The Professional Technician's Guide to Solid-State Servicing

A to-the-point presentation of the information electronic technicians need to proficiently service solid-state circuitry. Included are concise, but thorough, explanations of how semiconductor devices function, their important service-related characteristics, their typical applications in consumer electronic products, and proven methods of testing them in and out of circuit.

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The Professional Technician's Guide to Solid-State Servicing

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Chapter 1

Transistor characteristics important to servicing

Knowledge of the internal construction and chemistry of a transistor is not necessary for efficient troubleshooting. But it is very helpful to take the basic physical construction of a typical transistor (Fig. 1A) and visualize it as two diodes wired back-to-back as shown in Fig. 1B. Of course, two separate diodes cannot possibly have collector-emitter current and thus cannot amplify.

In an actual transistor, the two diode junctions are seldom symmetrical and the base material is so thin that current can flow through it between collector and emitter when stimulated by collector voltage and a forward base bias. Varying the base bias by a signal causes collector current variation; this is amplification.

According to the way a transistor measures on an ohmmeter, its "black box" circuit consists of three diodes and two resistors, as shown in Fig. 2A. The chart in Fig. 2B is a good guide to the approximate readings expected with germanium transistors when checked on a VTVM has a 1.5 volt ohmmeter battery. Don't be surprised if many normal transistors show more base-emitter than base-collector leakage. This only means the collector and emitter are not symmetrical. If you use other scales, or a meter with another battery voltage, the resistance readings will be radically different, since all solid-state diodes change resistance according to the voltage applied to them.

The same low base-emitter, base-collector or collector-emitter ohmmeter reading when the test lead polarity is reversed, indicates a defective transistor with a shorted junction. An open reading for both polarities indicates an open junction. One common defect is a short from collector to emitter. Often there is no corresponding short from the base to either the collector or emitter. This is difficult to understand since the base is located between them. Evidently the excessive current caused by the collector-emitter short burns away the base material around the shorted area.

Silicon power transistors also can be checked as shown in the chart of Fig. 2B, although all the resistances will be much higher than those listed. Tests of small silicon transistors will be limited since the leakage resistance will be above the highest ohmmeter scale. During checks on both germanium and silicon transistors, don't use a lower scale than the ones specified in the chart for forward bias readings because the ohmmeter current (which reaches 150 mills on the X1 scale) might damage small transistors.

You may question why we should bother to check transistors with an ohmmeter when there are many excellent transistor testers on the market. First, there are many more ohmmeters than transistor testers around a typical workbench. But more important, the ohmmeter tests give more of an insight into circuit voltage and resistance measurements and how they are affected by transistor defects. It is excellent belt-and-suspenders technique to use ohmmeter readings to verify the verdicts of the transistor tester.

Tubes vs. Transistors

After the obvious lack of a heater in a transistor and the necessity for a high vacuum surrounding the elements of a tube, the next radical difference between tubes and transistors is in the polarity of the bias and the elements (Fig. 3.)

A tube without bias (grid shorted to cathode) will draw excessive plate current. A transistor without bias (base shorted to emitter) will have a minimum collector current, and making the base positive increases the collector current. The tube plate voltage is positive, the polarity to cause maximum conduction, while the grid is negative to prevent any grid current.

By contrast, the positive voltage applied to the transistor collector will cause less collector current than would a negative supply (but this current would not be under the control of the base-emitter). The base is positive which is the polarity to cause maximum base current. A negative base voltage would be reverse-biased and would result in no base or collector current (except leakage).

To say these facts another way, a grid is reverse-biased, a plate is forward-biased, a base is forward biased and a collector is reverse-biased. A transistor always draws base current (low impedance input) and a tube has no grid current (high impedance input) when both are operated in class "A".

Effects of Heat

Current and gain in vacuum tubes are affected very little by ambient temperature since each tube has its own private built-in furnace that is many times hotter than the surroundings. Not so with transistors. Heat is not necessary for normal operation; any generated heat is strictly a byproduct, and often a detrimental one.

Those of you who have experience only with well-designed solid state circuits may be surprised how thermally unstable some of the simpler circuits can be. In the low-level audio circuit of Fig. 1A, assume that the base resistor is the correct value to produce maximum gain. Use an audio oscillator for an input signal, monitor the output with an AC meter and the collector with a DC meter. Just cup your thumb and forefinger around the transistor case for a few seconds and watch both the output AC and collector DC voltages drop enough for a definite difference in reading. If you go one more step and also monitor the base-emitter voltage, you will discover that the base voltage decreased from this slight increase in heat. The transistor conducted more collector current with less base voltage. Or turn that statement around so it reads: for the same collector current, less forward bias is required at higher temperatures.

It is undoubtedly true that more base current caused more collector current (transistors are "current amplifiers"), but base current is very difficult to measure, while base voltage measurement is simple if you have a meter with a full-scale reading of .5 or 1.0 volt. Later we will show that collector or emitter current can be measured easily by reading a resistance, the voltage drop across it and calculating the current by Ohms Law.

Stabilization

Four basic types of temperature stabilization are commonly used. Fig. 4B shows the base voltage supply taken from the collector rather than the supply voltage. This is an effective method, if the resistance in the collector circuit is fairly high. Any increase in collector current will lower the collector voltage which in turn reduces the base supply voltage. And this lower base voltage will decrease the collector current. The opposite action takes place if the collector current goes down.

There are two limitations. Transformer output coupling is not practical since the collector DC voltage would not change enough for effective control, and the resistor between collector and base can introduce negative feedback which lowers the gain.

The two most common thermal stabilizing methods are both shown in Fig. 4C. Forward bias for the base is developed by a voltage divider to minimize voltage variations, and more important, an emitter resistor is added. For example, increased emitter current raises the emitter-to-ground voltage and any emitter voltage is subtracted from the base-to-ground voltage to give the true forward bias. The more emitter voltage, the less forward bias and this causes less gain and collector current.

Let's consider some hypothetical voltages. Assume a base-to-ground voltage of −2.15 and an emitter-to-ground voltage of −2.0; the forward bias is −.15 volt. Suppose that a higher transistor temperature increases the collector-emitter current so the readings become: base −2.15 and emitter −2.05 for a forward bias of −.10. This reduced forward bias decreases the collector-emitter current and restores the change in gain. Of course, reverse action takes place if the emitter current goes down, but we are not so concerned because this is just the opposite of "thermal runaway".

Omission of the emitter bypass capacitor would allow AC current feedback which reduces gain just as an open cathode capacitor will do in tube circuits. In practice, however, we find the gain reduction in transistor circuits to be much larger than that caused in tube circuits by an open capacitor, where the resistor is the same in both cases. In a tube circuit, the gain might be reduced 10 dB, while the transistor circuit gain could be decreased by 20 to 30 dB.

The fourth type of heat stabilization uses a diode (of the same material as the transistor) as a voltage regulator.

How Critical is Forward Bias?

The forward bias of a transistor

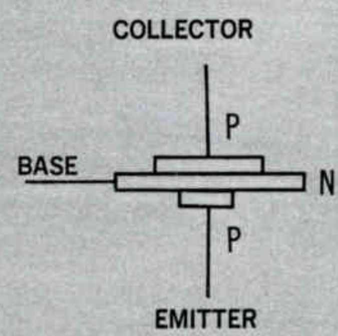


Fig. 1A PNP transistors have a thin section of "N" material between the "P" sections. NPN types are reversed.

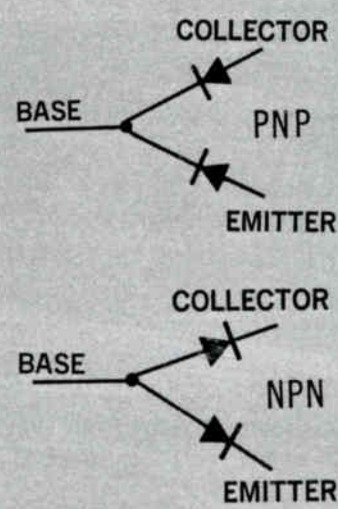


Fig. 1B Each junction of "P" and "N" material has diode properties. For resistance tests they can be diagramed as diodes.

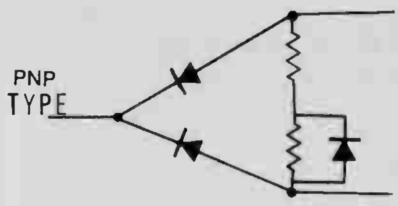


Fig. 2 This is the equivalent of a transistor when it is measured by an ohmmeter.

Test	Connect negative lead to:	Connect positive lead to:	Ohmmeter scale	Desired reading in ohms
		Small RF and audio transistors		
Forward	base	collector	X10	50 or less
Forward	base	emitter	X10	50 or less
Leakage	collector	base	X10K	20K or more
Leakage	emitter	base	X10K	20K or more
Forward E-C	collector	emitter	X1K	2K or less
Leakage E-C	emitter	collector	X1K	25K or more
		Power transistors		
Forward	base	collector	X1	5 or less
Forward	base	emitter	X1	5 or less
Leakage	collector	base	X1K	10K or more
Leakage	emitter	base	X1K	10K or more
Forward E-C	collector	emitter	X10	2K or less
Leakage E-C	emitter	collector	X100	4K or more

Fig. 2B Chart for measuring the junction resistances of PNP germanium transistors. All polarities should be reversed to test NPN types. These readings are for VTVM's using a 1.5 volt ohmmeter battery. Meters with other battery voltages will show different resistances.

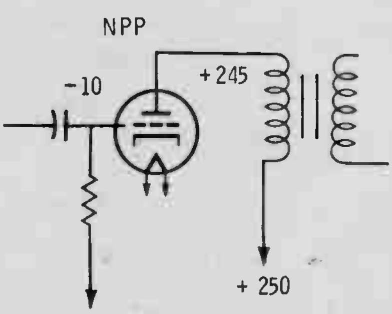


Fig. 3A Any tube could be called an NPP type since both grid and plate will pass current if they are positive in relation to the cathode. In practice, a tube is operated with a reverse-biased grid and forward-biased plate.

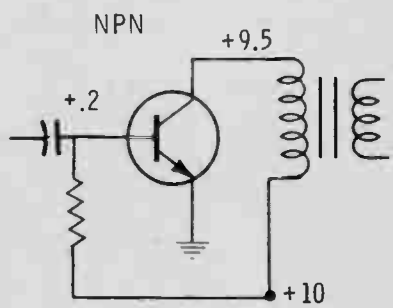


Fig. 3B Transistors are operated with the base (grid) forward-biased, and the collector (plate) reverse-biased. Forward-biased elements are low impendance and reverse-biased elements present a high impedance.

is the most critical factor that determines the performance of transistorized circuits. Without some forward bias, there can be no collector current (except undesired leakage), and since a small transistor typically operates with about .2 volts of forward bias for a germanium type and about .7 volts for a silicon, small voltage changes are significant merely because the bias is small. Logic and reason tell us that a 10% change in forward bias should have the same effect on gain and output current as a 10% change in tube bias. This is not so! In some transistor circuits a bias change of far less than 10% can increase or decrease the gain 30 dB, for example. This is far more critical than the bias on a high-gain sharp-cutoff tube.

