resistance, you'll read the same voltage on the base as you have on the collector or the same voltage on emitter and collector. To make sure, take the transistor out of the circuit and make ohmmeter tests or use a transistor tester.

IN-CIRCUIT OHMMETER TESTS OF TRANSISTORS

The ohmmeter is very useful for transistor testing, in-circuit and out. In troubles like those just described, turn off all power and take resistance readings between all elements of the transistor. You can quickly locate either an open junction or an internal short.

There's a special test you can make with the ohmmeter. First, find out which lead of the meter has the positive battery voltage connected to it. (In voms, it is often the black lead; in the average vtvm or FET vom, it will be the red lead.) You can use this to find out the polarity (type) of an unknown transistor, and tell whether it has either a shorted junction or an open one.

For npn transistors like the ones shown here, put the positive ohmmeter lead on the base. You should now read a low resistance to both collector and emitter. Reverse the ohmmeter prods, and you should read a much higher resistance to both elements. If you get an open circuit reading between any pair of elements, either way, they are open. If you get a short-circuit reading both ways between any pair of elements, they're shorted. This is exactly the same kind of results you'd get if you were checking a diode, out of circuit. So, this is called the "diode-effect" test when used for checking transistors.

If you get a short reading across two elements of the transistor, take it out of the circuit, and repeat the tests. If you get the same results, all right; the thing is shorted. However, if the transistor reads good, out of the circuit, go back and check the circuit. Some of the parts are shorted, but the transistor itself is good. Check the resistances around the open socket of the transistor. For checking resistance values which may be suspected, you'll have to remove the transistor; otherwise you'll have the diode-effect in the circuit and get wrong readings, which makes things very confusing!

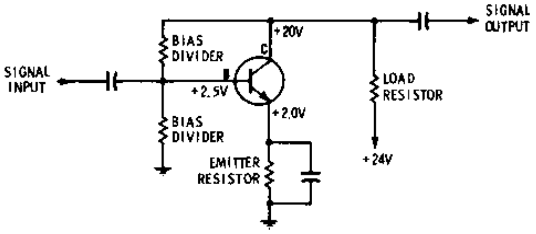
CIRCUIT VARIATIONS

There's an old French saying, "The more things change, the more they stay the same." This was never more true than in transistor circuits. You'll find examples of this in many amplifiers; circuits that look upside down, backward, and so on. However, if you look at them from the right viewpoint, you'll see that they *are* still the same. One good example of this is our old friend the common-emitter circuit.

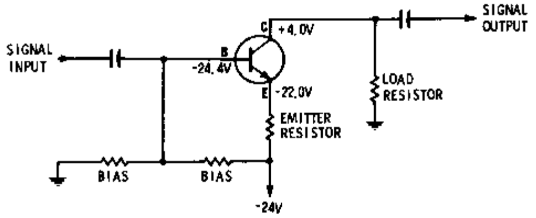
Here are its characteristics. The collector is always reverse-biased, with respect to the emitter; for an npn transistor, this means that the collector is highly positive to the emitter. The base must have a slight forward bias for the transistor to conduct; again, with respect to the emitter. Remember these. Now let's see how they can be used.

Fig. 4-6A shows one of these circuits, with the voltages applied in the "conventional" way, like those in a tube stage—input signal to the base, output signal taken off the collector, dc voltage fed to the collector through the load resistor. Dc voltages on the transistor are measured from the emitter.

Now, look at the circuit of Fig. 4-6B. Does it look entirely different? It is not. Here, the collector is grounded through the load resistor and a negative voltage is applied to emitter and base. However, if you'll take the voltage readings *from the emitter*, you'll see that all voltages are exactly the same as before! The collector is 18 volts *more positive* than the emitter. The base is still +0.6 volt more positive than the emitter. So, everything is right back where it was! The only difference between the two is the point where the *ground* is connected.



(A) Voltage applied to collector.



(B) Voltage applied to emitter and base.

Fig. 4-6. Common-emitter circuit.

In Fig. 4-6B, the collector current still flows through the load resistor in the same direction, and, if you'll notice, develops exactly the same voltage drop across this resistor, meaning that the signal amplification is the same (4.0 volts drop in both cases). The signal once again is taken off through the coupling capacitor and fed to the next stage.