It is poor design and practice to apply a fixed bias even from a well-regulated supply, for the optimum bias will be different for each individual transistor and will vary widely according to the junction temperature. For stages such as power output that are difficult to stabilize, a bias-regulating diode may be used if it is made from the same type of material as the transistor so it will have a similar temperature coefficient. Even applying a constant base current is not enough stabilization. If it were, a large source of voltage through a large base resistor would be sufficient. Two methods of stabilizing a single stage were given previously. One is to use a large emitter resistor, and the other is to take the bias from a source (such as the collector) that varies in voltage according to collector current. Later we will explore how multiple direct-coupled stages are stabilized.

Gain Control by Bias Variation

Every transistor has an optimum forward bias that gives maximum gain. Either more or less bias decreases the gain. There is no precedent in tube circuitry for this characteristic. The graph in Fig. 5 is not intended to be accurate, but only to illustrate general transistor functions. The forward bias is increased at a linear voltage rate. The collector current increases and the input impedance decreases at a logarithmic rate, while the gain peaks at one definite bias voltage. Starting at the bias for maximum gain, a decrease in bias uses the "cut-off" mode, and in increase takes advantage of the "saturation" characteristic for gain reduction. Either method can be made to give about the same degree of gain reduction. Current consumption would dictate use of the cut-off type of AVC for battery-operated equipment such as portable radios. AGC in television receivers usually employs the saturation method, for the lower input impedance obtained on stronger signals widens the bandwidth of the tuned circuits.

Silicon transistors used for IF and RF amplifiers in color TV receivers appear to have an extremely sharp cut-off when saturation biasing is used for AGC. Actual measurements made on several brands of receivers indicate that a bias increase of only .04 to .05 volts over the no-signal bias of about .7 volts will accomplish adequate gain reduction for a very strong TV signal. Translated, this means a bias increase of 7% will reduce the gain to virtually zero.

Pulsed Signal Operation

The preceding statements apply to AF, RF and IF amplifiers operated in class "A". Class "C" amplifiers (including oscillators, sync separators and power output stages) usually show reversed bias measured on a meter. This does not contradic facts on forward bias already given. Diode action of the base-emitter junction rectifies the incoming signal to produce reversed bias that

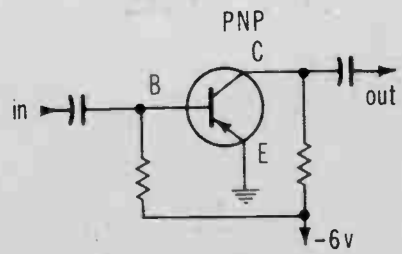


Fig. 4A Simple audio amplifier without thermel stabilization.

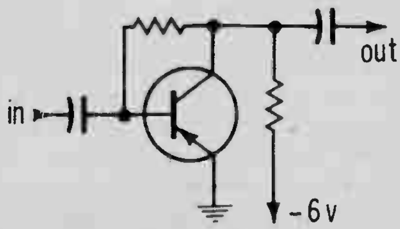


Fig. 4B Effective stabilization for resistance-coupled circuits.

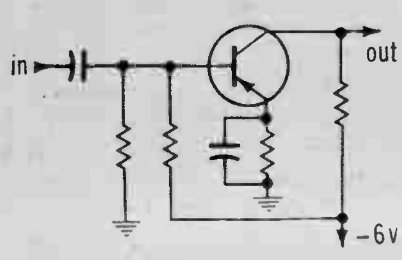


Fig. 4C Base voltage stabilization by a voltage divider. The emitter resistor helps thermal stabilization the most of the two methods.

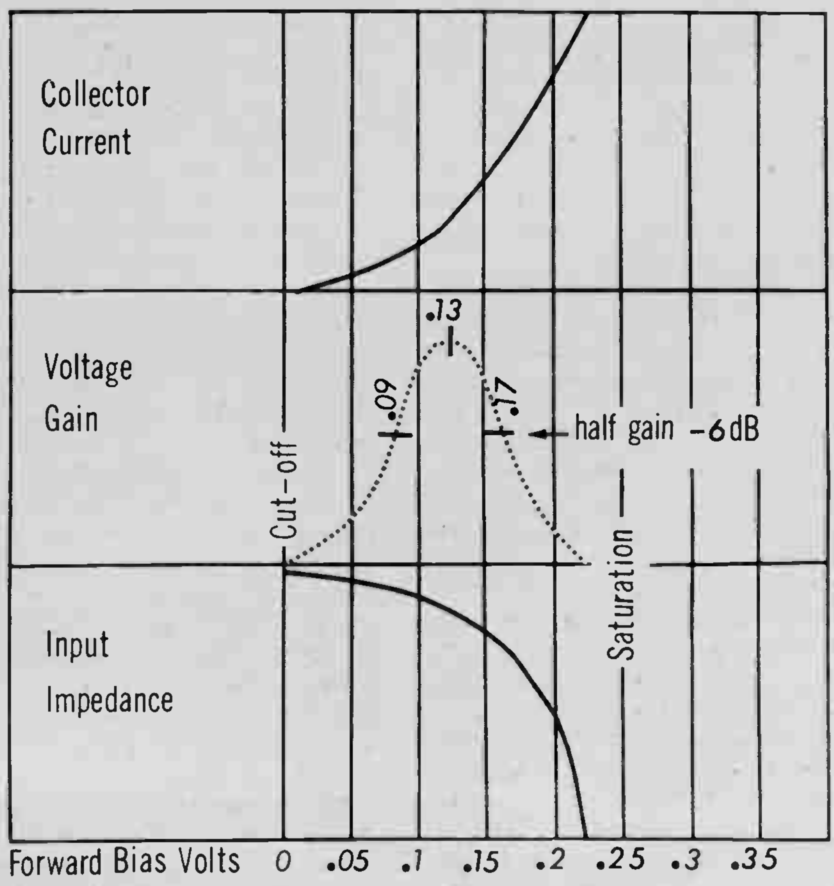


Fig. 5 Characteristics of transistor.

is overpowered by the highest amplitude tip of the incoming waveform to become forward bias. Thus the base has reversed bias most of the time, and forward bias for a very short time during each cycle. A meter will average these voltages to read as reversed bias.

Load Impedance vs Gain

Load impedance in the collector circuit has a large effect on transistor gain. At the usual transistor impedances (under 50,000 ohms) the gain is in direct proportion to the load. If the collector load impedance is doubled, so is the gain (+6 dB). If the impedance is decreased 20%, the gain is reduced 20%. Remember this when analyzing some of the beginner circuits where the collector resistor is about 1.5K.

Other Factors Affecting Gain

Collector voltage is not a critical factor in determining gain except when the collector-emitter voltage drops to a few tenths of a volt, then the gain drops to nearly zero.

Negative feedback or degeneration in the emitter circuit from unbypassed resistors reduce gain with transistors the same as it does in tube equipment. ▲

Chapter 2

How component defects affect the operation of transistor circuits

by Bruce Anderson

The precise manner in which a transistor operates may be of interest and value to some; however, those of us engaged daily in repairing transistorized equipment can perform our task with considerably less information. Nevertheless, a few of the characteristics of a transistor must be remembered. These essential bits of information are summarized as follows:

1. The average amount of DC voltage present between base and emitter remains nearly constant, so long as the transistor is in a state of conduction. Obviously, if the base voltage is insufficient to allow emitter-to-base conduction, the potential between these two elements may vary; but if there is normal conduction, the voltage will remain almost constant. This is quite different from a tube, in which the grid voltage may vary over a fairly large range, perhaps 10 or 15 volts, during normal operation. Conversely, the grid current is very small (and nearly constant) throughout the operating range, while base current is significant and variable.

2. Since the base voltage remains nearly constant throughout the normal range of operation, the input impedance of the device itself is inversely proportional to the input signal level. The input impedance may be increased by connecting an unbypassed resistance in series with the emitter of the transistor. This raises the overall impedance seen at the base and tends to make it independent of the signal level.

3. Unlike a tube, whose input impedance is normally in the order of thousands or millions of ohms, the input impedance of a transistor connected in a common-emitter circuit is quite low. As a general rule, it may be estimated by multiplying the impedance between the emitter and ground times the beta of the transistor. Thus, if the transistor shown in Fig. 1 has a beta of 100, the input impedance probably will be about 1000 ohms. Any biasing resistors in the base circuit will be shunted across this input impedance. This resistive component of the impedance might be shunted by a fairly low value of capacitive reactance, which will lower the impedance further. Naturally, if the emitter resistor is bypassed, the capacitive reactance "seen" at the base will approximate the reactance of the capacitor multiplied by the beta. To calculate this impedance, the frequency of operation has to be known.

4. Since the amount of collector current is determined by the emitter-to-base current to a much greater degree than it is determined by the collector voltage, the collector load impedance of a common-emitter transistor circuit can be quite high.

5. If the emitter-to-base current is made high, driving the device into saturation, the voltage drop from emitter to collector may become almost negligible. This is unlike a tube, in which the cathode-to-anode drop is considerable, even when the control-grid voltage is positive with respect to the cathode.

6. Transistors are available in either of two types, NPN and PNP. This allows operation with the collector supply either positive (NPN) or negative (PNP). This allows greater latitude in the design of complete circuits, by using stages of different types. In the discussion here, NPN devices are considered. If a PNP device is encountered in a circuit, the operation will be about the same, except that all polarities are reversed.

7. Unlike a tube, the characteristics of a transistor are not as likely to change over long periods of time. A tube gradually wears out, from the time it is placed in operation. On the other hand, a transistor which has been in service for an extended period is likely to produce

just as much gain as it did when first installed. Tubes usually fail because they no longer can produce gain; transistors usually fail because of shorts, opens or leakage.

8. Also unlike a tube, the characteristics of a transistor vary considerably with temperature. This can lead to a condition called "runaway," wherein an increase in temperature causes an increase in current, which causes an increase in temperature, etc., until the device is destroyed. This is primarily a design problem, but it may be the result of circuit malfunction. Also, it makes it doubly important not to obstruct the normal circulation of air inside the cabinet of transistor equipment.

9. The beta of a transistor, which is directly related to the amount of gain possible in a transistor-equipped circuit, is not held to tolerances which are as stringent as the transconductance tolerances of tubes. Since the beta of each of a number of transistors of the same designation may vary considerably at the time of manufacture, and since these values of beta are not apt to change very much throughout the life of the transistors, the measuring of beta is not a particularly exact test of a suspected transistor. This, however, does not discourage the use of a beta-type transistor tester, which provides a convenient means of testing for shorts, opens and leakage.

In the light of the above characteristics, it is possible to predict the manner in which certain malfunctions of the surrounding circuit may affect the operation of the transistor and the circuit.

The effect of a change in the value of each of the components in Fig. 2 can be studied, and, by extension, these may be used to predict the operation of similar circuits.

Changes in R1

The value of R1 can increase or decrease; this change may be rather slight, perhaps 20%, or it may be drastic, such as a complete short or open.

Suppose that the resistor were to increase moderately in value. If this should happen, the voltage drop across it would increase and the drop across R2 would have to decrease. (Since the bleeder current through R1 and R2 is much greater than the base current of the transistor, which also passes through R1, this latter current may be ignored for simple calculations.) As the drop across R1 increases, the bias voltage on the base of the transistor must decrease; but as the base voltage and current decrease, the emitter and collector currents of the transistor also will decrease, reducing the emitter voltage.

The result of this moderate increase in the value of R1 is a reduction of the base and emitter voltages of the transistor, and because the collector current has been diminished, the collector voltage will increase. These would be the most obvious symptoms observed with a meter.

Most transistors used in audio applications are biased at a point where an increase in emitter-to-base current will increase the gain of the stage (if it has any effect at all), so a moderate decrease in the base current also might decrease the gain moderately.

Suppose that the value of R1 should increase drastically, perhaps to 100K ohms. With so much resistance between B+ and the transistor base, the base voltage is forced below the barrier potential of about .7 volt. This, of course, will cause the transistor to cut off, dropping the emitter voltage to zero and causing the collector voltage to increase to nearly 13 volts.

Before proceeding, there is an important exception to the usual rule that gain increases as the emitter-to-base current of an NPN transistor is increased. In the IF-amplifier circuits of many television receivers, the transistors are biased so that an increase in emitter-to-base current causes a decrease in amplification, even though the collector current does increase. This is called "forward AGC", and can cause a lot of confusion to the unwary. (Dale's Service Bench in this issue explains forward AGC.)

Now consider the results if R1 decreases in value. According to Ohm's law, the base voltage must increase, increasing the emitter-to-base current. The emitter voltage rises right along with the base voltage (discounting a couple of millivolts), and the collector voltage falls because of the additional current through R4. As the value of R1 continues to decrease, the base and emitter voltages will continue to rise, and the collector voltage will continue to fall until they are all about the same, or until the transistor burns out from excessive base current.

Regarding the burnout problem, this is sometimes difficult to predict. In the circuit shown, the emitter resistor will limit base current to about 18 ma, even if R1 is shorted. Some transistors will withstand this overload; others will not. Nevertheless, the circuit shown does provide some protection to the transistor. If the value of R3 were only 3 or 4 ohms, it is almost a certainty that shorting R1 would burn out the transistor. For more information on transistor overloads and burnouts, refer to ELECTRONIC SERVICING, November, 1969, pages 26 to 28.

Changes in R2

To some degree, the effects of changes in the value of R2 will be opposite those caused by changes in R1; however, there are some exceptions. If the resistance of R2 decreases, there will be a reduction in base voltage and emitter-to-base current, and if the change is sufficient, the transistor will cut off.

If the value of R2 increases, base voltage will increase; but even if R2 should open, the base current will not "go through the roof." Since

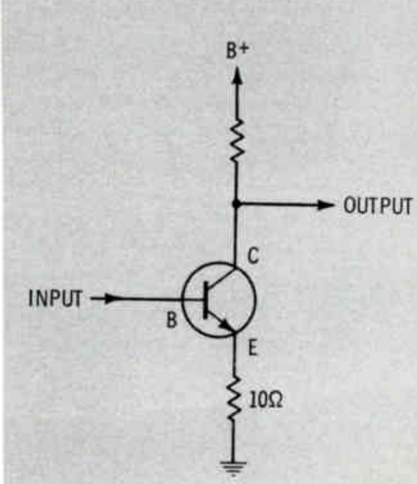


Fig. 1 Basic common-emitter circuit.

the base current causes a drop across R1, the base current cannot exceed that value which will drop all the supply voltage across R1. About 2 ma will drop 13 volts across R1, and the base current will be even less than this, since there is some drop across R3. Perhaps 1 ma is a reasonable "guess-timate" of the maximum base current possible if R2 is open. It is apparent that the transistor is less apt to be damaged by opening R2 than by shorting R1.

Changes in R3

An open cathode resistor in a vacuum-tube circuit will cause the cathode voltage to rise almost to B+, but the effect of opening the emitter resistor (R3 in Fig. 2) in a transistor circuit is not the same. If the transistor base was disconnected from the junction of R2 and R1, the voltage at this point would increase to about 3.7 volts. With the transistor again connected back in the circuit, it cannot conduct if its emitter rises above about 3 volts, so the emitter voltage normally will never increase above this level, regardless of how large R3 becomes.

The decreased conduction will cause the voltage at the collector to rise, but probably not much. A large increase in the emitter resistance in Fig. 2 might increase the emitter voltage to nearly 3 volts. This leaves about 10 volts to be dropped across the transistor itself and the collector load—not much change from normal conditions. The most obvious symptom would be a loss in amplification.

Decreasing the emitter resistance tends to decrease the emitter voltage, but this, in turn, increases the base and collector currents. The result is that there will be a sag in the base and emitter voltages, but it will not be in proportion to the reduction in emitter resistance. For example, a 25% reduction in emitter resistance might cause a reduction in emitter voltage of only 10%. However, the emitter current would increase significantly, reducing the collector voltage, and there is a good possibility that the current ratings of the transistor would be exceeded.

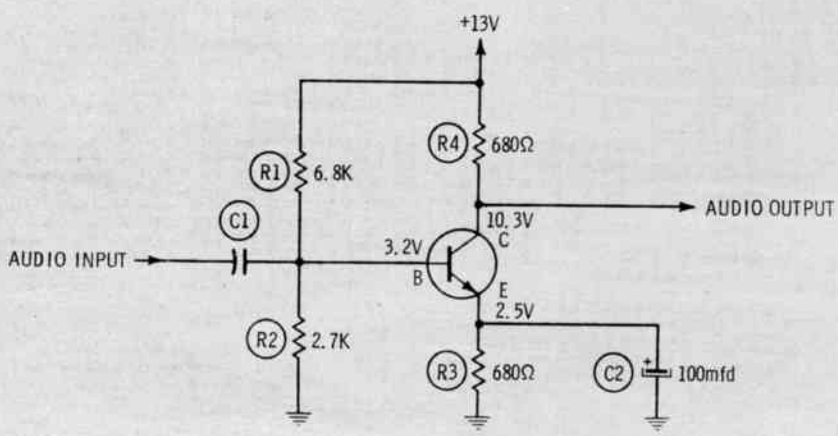


Fig. 2 Typical common-emitter audio amplifier.

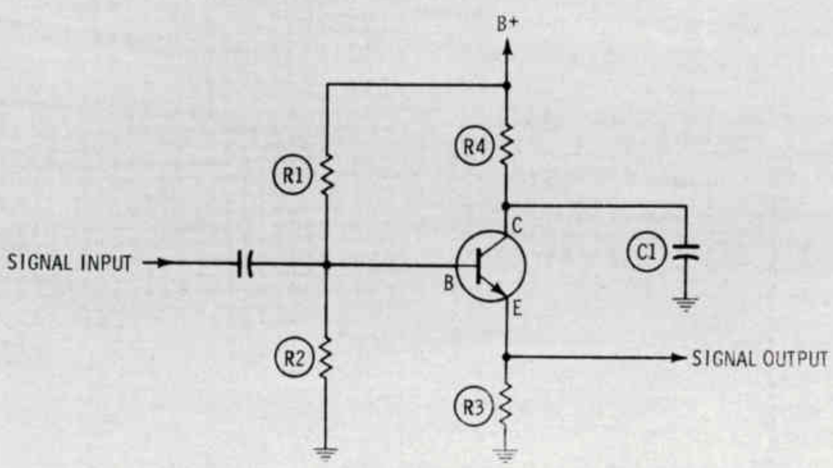


Fig. 3 Basic emitter follower.

Changes in R4

The collector current of a transistor is fairly independent of the collector voltage, much the same as in a tube. A loss of 25% of the collector resistance of Fig. 2 would cause a corresponding decrease of 25% of the drop across R4, and the collector voltage would increase to about 11 volts. However, this might be rather difficult to detect with a meter having only 5% accuracy. For his reason, it is wiser to measure the voltage across the resistor instead of the voltage from collector to ground.

If the collector-load resistance changes, it will have very little effect on the voltages at the emitter and the base. And this is the tip-off —if the collector voltage is wrong, but the base and emitter voltages are right, look at the collector-load resistor. Of course, if the resistor is off by 200 percent, this rule may not hold.

If the collector load resistance is off tolerance, the gain will be changed by the amount of tolerance shift, since gain is more or less proportional to load resistance. Of course, this cannot go on without limit if the resistance increases—the amplitude of the output signal cannot exceed the collector supply voltage. Also, the transistor might go into saturation or cutoff if the collector resistance is out of tolerance, This will cause distortion.

Changes in C1

If the value of the input coupling capacitor is not within tolerance, there can be an increase in distortion of low-frequency signals, and if the capacitance loss is sufficient, the gain of the amplifier will be decreased seriously. Finding this particular trouble is a job for the scope or perhaps even more practical, a quick job of bridging the capacitor with a new one.

If the coupling capacitor becomes leaky, the result is about the same as decreasing the value of R1. The emitter and base voltages will rise, and the collector voltage will drop. If there is enough leakage to drive the transistor near saturation, distortion will be produced; more leakage probably will destroy the transistor.

Changes in C2

The function of C2 in Fig. 2 is analogous to the function of a cathode bypass of a tube-circuit. If it loses its capacitance, degeneration of the signal will result (the emitter voltage will vary with the AC signal). If C2 becomes leaky, the result is about the same as if the resistance of R3 had been decreased.

Common-Collector Circuits

The common-collector circuit shown in Fig. 3, also called an emitter follower, is encountered quite often in solid-state circuitry. Essentially, it is an isolating stage used to match the impedance of the preceding stage, or the input to the instrument, to some lower-impedance load. This may be the next amplifier stage, or perhaps the load to which the instrument is connected. The input impedance may be very high, as in some solid-state electronic volt-meters, if the value of R3 is made sufficiently large. As with the common-emitter amplifier, the input impedance is approximately the value of unbypassed emitter resistance times the beta of the transistor.