Note the voltage-divider resistor network used to provide the proper base bias in both circuits. This is a very good circuit, and a common one. These resistors have a ratio which applies the proper bias voltage to the base. There is a variation of this, in which the "ground-end" resistor is left out. Its place is taken by the internal resistance of the base-emitter junction of the transistor. This saves one part, but does not work quite as well as the full divider circuit. The results are about the same. For a definite reference, look up the dc voltages given on the amplifier schematic. This will show you what to expect in any stage.

The collector voltage in either of these circuits will provide you with a valuable clue as to the operation of the stage. Note that in the circuit of Fig. 4-6A there is a 4.0 volt drop (+24 volts −20 volts on collector); this shows that there *is* current flowing in the collector circuit. In the circuit of Fig. 4-6B, there is no applied voltage, but the collector current still develops its 4.0-volt drop across the load resistor. If the collector voltage in the Fig. 4-6A circuit reads +24 volts, the same as the supply voltage, then you know that this transistor is not conducting, and thus not working. Find out why. In the Fig. 4-6B circuit, if the collector voltage is zero, same thing—no current, no conduction, and no signal output. Check the base-emitter bias, or check for an open transistor.

The Emitter Voltage

There's one handy quick-check, for all common-emitter stages. This is the emitter voltage. If there is a resistor from emitter to ground, or to the voltage supply as in Fig. 4-6B, check for the voltage *drop* across this resistor. If this is normal, this stage is conducting current, and is probably all right. With no emitter voltage there is no current or amplification; the transistor is open, the emitter or collector resistor is open, or the transistor is biased-off.

SIGNAL TRACING CAPACITY-COUPLED CIRCUITS

If your amplifier is dead, but the dc voltages are all proper, this symptom points to one of two things—an open coupling capacitor, or broken wiring in a "signal-only" circuit. Something has stopped the signal, but left the amplifier stages working, as far as dc voltages are concerned.

This is easy to find with signal-tracing methods. Feed a signal into the input, then quickly check it through the amplifier signal path with the scope. Look for the point where you find signals on the input side of a coupling capacitor, but none on the output side. There you are! (In one actual test, an open capacitor was located with this method in exactly 73 seconds.) When replacing the electrolytic capacitors commonly used for couplers in these circuits, observe the polarity.

SOLID-STATE AMPS—FINDING VOLTAGES WITHOUT SERVICE DATA

Earlier, you saw the method of determining what dc voltages should be found in a tube amplifier, without any service data. This will work just as well in transistor amplifiers. Go to the dc power supply, and read the maximum output voltage. This will be the voltage used on the output stage; you should find this voltage on the "hot collector" or power-input point of the output pair.

The small-signal stages will often use lower voltages. Starting at the highest dc voltage point in the power supply, follow the dropping resistors. These will normally be higher wattage than the types used in tube amplifiers. They must handle somewhat greater currents than the tube resistors, so they'll be bigger and easier to locate. Key point—look for a large resistor going from the high dc point to a big electrolytic capacitor. Decoupling and filtering in transistor amplifiers must be very good indeed, to prevent regeneration and oscillation.

You may find two- and three-section dropping resistor networks in these amplifiers. The farther we go through the dc supply network, the better the filtering. The input transistors must have an absolutely "pure dc" supply, to reduce the hum to the lowest possible level. Transistors are more sensitive to hum than tubes. More filtering will be used to eliminate this.

SELECTING REPLACEMENT TRANSISTORS

As we said earlier, getting a suitable replacement transistor, for an unknown type, can be a problem. In most cases, you'll have two alternatives. One, get an exact duplicate of the original from the manufacturer of the amplifier. Two, select a suitable replacement from one of the Replacement Guides. If your shop is a "Factory Service Agency," you'll have the exact duplicates in stock. However, if this is a strange instrument, or one of the unknown-make import types, you've got a problem. In a lot of instances, you will be able to find the stock number or type number of the bad transistors listed in the Replacement Guides. The replacements listed in these guides will work; at least, they have in all of the tests we made.

If neither of these alternatives can be used, and you have a completely unknown type to replace, there's still a way to do it. Fortunately for us, transistors are *not* nearly as critical as they were once supposed to be. They have a pretty wide "parameter spread;" in other words, the operating conditions can vary over a pretty wide range, with no loss of performance. Replacement tubes are made with almost precisely the same characteristics in every manufacturer's line. Transistors, even of the same type number, can have characteristics which vary quite a lot. The amplifiers are designed to handle this variation, which makes our job a lot easier.

First of all we can say this: all bipolar transistors are *alike*. They're all triodes, with a base, an emitter, and a collector. There are two major differences—the type, pnp or npn, and the material, germanium or silicon. So, this is what we must find out. Get a piece of scratch paper, and make up a list. What we're going to do is find the characteristics of the *original* transistor, so that we can find a duplicate.

First, we need the type, npn or pnp. If you have a schematic, this is easy. Look at the emitter arrow. If it points toward the base, it's a pnp; if it points away from the base, it's an npn.

To determine the material, germanium or silicon, check the voltage between base and emitter. Silicon transistors need a 0.6 volt base-to-emitter voltage to reach the conduction threshold. Germanium types need only 0.2 volt. In most of these circuits working in Class-A, the bias will be slightly above this value. However, if the bias voltage is *less* than 0.6 volt, the transistor *has to be* a germanium. If it's 0.6 volt or slightly more, it is most likely to be a silicon. (In practically all of the later model amplifiers, *all* transistors will be silicons, from the small-signal types to the power outputs. Silicon transistors have quite a bit better leakage characteristics, and they will be found in the great majority of amplifier circuits today.)

Now, we have two things. Next, what kind of stage is the transistor working in? There are three groups—small-signal, including preamplifiers and all small transistors up to the drivers; the drivers, which must have a slightly higher power rating, and the power output types. With a schematic diagram, you can look at the position of the transistor in the circuit and tell how it is being used.

In the small-signal types, we don't have to bother about anything except voltages. These transistors work with very small currents, well within the ratings of even the smallest types. So, without the schematic to tell us, we can read this voltage from the transistor terminals and find out. Take the defective transistor out of the circuit. If possible, identify the basing; emitter, collector, and base. (Compare the type against the base diagrams in the Replacement Guides.)

Turn the amplifier on, and read the dc voltages on the three holes in the PC board. The chances are that this transistor is working in a common-emitter circuit, with an emitter resistor, as in Fig. 4-7. Now, what voltages would you read with this transistor out of the circuit? You would read the full dc supply voltage on the collector terminal, the normal base-bias voltage on the base terminal due to the voltage-divider connected from the dc supply to ground, and zero voltage on the emitter terminal. There is no current flowing in this circuit, so there is no voltage drop across the emitter resistor. You can often identify parts in this circuit visually. Look for a small resistor from one terminal to ground; the chances are that this will be the emitter resistor. If there is a bypass capacitor across it, even more so.

This gives us what we want to know. The dc voltage on the collector will be the maximum voltage applied to this transistor in actual operation, since we will have a good bit lower voltage with the transistor working (drawing current) than we do now, with only the meter drain to load it. The *polarity* of this voltage gives us the type of transistor—pnp or npn. If it is an npn, as in Fig. 4-7, the dc collector voltage will be positive. (Collectors are always reverse-biased, remember?) If it is a pnp, the collector will be negative.

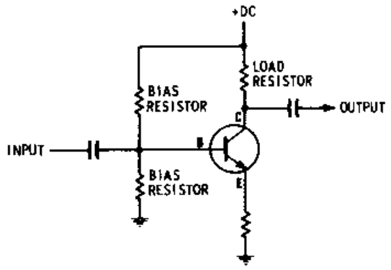


Fig. 4-7. Typical transistor common-emitter stage.

Now we've got a few facts, so we can start making out our list of the characteristics of the original transistor. For example, we need a preamplifier transistor, npn, very probably silicon, that has a maximum of 20 volts on its collector.

We're ready; now, we get one of the Replacement Guides, and start looking through the characteristics charts in the front (or back) of the book. The Motorola HEP Guide shows quite a few types that should work. For instance, a HEP-53 npn, silicon, breakdown voltage 30 volts. This is above our maximum voltage, but for peace of mind, let's keep on. We find a HEP-738, same characteristics, but a breakdown voltage of 40 volts. That's better. HEP-53 is in the TO-5 case, round metal 0.35 in. wide. HEP-738 is in the TO-92 case, a very small epoxy type. So, if the location is crowded, we can always get this one in.