One important fact about an emitter follower is that the voltage gain can never be greater than unity (1). If the input signal has an amplitude of 1 volt, the output must be less than 1 volt. On the other hand, the power gain of an emitter follower may be fairly high. For example, assume that R3 is 100 ohms and that R1 and R2 each have resistances of several thousand ohms. If the transistor beta is 50 and the input signal is 1 volt, the input impedance is about 5K ohms, and the driving power is about .2 milliwatts. An output signal of .9 volt is entirely possible under these conditions, and this signal is developed across R3, 100 ohms. Therefore, the power output is 8.1 milliwatts, and the power gain is about 40.

When troubleshooting an emitter follower, it is important to remember that fairly large variations in the values of the components might not cause the circuit to become completely inoperative. An increase or decrease in base bias, caused by a change in R1 or R2 in Fig. 3, will cause a corresponding change in the emitter voltage, but the gain of the circuit may not be affected noticeably. It is more likely that the new bias levels will cause the transistor either to cut off or saturate during some part of the cycle of the input signal, in which case distortion will occur.

R4 in this circuit may be omitted if the supply voltage is correct for the transistor being used. If this is the case, the collector voltage is not likely to change, regardless of the condition of the circuit. When the collector is connected directly to B+, the transistor is very vulnerable to burnout if the emitter resistance becomes too small.

In many applications, the emitter resistance actually is the base circuit of the next stage, as shown in Fig. 4. Characteristically, if the output stage shorts, placing B+ on the emitter of the emitter follower, the emitter follower also will be damaged. Even if the device does not fail immediately, it can after a few hours of operation, and it sometimes is smart to replace it while the set is on the bench.

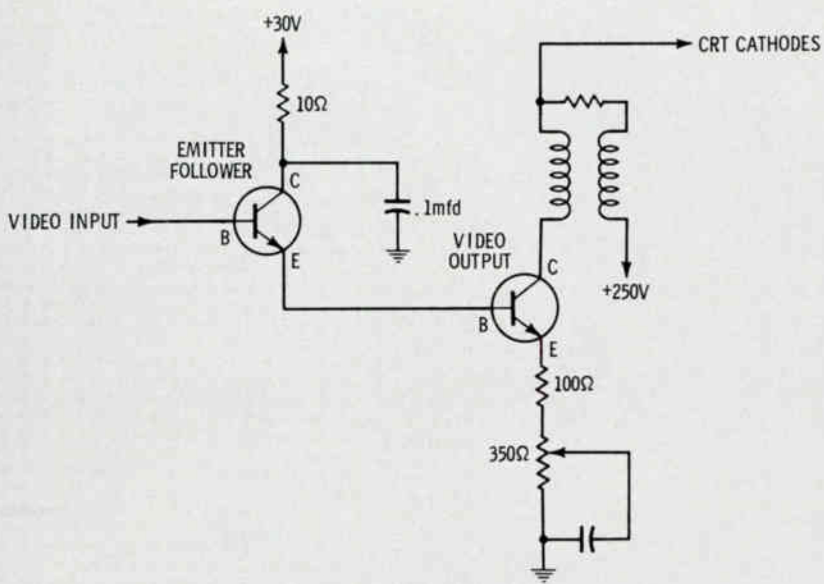


Fig. 4 Direct-coupled emitter follower and video amplifier.

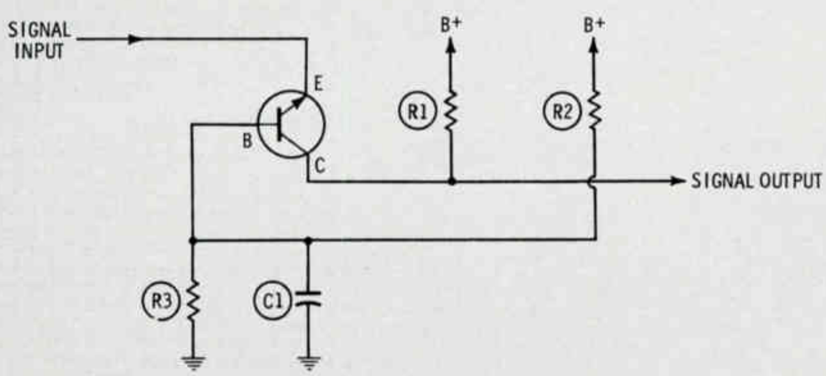


Fig. 5 Typical common-base amplifier.

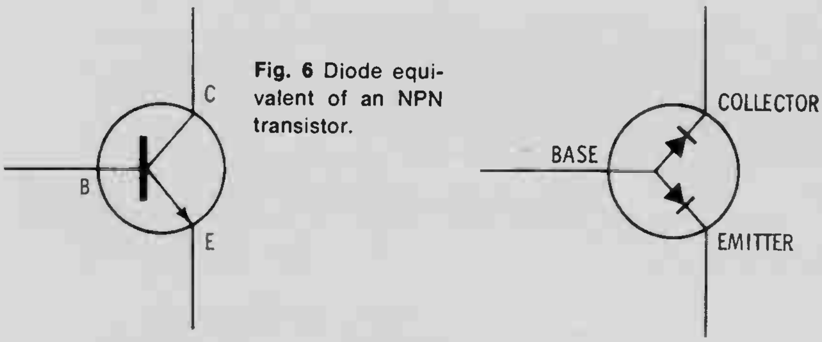


Fig. 6 Diode equivalent of an NPN transistor.

(A) Basic NPN transistor.

(B) DC equivalent.

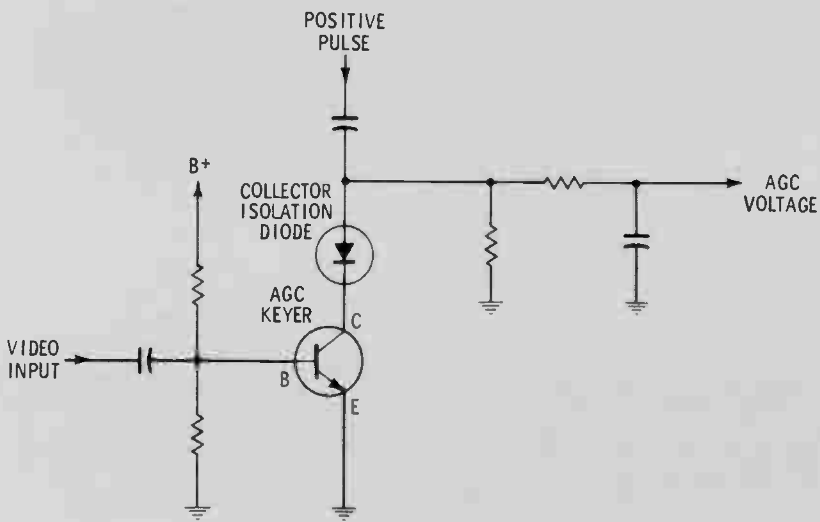


Fig. 7 Diode used for collector isolation.

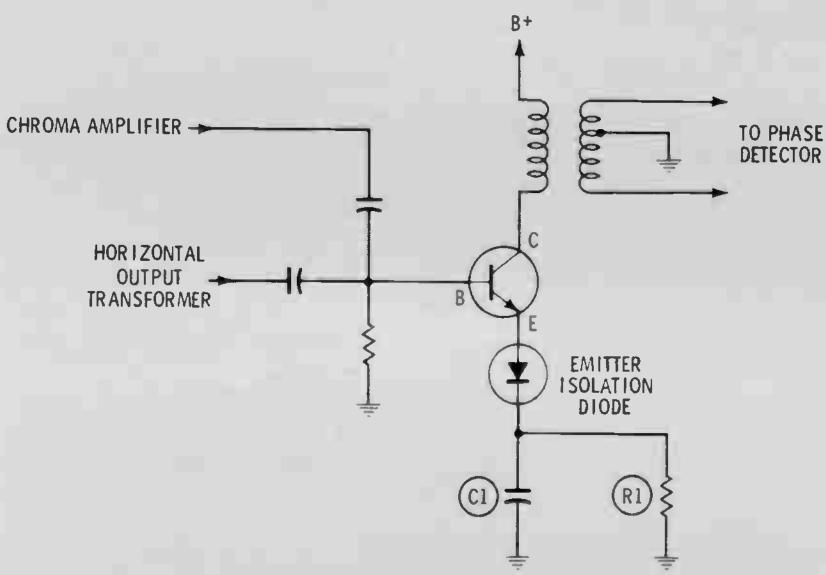


Fig. 8 Diode used for emitter isolation.

Again referring to the circuit in Fig. 4, a word of caution is in order: It is common practice to short together the emitter and base of a transistor to check it for leakage. In this circuit, if the base and emitter of the video-output stage are shorted together, the emitter resistance of the emitter follower will be reduced severely, and it is very possible that the transistor will burn out.

Common-Base Circuits

The third configuration of a transistor amplifier is the common-base circuit. Like the common-emitter circuit, it has voltage gain, but the input impedance always is very low. The common-base circuit may be used to follow some low-impedance source, such as a video delay line, or as the voltage amplifier for a cascode amplifier or mixer. The output impedance can be quite high, comparable to a common-emitter amplifier.

For the circuit to operate properly, the base must be grounded insofar as the AC signal is concerned. A bias network like that shown in Fig. 5 can be used, if the value of C1 is large enough to provide good bypassing. If the capacitance of C1 decreases, the gain of the amplifier will be decreased, particularly at the lower frequencies.

By the nature of the circuit, the resistance from emitter to ground is likely to be quite low, and this makes it possible for a small change in the base biasing network to cause large changes in the emitter-to-base current. Burnout is very possible if the bias is allowed to swing too far positive. Increases in base-bias current are the result of an increase in the value of R3 or a decrease in R2.

An increase in the value of R1 will cause the collector voltage to drop; a decrease in R1 will cause it to rise. These are the same conditions that are encountered in a common-emitter circuit.

When troubleshooting a common-base amplifier, do not be surprised if the scope does not indicate a signal at the emitter. Since this type of circuit is driven by current (very low input impedance), the signal voltage at the input may be so slight that the scope will not have enough sensitivity to detect it. If there is no easier way to tell if the signal actually is reaching the emitter, try disconnecting the base bypass capacitor. This will raise the input impedance and the signal voltage so that it can be observed. (Of course, the transistor cannot amplify under these conditions, and there will be no output.)

Other Circuits

The active material of a transistor is arranged so that an NPN device appears as two diodes, with both anodes connected to the base lead, as shown in Fig. 6. (In a PNP device, the diodes would be reversed from their positions in Fig. 6.)

The collector of an NPN transistor cannot be made more negative than the base, because the base-collector diode simply will conduct and bleed off the voltage. Because of this, certain circuits must include an isolating diode if the output circuit is to be negative during some portion of the cycle. The AGC keyer shown in Fig. 7 is such a circuit.