There are many others. RCA's SK-Guide shows an SK-3024, same characteristics, TO-5 case, and a breakdown voltage of 90 volts. Sylvania lists a type ECG-128, same characteristics and a breakdown voltage of 80 volts. General Electric's Guide shows a GE-10, TO-92 case, 25-volt breakdown. So, you can see that any of these transistors would work in this circuit; the major consideration here is to get one with ample safety factor to avoid breakdown from high voltage.

So, there it is. That's the basic method. You make up your scratch-paper list of the characteristics of the original transistor, then match them as closely as possible. Be sure to choose a replacement with a collector-emitter breakdown voltage well above the maximum voltage applied to the original transistor. The actual basing of the replacement is not at all important. You can always twist the leads around to go into the correct holes in the PC board. Spaghetti can be slipped over one or more leads if they are too close together. The basing of the new transistor will be shown on its package.

After replacement, turn the amplifier on, and check for the dc voltages on each element. Better still, feed a test signal into the amplifier, and read the waveform on input and output of the new transistor. This is the fastest and surest way of telling whether the replacement is going to do the job. If you do run into trouble, such as clipping, for example, try a transistor with a slightly *lower* beta than the first choice. This seldom happens, but it could.

There is one other "method" that can save a lot of work. Check over the amplifier and see if there is another transistor in there with exactly the same numbers that you found on the defective one. If so, take it out (making a careful sketch or note of how it is connected) and test it. Your transistor tester will tell you, very quickly, its type, and its beta reading. It will often tell you whether it is a germanium or silicon, although there *is* a small chance of confusion, in one way. A small-signal transistor with absolutely no leakage at all will probably be a silicon. If it shows a small amount of leakage, it could be a germanium. (Small leakage is normal in germanium transistors.) With this data, plus the measured dc voltages, you can make up your spec sheet much faster. The use of identical transistors in several preamp and small signal stages, fortunately, is pretty common.

SELECTING DRIVER TRANSISTORS

To find a replacement for a driver transistor, use the same method. However, since driver stages need a little more power output, you'll have to check the current and power ratings of the replacement. In smaller amplifiers, you'll find that drivers will be rated at about 5 watts, as a sort of ball-park figure. These drivers will be in TO-5 cases, and have dc voltages up to say 25 volts, with currents that are in the 25-50 mA range.

In the bigger amplifiers, you may find dual driver stages; a medium power type, driving a driver transistor that may be of the same type as the big output transistors. This would be most likely in the 100-150 watt class of amplifiers, where a lot of drive power is needed to push the output pair to full output.

For medium-power driver transistors, the lists will show you such types as RCA SK-3048, 5 watts, 30 volts breakdown; SK-3024, 5 watts, 90 volts breakdown; both npn's. For pnp, SK-3025, 7 watts, 90 volts breakdown. In Motorola, HEP-242, 6 watts, 40 volts breakdown, pnp. Duplicate in npn, HEP-243. Sylvania, ECG-152 and ECG-153 are similar; 40 watts max, 60 volts breakdown. So, as you can see from these examples, there are many driver transistors that will work.

POWER TRANSISTORS

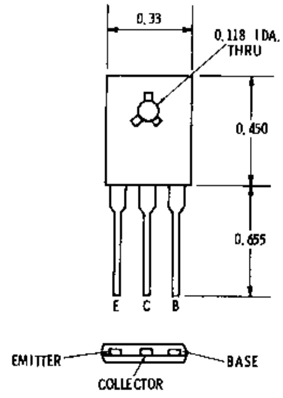
Now, we come to the "big boys"—the power-output transistors. You'll find some of these with amazingly high power-handling ability. Some can actually dissipate 100 or even 150 watts. Bass amplifiers (which need the greatest power), vocal amplifiers, and other instrument amplifiers are now being built in all solid-state designs with total undistorted power outputs up to 300 watts. In most cases, as you'll see by the schematics in the back of this book, the amplifier will be designed with two output "channels," each one feeding a single speaker or speaker system, 150 watts each, for a total of 300 watts UPO (undistorted power output). The actual peak power will be something like double that, but is not usable due to the increase of distortion.

At the time this is being written, 150 watts UPO seems to be about the practical limit. By the time you read this, there may be higher-powered devices available. However, they'll all use the same circuitry, only the voltages and currents will be different.

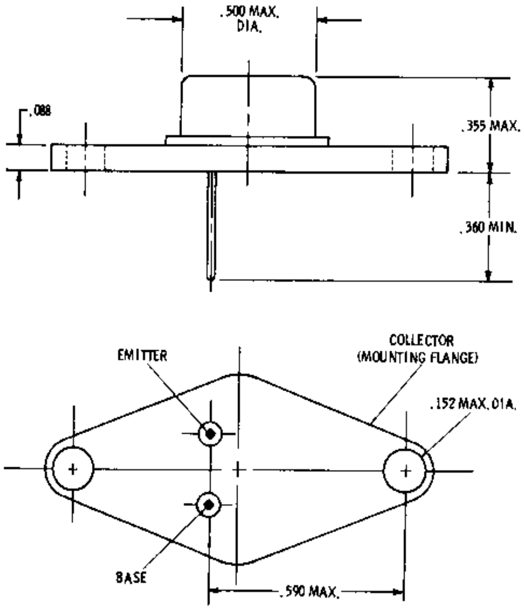
Some of these stages use a comparatively low voltage, but the current, of course, is higher. For example, 30 volts on the collector, with a current of 5.0 amperes, equals 150 watts of power dissipation; 80 volts collector, at 2.0 amperes, about the same. Note that this refers strictly to the power-dissipation ability of a *single* transistor, and not to the total power output as developed across the speaker. This will be discussed very soon. What we need now is the absolute maximum that will show up across this transistor, so that we can find a replacement type that will stay in there and take it. This means choosing one with maximum ratings much *higher* than the normal maximum voltage/current product applied to the transistor in actual service, so it will not be overloaded, or run too close to its maximum rating. Overloaded transistors run very hot, and don't last too long.

Cases and Mountings

In low-power and medium-power applications, say from 5 watts up to 35-50 watts, you'll find power



(A) Case 77.



(B) TO-66 case.

Fig. 4-8. Cases for low- and medium-power transistors.

transistors in the flat three-lead cases called case 77. Fig. 4-8A shows these. Typical examples of this type are the Motorola HEP-245 and HEP-246. Some transistors in this power range will be in the TO-66 case, shown in Fig. 4-8B, which is the familiar "diamond-shaped" case with the dome, like the larger TO-3.

Fig. 4-9 shows the TO-3 case used in almost all of the very high-powered types. In these (and in the preceding types as well) the collector of the transistor is electrically and physically connected to the case. This is done to get heat away from this junction as fast as possible. The flanges of the case are bolted tightly to large heat sinks.

Use the same method of selecting replacements that you did before. Now, you *must* match the case-type, but this is easy; they'll mostly all be in TO-3 cases anyhow. You'll find the high-powered types listed in all of the Replacement Guides, except in rare cases. When this happens, use the "breakdown voltage/maximum current/maximum power dissipation" checklist.

For example, in one of the very high-powered amplifiers, Ampeg's ST-42, with 120 watts UPO a total of four RCA type 10003 power transistors are used, two in each half of the OTL pair. Checking the Replacement Guides, you'll find that RCA lists an SK-3036, Motorola a HEP 707, Sylvania an ECG-130, and so on. (The number of "10003" is an "industrial device" number; others with similar characteristics will be found in the "40000" series, and so on. Same thing; they're all just big power transistors!)

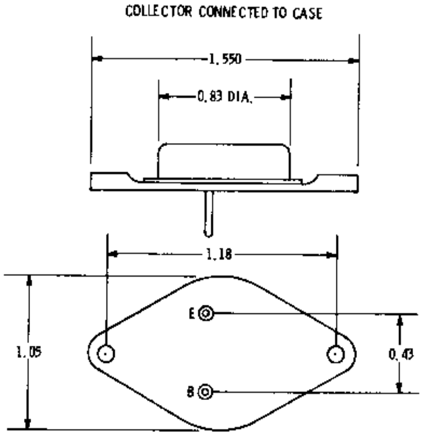


Fig. 4-9. The TO-3 case used for high-power transistors.

Heat Sinks and Mountings

When you replace any high-power transistor of a type big enough to need a heat sink, be very sure that you get *all* of the insulators, etc., back *exactly* as they were. Don't forget to check that little mica insulator. If it's cracked or broken, use a new one. You'll find a new one packed with each replacement power transistor. Even if the silicone grease wasn't originally used between the transistor case and insulator, and insulator and heat sink, put it on. This helps the heat transfer between transistor case and heat sink, and helps the insulation, too. Replacing a transistor "dry" can let it run several degrees hotter than it should.