The horizontal sync pulses from the video detector (or amplifier) arrive at the base at the same times that the positive keying pulses from the horizontal-output transformer arrive at the collector. The amount of conduction depends on the amplitude of the sync pulses. The output from the keyer is a negative AGC voltage that is proportional to the level of the input signal.

As mentioned previously, a negative voltage cannot remain on the collector of an NPN transistor. For this reason, a diode must be placed in series with the collector lead of the AGC keyer to prevent the negative voltage from leaking away between pulses.

When troubleshooting this type of circuit, be sure to check the diode before assuming that the transistor is causing the loss of AGC.

Fig. 8 shows another application of a diode in series wtih a transistor lead. This circuit is a burst amplifier that has the usual inputs: chroma signal and a positive pulse from the horizontal-output transformer. The horizontal pulse arrives coincidentally with the arrival of burst, and the transistor is turned on long enough to pass the burst to the output.

When the transistor conducts, the emitter capacitor, C1, becomes charged positively by the drop across the emitter resistor, R1, and this positive voltage holds the transistor cut off until the next pulse arrives at the base.

To assure positive keying action, it is desirable that the bias voltage on the emitter be rather high, but this voltage can become excessive and break down the emitter-to-base junction. To protect the transistor, a diode is used to isolate the emitter from the bias voltage.

An unusual situation involving the transistor itself has come to light in the past year, but may not be well known. Certain transistors used as IF and chroma amplifiers have a very low reverse-voltage breakdown potential between emitter and base. This voltage can be about only .5 to .8 volt. If one of these transistors is tested in many of the present-day transistor testers, or with an ohmmeter, the battery voltage can be sufficient to cause reverse current through the base-to-emitter junction. This gives the indication of a shorted or leaky transistor, although such is not actually the case.

The test does not usually damage the transistor, and it may be reinstalled in the circuit, where it will function normally. To prevent the erroneous indication, check these transistors on the lowest beta scale of a transistor tester, or reduce the ohmmeter battery voltage to less than .5 volt. Either procedure will reduce the voltage across the emitter-base junction below the critical reverse-voltage-breakdown potential, and a valid test of leakage can be made.

Summary

Some of the more important characteristics of transistors have been discussed in this article, and the effects of changes in the associated components have been examined. Because of the myriad of transistors available and the vast number of circuits in which they can be used, it is impossible to anticipate all the reactions to circuit defects.

Probably the most important thing to remember when trouble-

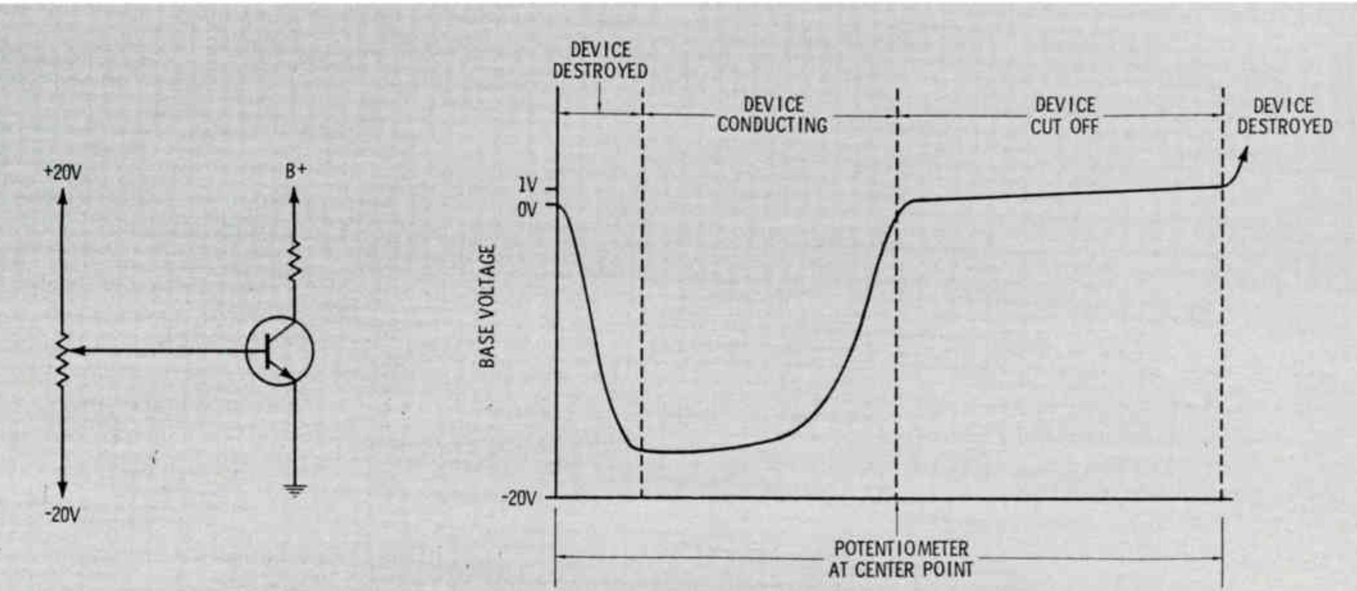


Fig. 9 Transistor base-voltage diagram.

shooting transistor circuits is that the average DC voltage between the base and emitter of a conducting transistor always will remain essentially constant, although in pulse applications a meter will indicate otherwise. Nonetheless, if a scope is used, it will be found that during conduction time, the average DC voltage remains nearly the same.

If a silicon transistor is considered, the emitter-base voltage is about .7 volt, and it will remain so as base current is increased from cutoff, through the normal operating range, and into saturation. This may be visualized by examining the circuit and curve of Fig. 9.

This circuit, which we have dubbed the "Anderson Handy-Dandy Transistor Eater," is constructed so that the voltage to the base of the transistor may be varied from −20 volts to +20 volts. With the potentiometer set to the center of its range, the base voltage is zero and the device is cut off by lack of bias. As the voltage is increased in a positive direction, conduction begins when the voltage reaches barrier, or turn-on, potential for the transistor (.7 volt for silicon and .3 volt for germanium). Further turning of the potentiometer increases the voltage very slightly, although the base current does increase, until the maximum base-current rating of the device is exceeded. At this point, the transistor is "eaten", or destroyed, by the circuit.

If the potentiometer is turned in the opposite direction from mid-range (toward negative), the base voltage decreases to the point of reverse base current. Turning the shaft slightly further will not increase the voltage, although the current increases. This is similar to the normal action of a zener diode. Then, as the shaft is rotated further, the maximum reverse-current rating of the device is exceeded, at which point the circuit again "eats", or destroys, the transistor.

This circuit requires very little skill to build; in fact, it can be "built" entirely by accident. The skill is required to prevent "building" it while troubleshooting a transistorized circuit, and also to recognize that it has been "built" when some part has failed in a solid-state circuit. ▲

Chapter 3

Field-effect transistors—operation, applications and testing

How do field-effect transistors (FET's) work? How do you test one? How can you tell which lead is which if they aren't marked? How are they used in circuits? These and other questions we hope to answer in this two-part series on the field-effect transistor.

Conventional transistors (NPN and PNP) are called **bipolar** transistors because their operation depends on the reciprocal action of two charge carriers (electrons and holes). The FET is called a **unipolar** device because it uses essentially only one charge carrier (although that carrier may be either a positive or a negative charge, as we will see).

Because it is a unipolar device, the basic FET has no sense of direction between its main current terminals, source and drain; that is, the source and drain terminals may be interchanged. Only the **gate,** which in many respects corresponds to a grid in a vacuum tube, must have a specific polarity of voltage with respect to the source terminal.

How FET's Work

The best way to understand FET operation, I think, is to think of an FET as a "sheet-beam" vacuum tube. That is, the controlling force is a charge that pushes (or sometimes pulls) the main current carriers out of (or into) a channel. Fig. 1 shows the action of a sheet-beam tube with an internal deflector plate.

Fig. 2 is a circuit diagram of an FET. This is an N-channel FET, which means that the active element has an abundance of negative current carriers (electrons). (Remember that semi-conductor material by nature has a limited number of charge carriers, unlike a piece of wire, for example, which has an almost infinite number of charge carriers.)

Let's first consider Fig. 2A. At each end of the N-channel material is a connection to the semiconductor. One of these connections is called the **source** and the other the **drain.** Because of the current carriers in the "N" material, current can flow through it in either direction, depending on which way the battery is connected. Because of the limited number of current carriers in the channel, the channel looks not like a piece of wire but more like a 1000-ohm resistor.

Next, consider Fig. 2B. Here a new element is positioned between the source and drain. This element is called a **gate.** Like any gate, it can be completely open or shut or one-quarter open, half-way open, etc.

In an FET, ideally, there is a high resistance between the gate and the channel. The gate may be a piece of P-type material with a reverse bias, or there actually may be a very thin slice of insulation between the gate and the channel.

With the gate tied to the source, as in Fig. 2B, current continues to flow just as if the gate were not present.

Next, let's consider Fig. 2C. When a negative bias voltage is connected between the gate and source, the current between the source and drain of the FET decreases. What has happened? The negative voltage on the gate repels the electrons (negative charge) in the channel and forces them toward the substrate. This leaves fewer current carriers available in the channel, and less current flows. In other words, the original "1000-ohm resistor" now looks like a 5000-ohm resistor. Applying a negative charge to the gate of the FET has caused the resistance of the channel to increase. Fig. 2D shows what happens if the negative voltage on the gate is increased enough. The current flow is completely "pinched off" between the source and drain. This is because all of the electrons have been forced out of the conducting channel.

No mention has been made of gate current flow. The reason? There is none! The flow of current between the source and drain is controlled by a **voltage** charge. This is why the FET, like the vacuum tube, has a high impedance . . . it requires **no power** in the input to control power in the output. The similarity that exists between vacuum tubes and FET's is reflected in the circuitry used with FET's, as you will see in next month's article.

Types of FET's

As mentioned previously in this article, there are two general types of gate structures. First, there is the junction FET (j-FET) which has the gate "junctioned" into the channel in much the same manner as a PN junction of a diode or bipolar transistor. This type of FET has the advantages of simplicity, ease of testing with an ohmmeter, and little likelihood of static-charge damage (to avoid such damage, the leads of some FET's must be kept shorted together until the FET is installed in the circuit). In the j-FET, the gate is reverse-biased by the circuit so that only a very small amount of current flows between the gate and channel.

The other general type of gate structure is itself divided into two distinct types: The MOS (metal-oxide semiconductor) and the IG (insulated gate), often referred to as MOSFET's and IGFET's. In these, the gate is actually insulated from the channel by an extremely thin layer of oxide. This insulation prevents current flow to the gate, whether it is positive or negative with respect to the source terminal. The input resistance of the MOSFET's and IGFET's can be in the hundreds of megohms.