Matching Output Transistors

You'll find that all of the big power transistors are used in pairs. Single power transistors are found only in the small amplifiers. The most common failure in these Class-B circuits is a breakdown of one or the other of the power transistors in the output pair. For some unknown reason, both transistors seldom blow at the same time. The "top transistor," that is, the one which is directly connected to the power supply, seems to be the one which fails the most often.

Regardless of which one is bad, always replace *both* transistors. This is necessary to get a good match between the two devices. Replacing only one and leaving one of the originals still in there, can result in a bad mismatch of characteristics. The least important result of this would be a bad distortion; the worst would be early failure, perhaps of the new transistor.

You can get specially selected "matched pairs" of power transistors in all replacement lines, either for the stacked circuits, with both transistors of the same type, or the complementary-symmetry circuit, with transistors of identical characteristics but opposite types. For example, Sylvania's ECG-130-MP, which is a matched pair of replacements for the big 10003 transistors; RCA shows a "SK-3037," which is a matched pair of SK-3036s, and so on.

For complementary-symmetry pairs, one pnp and one npn, you'll find listings of special complementary pairs. RCA's SK-3024/3025, Motorola's HEP-245/246 in the 30 watt range, or HEP-247/248 in the 100-150 watt range, and so on. Or, if you can't find exactly what you need in a factory-matched pair, look up suitable types in the listings. You can get a very good match by checking the proposed replacements on your transistor tester, and comparing the beta readings, etc. There is only one pitfall you must watch for: DON'T pick a silicon type for one and a germanium for the other. The distortion that this causes has to be seen to be believed! (For obvious reasons, I will not disclose exactly HOW I got this little gem of information but you can believe it. This is borne out by actual experience.)

Replacing transistors is not at all hard, if you go at it in a logical way. Just make up your list of characteristics, and then allow yourself as high a safety factor as possible. If you do this, your replacements will work just as well as the originals: in some of the import amplifiers and the cheaper types, even better!

TROUBLESHOOTING THE TREMOLO CIRCUITS

The first symptom of trouble in the tremolo circuit will be the absence of any tremolo effect in the tone. With the strength control wide open the tone will still be plain. This can be checked out just as you would any other trouble. The first thing to check is the tremolo oscillator tube. Replace it and see if this helps. If it does not, then see how far the tremolo signal is going.

You will not need a scope to trace such a low-frequency signal. Put your voltmeter on the plate or cathode of the tremolo oscillator tube, and set the speed control to its lowest point; this will be only 1Hz or so. You will be able to see the oscillations—the meter needle will move back and forth. If it remains steady, the circuit isn't oscillating.

In all oscillator circuits, failure to oscillate is due to one of three things: (1) a bad tube or transistor, (2) wrong supply voltages, or (3) the failure of some part in the feedback loop—unless the output signals get back to the input in the right phase, the circuit will not oscillate. After you have checked the tube by substitution, check the plate voltage to make sure it is all right. If it is not, then find out why—open plate resistor, open depth or strength control, etc. If there is plate voltage but still no oscillation, check all of the capacitors in the feedback loop. If one of them is open, it will open the loop.

A leaky capacitor here will change the phase-shift angle; the oscillator will work, but on the wrong frequency. So, if it is working much too fast or slow, check the capacitors in the feedback loop. Also check for any drift in the value of the resistors; they are equally important in making the thing work on the right frequency. Use the same servicing methods here that you did on the amplifier stages earlier; there are only a few parts in the circuit, and if the oscillator does not work, then some component must be defective.

If the oscillator is working as shown by the swinging of the meter needle, but there is no tremolo effect, signal trace the varying voltage. Start at the plate where the signal is all right, and follow it through the various parts until you find where it is being blocked. In the circuit of Fig. 2-10 the tremolo signal comes from the 12AX7 oscillator, through the 250,000-ohm depth control, a 750,000-ohm resistor, and a .1-μF capacitor, and is applied to the screen grid of the 5879 second preamplifier stage.

You can follow the voltage swings up through the control and the 750,000-ohm resistor, and even through the capacitor onto the screen grid itself, if they are very slow. Failure of any part in the circuit will show up right away. For example, if the .1-μF capacitor gets leaky, it will change the screen grid voltage. There is about 90 volts on the plate of the tremolo oscillator and only 20 on the 5879; a leak in the capacitor would result in the screen grid voltage going above normal. Incidentally, if you get a peculiar action in this circuit—the tremolo is working but isn't working right, or you can't get enough depth or strength—check that 6.8-megohm resistor. If it has increased in value, it will reduce the screen grid voltage and upset the action of the tremolo. A key clue here will be the fact that without any tremolo being used, the amplification of that channel is very low, since there is no screen-grid voltage at all. It can even work very peculiarly—you may not be able to get any signal at all through that input unless the tremolo is turned on. Always suspect any big resistors you may find in these circuits. Many servicemen have a habit of thinking, "Oh well, 6.8 megohms. What if it does drift a little off value? It's so big that it won't make any difference!"

This is not so. Most of the very large resistors are critical, especially if they are used in a B+ voltage distribution circuit as this one is. When they do drift, they seem to want to increase in size most of the time. Many of these have been checked and found to be up to 10, 12, or even 20 megohms in value, when the color code stated plainly that they were supposed to be 3.3, 6.8 megohms, and so on. Don't ever overlook these resistors—that just might be the trouble.

VIBRATO

A true vibrato is very hard to get electronically, so all manufacturers use the mechanical type; a tailpiece on the guitar can be moved up slightly back and forth by a long lever. Troubles here are mechanical. Frankly, the author has encountered very little trouble in this assembly, but it is always possible. One of the bearings or suspension brackets can wear or become loose, and this would lead to some odd troubles when the vibrato lever was moved.

REVERBERATION CIRCUITS

Troubles in the reverberation units are typical—plenty of signal (volume), but no reverb effect at all. Check tubes, voltages, capacitors, and resistors, and follow the signals through the reverb unit just as you would through any other amplifier. Leaky coupling capacitors in tube units can cause a very odd distortion: the straight signal will not be distorted but the delayed signal will. Open electrolytics in transistor units can cause trouble; so can shorted transistors. Check base and emitter voltages very carefully on transistors to make sure that the bias is all right. Since this is only a few tenths of a volt, incorrect bias can be easily overlooked.

The reverberation unit springs must be left severely alone. Because of their construction, they can seldom be repaired successfully in the field. There are only two things that go wrong with these: failure of the transducer or failure of the pickup unit. In either case the defective unit must be replaced, which involves taking the springs out and putting them back later. This inevitably causes them to get stretched, and their delay time changes very drastically. Since no service shop has the facilities for testing delay times in milliseconds, the best thing to do with a defective reverb unit is replace it with a new one. Some manufacturers have service facilities where the bad unit can be sent back for repairs.

Reverb units are easy to test, so you can be sure that the unit is definitely defective. Simply feed a signal into the grid of the reverb input tube, and check to see if it is coming through the reverb unit and is getting to the grid of the reverb output tube. If the circuit is confusing, the direct path circuit can be broken by disconnecting a resistor. That way you know that any signal you get must be coming through the reverb unit itself. Broken wires are not uncommon, and these, of course, can be repaired; as long as the delay springs are not disturbed, you can do anything you have to.

TEST EQUIPMENT FOR SERVICING GUITAR AMPLIFIERS

You won't need any "specialized" test equipment for servicing guitar amplifiers. Ordinary "shop-type" test equipment will do everything we need. The average service shop has practically everything necessary. There are a few pieces of auxiliary equipment such as dc ammeter, Variac, wattmeter that will be very useful, but these aren't expensive.

Tests on these amplifiers will be confined to reading ac and dc voltages and current, signals, and resistance. You'll need a source of test signals, for the signal-tracing tests.

AC and DC Voltmeters

You'll need an instrument to read ac and dc voltages. For this, you can use one of two types—the electronic volt-ohmmeter which can be a vacuum-tube voltmeter, or a solid-state vom, generally using FET's. These instruments have a very high input impedance, which means that they load the circuits under test very little. For our purpose, either type will do. Servicemen in general refer to them all as "vtvm's," so that's what we'll call them from now on.

Many shops use the vom. This is a "straight" meter, without electronic amplification, as used in the vtvm's. Voltage and resistance ranges will, in general, be about the same. The main difference is that the vtvm's will not be damaged if connected to voltages higher than the full-scale setting. The vom will be damaged. For best results, you can use the vtvm for all ac or dc volt-ge measurements, and use the vom mainly for current eadings. These have dc current ranges from a few miliamperes up to several amperes. One handy service rocedure is to use the vom to read the current in a tage under test, while taking voltage readings with the tvm at the same time. For example, while setting the ollector current and base bias voltage on a high-power utput stage; two meters make this job much easier. Many men keep a single high-range dc current meter n the bench, for current testing.