Since the insulating coating between gate and channel is so thin, there is a danger of "static puncture" of the coating. Enough static charge can build up on an open gate lead to pierce the coating and make a high-resistance connection between gate and channel. (When this happens, the transistor often can still be used as a junction transistor by applying a reverse bias to the gate.)

Other Types and Classifications

In addition to the j-FET's, MOSFET's and IGFET's, any of these various types may use either an N- or a P-channel. Basically there is no difference in the channel type, except that the gate bias is opposite for the two.

So far we have talked only of **depletion** FET's, in which a bias on the gate causes the current to be depleted or decreased. Insulated-gate transistors may also have an **enhancement** mode, in which the current is increased by a charge on the gate; in other words, more current carriers are pushed or pulled into the channel by the gate voltage rather than pushed out as in the depletion mode.

How FET's are Used

JFET

The junction field-effect transistor (JFET) operates with a high impedance input only as long as the gate-to-channel diode is reverse biased. Circuits using JFET's use either fixed- or self-bias (Fig. 3) to make sure the signal input does not forward bias the gate. For an N-channel JFET, the bias from gate to source is negative, and on a P-channel JFET it needs to be positive, as shown in Figs. 3 and 4.

MOSFET

Metal-oxide semiconductor field-effect transistors (MOSFET's), which are sometimes called insulated-gate field-effect transistors (IGFET), can operate with both reverse and forward bias voltages applied between gate and source. For example, no bias is used in the circuit in Fig. 4. The input signal can go both positive and negative without causing distortion in the output. This is because no gate current can flow; when the gate goes positive,

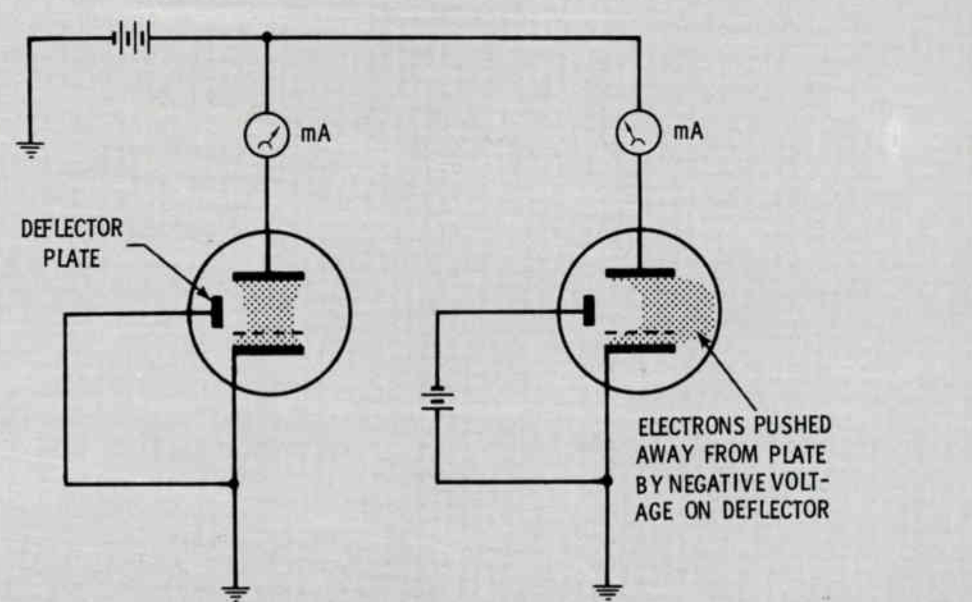


Fig. 1 Simplified action of a sheet-beam vacuum tube. The "gating" action of field-effect transistors is similar to that shown here.

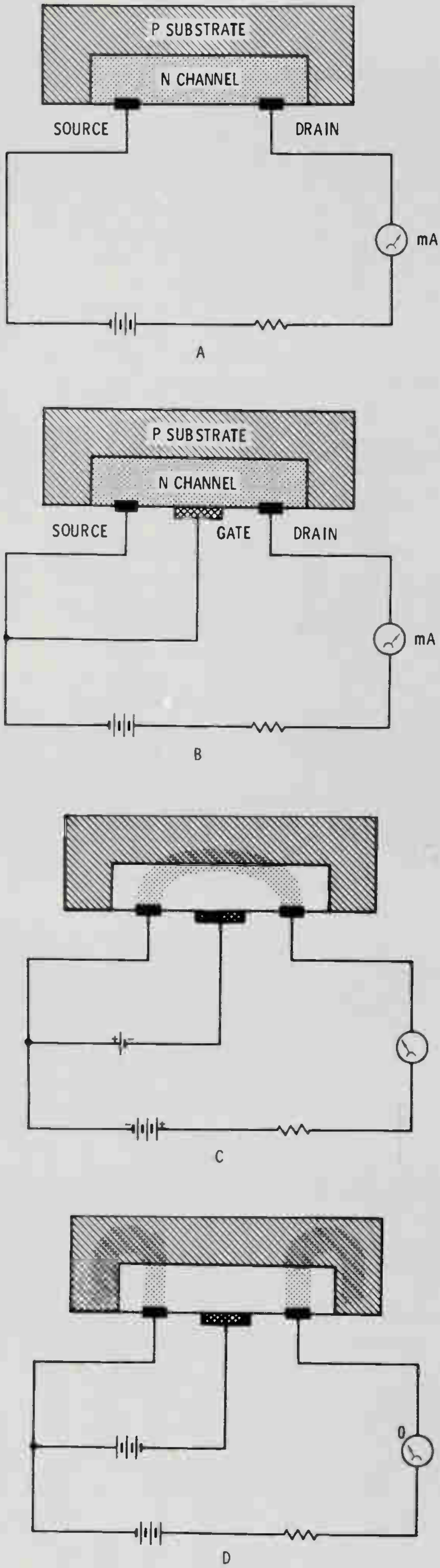


Fig. 2 Circuit diagrams showing construction and operation of N-channel FET.

A) Current can flow in either direction in region between source (cathode) and drain (plate). Limited number of current carriers made this region appear as a 1000-ohm resistor.

B) Variable control element called a "gate" is positioned between source and drain.

C) Current flow between source and drain is reduced when a negative bias voltage is applied between gate and source elements.

D) Complete "pinch off" of source-to-drain current is accomplished by gate when gate bias is high enough to force all electrons out of conducting channel.

the source-to-drain current simply is increased above the zero bias value. When the gate signal goes negative, the source-to-drain current is reduced much like it would be in a JFET circuit.

This JFET type of operation, in which the bias is sufficient to prevent the input signal from producing forward bias, is called type A operation. MOSFET's can be, and often are, operated in this mode, even though it is not necessary.

The circuit operation that permits both a positive and negative excursion of the signal voltage on the gate of the MOSFET is called type B. (Because JFET's would draw gate current if forward biased, they normally do not operate in the type B mode.)

Certain kinds of MOSFET's are called **depletion** types (all JFET's are depletion types) because they produce current flow with zero bias, and additional gate bias will reduce this source-to-drain current.

Other MOSFET's are known as **enhancement** types, which have virtually zero source-to-drain current until they are biased on. For example, the source-to-drain current might be no more than a microampere at zero bias, but when a +1 volt is applied to the gate, the source-to-drain current will increase to about 1 milliampere. This action is comparable to that of the familiar bipolar conventional transistor, which must be forward biased before current flows between emitter and collector. The difference is that the MOSFET, because of the insulated gate, has a very high input impedance (up to 100 megohms or more).

Operation in the enhancement mode is called type C. (See Fig. 5.)

The insulated gate of the MOSFET gives it exceptional isolation between the input and output circuit (even considerably better than a tube). MOSFET's used as radio-frequency amplifiers in radios are less susceptible to cross-modulation interference; that is, they can operate among several strong local stations with less chance of beats, whistles, or stations coming in at more than one place on the radio dial.

The dual gate FET (see symbols in Fig. 10) can be used as a mixer, and has better isolation than a twingrid tube.

Fig. 5 is an example of a circuit that is difficult to design using a tube, almost impossible with a bipolar transistor, but which is easily adaptable to the FET. This is a remote volume-control circuit that uses pure DC voltage to control amplifier volume from almost any distance. The signal input is fed to the drain terminal of the control FET through a 1-megohm resistor. The source terminal is tied to ground. By applying more or less negative voltage to the gate, the FET changes from high to low resistance. The equivalent circuit in Fig. 6B shows how this shunt circuit works. Increasing the negative voltage to the gate increases the source-to-drain resistance, less signal is bypassed to ground, and the volume increases. Note that there is no need of any DC voltage between the source and drain.

Comparison of Circuits

Fig. 7 shows three comparable circuits using a FET (A), a bipolar transistor (B) and a tube (C) in a simple RC audio amplifier circuit. Note that the FET and tube circuits are almost identical except for the size of the supply voltage.

The bipolar transistor differs from the other two, both in method of biasing and in the amount of input impedance. The lower input and output impedances of the bipolar NPN transistor mean that resistors used in the circuit are smaller in value, and capacitors are much