The Oscilloscope

For all signal testing, the oscilloscope is by far the most useful instrument on the bench. It can do things that none of the rest will. The scope will not only show you the peak-to-peak voltage of the signal, but it will also show you the *waveform*. So, this is the only instrument that can be used for finding the cause of distortion. Any change in the signal waveform means distortion of the output; clipping, unequal amplification of both halves, and many other faults can be quickly and accurately spotted with the scope.

With only two tests, you can tell whether a given stage is passing a signal, or amplifying it as much as it should. For signal-tracing tests, to locate a dead stage, the scope will get results in about one-fourth of the time needed with all of the rest put together. Simply touch the probe to the input, then the output of a stage, and note the difference between the amplitude of the two signals. If you have signal at the input, but none at all on the output, that stage is dead. Put down the scope probe and start taking dc voltage measurements; you have found the source of the trouble.

This is all audio work, so an expensive wideband scope is not necessary. Many shops have perfectly good, but old, scopes which won't work on color TV, etc.; they will be perfectly good for audio, since the highest frequency we'll be working with will be about 20 kHz.

The scope can make one test that no other can make. With a quick jab of the scope probe on a filter capacitor in the dc power supply, it can locate the cause of hum, oscillation, feedback, etc. If you see any kind of *signal* on the dc power supply circuits, look out! This means trouble.

The Audio-Frequency Signal Generator

The preceding instruments have all been what we might call "output" testers. They read the dc supply or output of a certain circuit, dc voltages, waveforms, etc. To complete the setup, we need an instrument that will give us a known source of *test signals*. For the best results, we need a single-frequency sinewave audio signal, which can be controlled in both frequency and amplitude.

This means some kind of audio-frequency signal generator. The typical instrument will cover a frequency range from 20-30 Hz up to 20 kHz, and have a maximum audio signal output of about 3 to 4 volts. Calibrated attenuators will reduce this to a very low level; for testing sensitive amplifiers, we need a level of about 50 millivolts. The audio signal generator does not have to be an expensive, high-precision type, but should have an output with less than about 3% distortion. This isn't hard to get; there are a great many makes and models to choose from, within a moderate price range.

The Auxiliaries

There are other things, some of which wouldn't be called "test equipment" alone, but which can be very useful in speeding up the work of getting the guitar amplifier back into good shape. These are not expensive, and will pay for themselves in a short time.

The *Variac*

A variable-output ac power-supply transformer, usually called a *Variac*, is extremely useful. With this, you can adjust the ac line voltage supply to the amplifier to any level from a few volts up to 135-140 volts, well above the normal line level. Later on, we'll show you a very useful test you can make with this instrument, one which can save you the entire cost of the *Variac* on one job.

Courtesy Sencore I

Fig. 4-10. Single unit multirange wattmeter.

Dummy Loads

For making full-power tests of guitar amplifiers, especially the very high powered types, a suitable dummy load must be connected in place of the speakers. (You simply can not turn loose up to 300 watts of audio power inside a small shop. It may break the windows!) So, you need a high-wattage load resistor, which can be adjusted to match the rated load impedance of the amplifier being tested, and carry the power to be dissipated.

You can get high-wattage, low-resistance resistors from surplus, or make them up of combinations of ordinary stock units. Ohm's law will give you the values needed. For example, ten 10-watt resistors in parallel will handle 100 watts of power. (ten 40-ohm resistors, paralleled, equals 4 ohms, and so on)

The Wattmeter

A wattmeter can be very useful, especially in dc power supply testing. By reading the actual power being drawn by the amplifier, it will tell you instantly if there is anything out of order. This will detect short-circuits, open circuits, high leakages; anything abnormal, instantly. Fig. 4-10 shows a typical single-unit, multirange wattmeter. No special connections are needed; you simply plug the amplifier into the panel outlet of the wattmeter, and turn it on. The actual power drain is read on the meter.

Later on, as we go through the various test procedures, we'll show you how to use these instruments, singly and in combination, to test any part of any circuit, and to make all necessary test readings to insure the best performance from the amplifier.