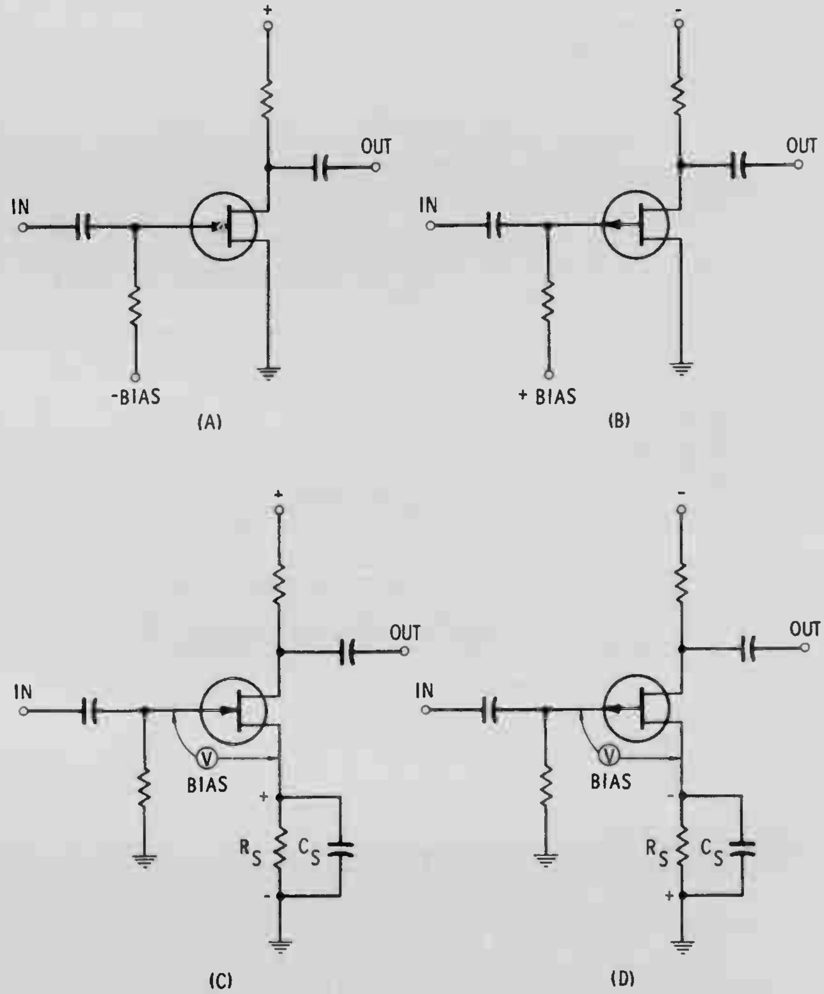


Fig. 3 JFET's are depletion-type FET's; that is, source-to-drain current can flow with no bias applied to the gate. Control of the source-to-drain current is accomplished by reverse biasing the gate, which reduces or completely cuts off source-to-drain current, depending on the amount of reverse bias applied. Either fixed- or self-bias is employed to assure that the input signal does not forward bias the gate and cause it to draw current. A) N-channel JFET with fixed bias applied to gate. B) P-channel JFET with fixed bias. C) N-channel JFET circuit employing self-biasing, which, in this case, is the voltage developed across resistor RS. The bypass capacitor, CS, may or may not be used, depending on how degeneration affects the function of the circuit. D) Self-biased P-channel JFET.

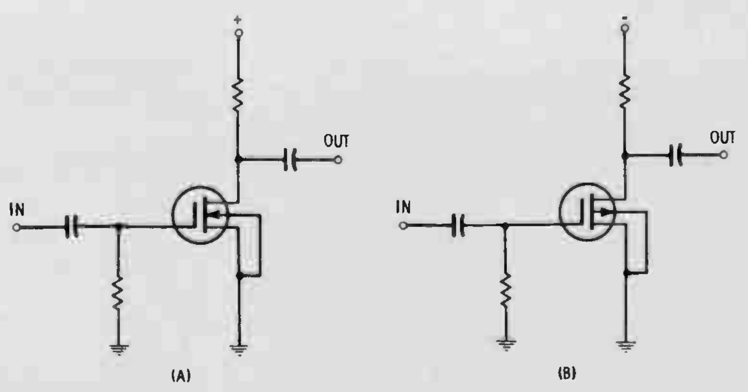
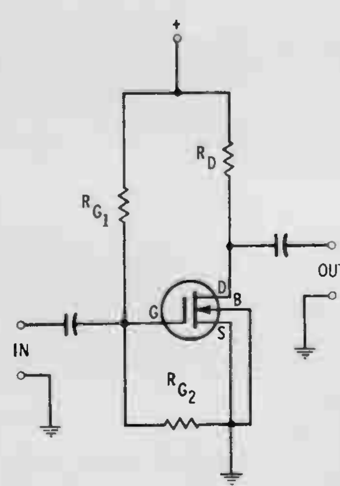


Fig. 4 Metal-oxide semiconductor field-effect transistors (MOSFET's) can operate satisfactorily with both reverse and forward bias voltages from gate to source because the insulated gate prevents the flow of gate current when the voltage on the gate swings positive. A and B show depletion MOSFET's connected for type B mode of operation (gate voltage can swing both positive and negative).

Fig. 5 Circuit employing enchancement MOSFET biased to operate in the type C mode (little source-to-drain current until gate potential is increased in positive direction). RG1 and RG2 form a bleeder circuit to supply turn-on bias to the gate. If you zero-bias the gate by connecting a jumper from gate to source, the source-to-drain current will be reduced to near zero, or about 1 microampere.



larger than those used in either the FET or tube circuits.

For example, in the FET and tube circuits shown in Fig 8, CC_1 and CC_2 could well be around .005 to .01 mfd, while in the bipolar transistor circuit the capacitors likely would be 2 mfd or more. The load resistor of the bipolar transistor likely would be no more than 10K, and probably less, while the load for the FET and tube would be 15K to perhaps 470K or more.

The input impedance of the FET and tube will be as high as the input resistor; the input of the bipolar transistor probably will be no more than about 1000 ohms.

Both the FET and the bipolar, in most cases, will operate satisfactorily on lower supply voltages than those needed by the tube. The power output of the amplifier using a bipolar will be higher than either the FET or tube because it will draw more current, but the FET or tube are better voltage amplifiers.

Testing FET's

If you service, or expect to service, a number of FET circuits, you should treat yourself to a FET tester. Most new bipolar transistor testers also make FET tests. You can, though, make a fairly valid test of any JFET using just your ohmmeter.

Although not all JFET's are symmetrical (drain and source terminals interchangeable), most are. If you encounter an unmarked FET, or if you're not sure whether it is a FET or a bipolar (since they use the same kinds of metal and plastic cases), you can use an ohmmeter to find out if it is really a FET, and which lead is which. To do so, measure with an ohmmeter (the R X 10 range is a good one) between any two leads. Note the reading, and then reverse the test leads and con-

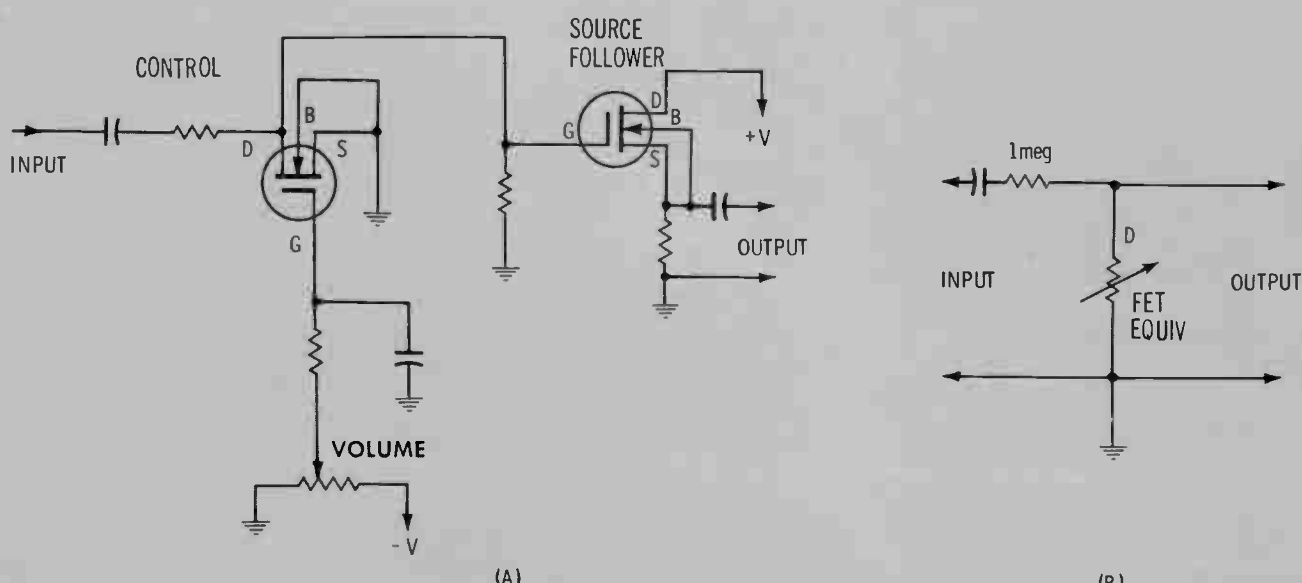


Fig. 6 A MOSFET circuit for remotely controlling volume. A) Actual circuitry. B) Equivalent circuit.

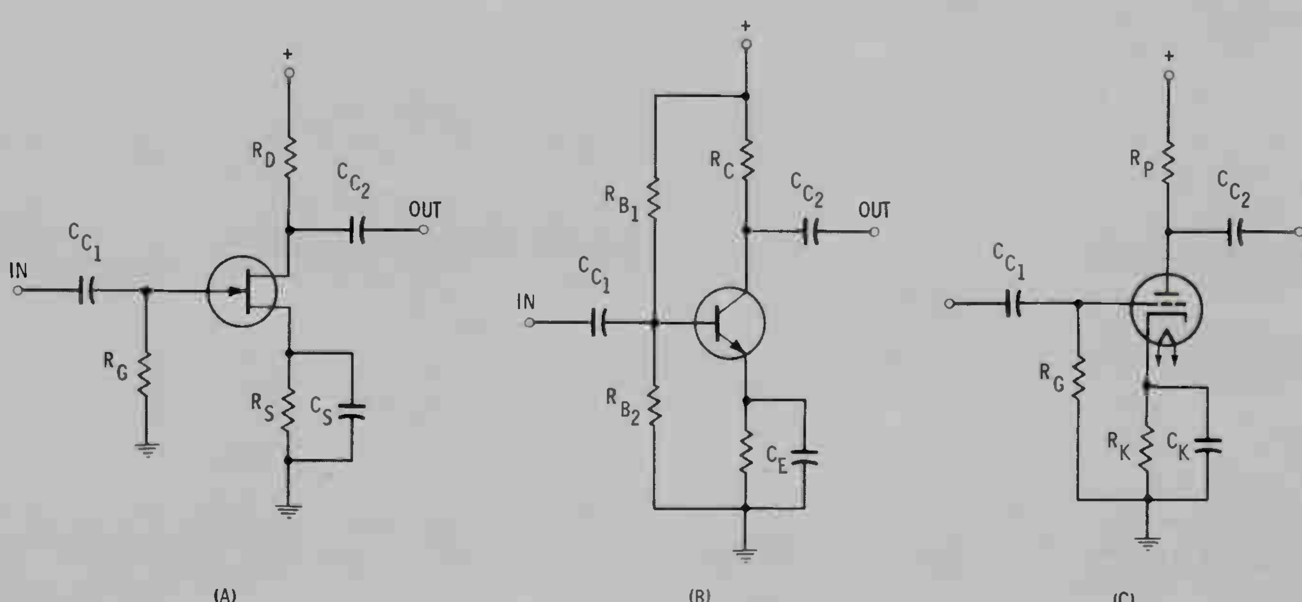


Fig. 7 Comparison of FET, bipolar transistor and tube circuits. Tube and FET circuits are similar except for values of supply voltage. Bipolar transistor requires lower supply voltage, smaller values of resistance and larger values of capacitance than other types of circuits shown here. A) FET, B) bipolar transistor and C) tube circuits.

nect them to the same FET leads as before. If the two readings are the same (maybe around 1000 ohms), the two leads are the drain and source terminals of the FET. The other lead will be the gate. The gate of the JFET will have diode action to either the source or drain terminal (high and low resistance readings when you reverse the ohmmeter leads while measuring between the gate and the drain or source).

Is it an N channel or P channel? That's easy, too, if you know your ohmmeter. An N channel will produce a high resistance if you place a negative voltage between the gate and the source or drain. A low resistance will be indicated if you place a positive voltage between the gate and the source or drain of the N channel.

The ohmmeter supplies this positive or negative voltage, but herein lies a pitfall: On most American-made ohmmeters, the "+" lead for measuring voltage will also be the "+" lead for testing ohms. However, on most Japanese-made meters, the "+" red lead for the voltmeter is tied to the negative side of the ohmmeter battery when mea-

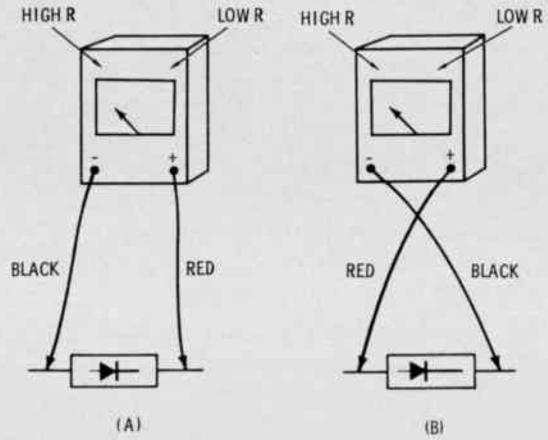


Fig. 8 Method for determining whether "+" lead for voltage function of VOM also is "+" lead for resistance function. A) If ohmmeter indicates highest resistance with leads connected as shown, **red lead** of VOM also is "+" lead for ohmmeter function. B) If ohmmeter indicates highest resistance when connected in this manner, **red lead** of VOM is **negative lead** for ohmmeter function.

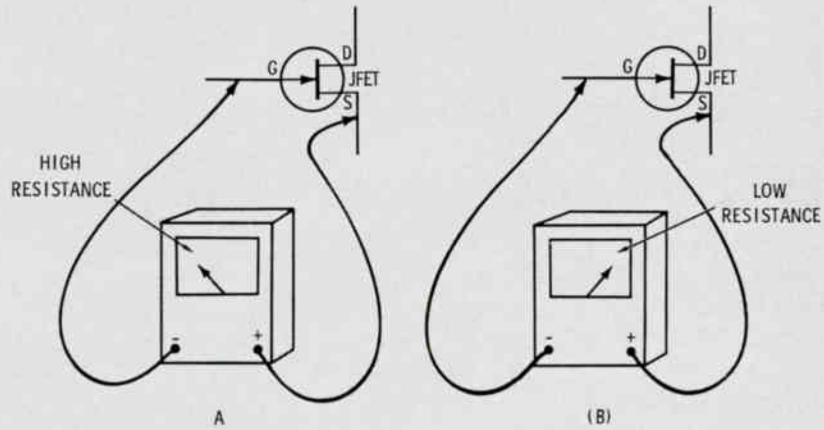


Fig. 9 Readings obtained using American and Japanese type VOM's to determine type of channel of FET (N in this case). A) American VOM. B) Japanese VOM.

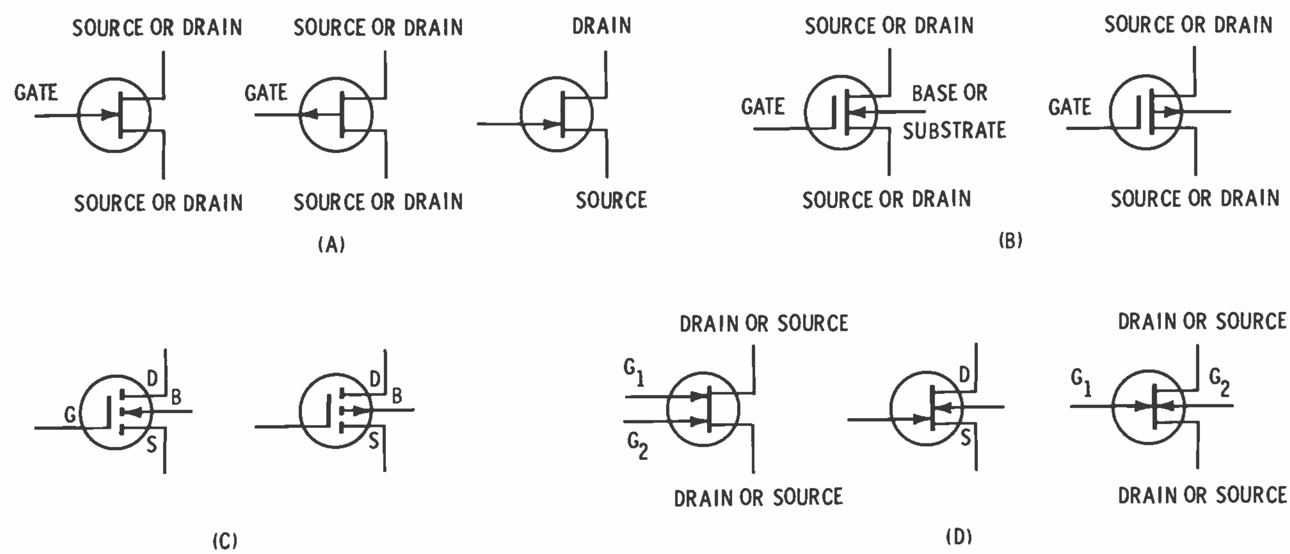


Fig. 10 There is never complete standardization of symbols for electronic devices, and certainly not while the device is relatively young. But in general, the symbols for FET's are similar enough so that they can be recognized. A) The JFET symbols are relatively well standardized. As in all transistors, the arrow points to "N" material. The N-channel FET is on the left and a P-channel FET on the right. The arrow is on the gate terminal. The N-channel JFET is normally biased negative from gate to channel; the P-channel type is normally biased positive. B) Symbols for the depletion-type MOSFET's or IGFET's. These FET's have a very thin oxide coating between the gate and the channel. The oxide acts as an insulator, and no current can flow between the gate and channel, regardless of the direction of the bias voltage. The arrow of the symbol shown is not on the gate terminal but on the substrate or base (not to be confused with the base terminal on a bipolar transistor). Again, the arrow indicates whether the transistor is an N- or P-channel type. C) Symbols used for enhancement type MOSFET's. As explained in December, the enhancement type requires bias voltage on the gate to **start** current flow between the source and drain terminals, while the depletion type requires bias voltage to **reduce** or pinch off the current flow between source and drain. D) Symbols for dual-gate FET's. On the left is an N-channel symmetrical type (drain and source are interchangeable). In the center is another symbol for the N-channel non-symmetrical type (drain and source are not interchangeable). ▲

suring ohms.

Fig. 8 shows how you can determine which of the preceding ways your meter is connected on the ohms function. Once you find out, all you have to do is remember which ohmmeter lead is positive. Fig. 9 shows how an American type and a Japanese type VOM will check the same N-channel JFET.

MOSFETS are not easy to check with an ohmmeter, though you can determine which is the drain, source and gate terminal. The gate terminal is a complete open circuit to either of the other two leads.

CAUTION: The oxide insulation in a MOSFET is very thin and delicate. The gate lead should always be returned through a resistance to the source terminal; otherwise it can pick up enough static electricity to puncture the insulation. MOSFET's should be stored with the leads taped or twisted together, and should be kept this way until **after** being installed in the circuit. ▲

Chapter 4

Rectifier diodes—operation, applications and testing

Facts all technicians need to know about series and shunt rectifier circuits. Explains how and why the shunt rectifier is the basis of most oscillators, sync separators and horizontal drive circuits. Practical methods of using a scope to diagnose rectifier circuit defects also are included.

Understanding Diodes

Only two things are necessary for rectification: a source of AC and a diode. All other parts are refinements—even a filter capacitor can be replaced by a battery in some circuits. Diodes can be vacuum-tube or solid-state types made of such materials as copper-sulfide, selenium, germanium or silicon. Assorted types of solid-state rectifiers are shown in Fig. 1. Later, we will see that the grids of tubes and the bases or collectors of transistors can function similarly to the anode of a diode.

Any diode is actually a voltage-controlled switch, regardless of its type of construction or efficiency. When the anode is positive, relative to the cathode, a near-perfect diode will have almost zero resistance, as shown in Fig. 2. Or, to say the same thing another way, when the diode is forward biased, the forward resistance is nearly a short-circuit. When the anode is negative, relative to the cathode, the diode is reverse biased, and a near-perfect diode will have infinite resistance. These statements are true even when the diode is used as a DC clamp, an AM detector, a power supply rectifier or a damper.

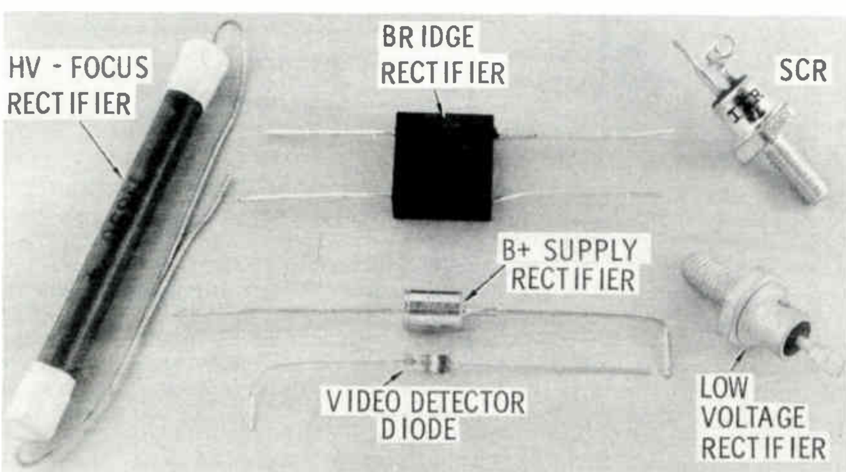


Fig. 1 An assortment of typical solid-state diode rectifiers.

The efficiency of any diode is measured by the power (wattage) dissipated across it as the result of both forward-bias voltage drop and reverse-bias leakage current. Let's again analyze the action of a near-perfect diode: Current produced by forward bias can be very large, but the voltage drop across the diode will be nearly zero, because the internal resistance also will be nearly zero. The formula is: Wattage = I^2 X R, but if R is zero, the answer also will be zero. When the diode is reverse biased, the voltage across the diode will be very high, but the leakage current will be nearly zero. Again, almost no power will be dissipated across the diode.

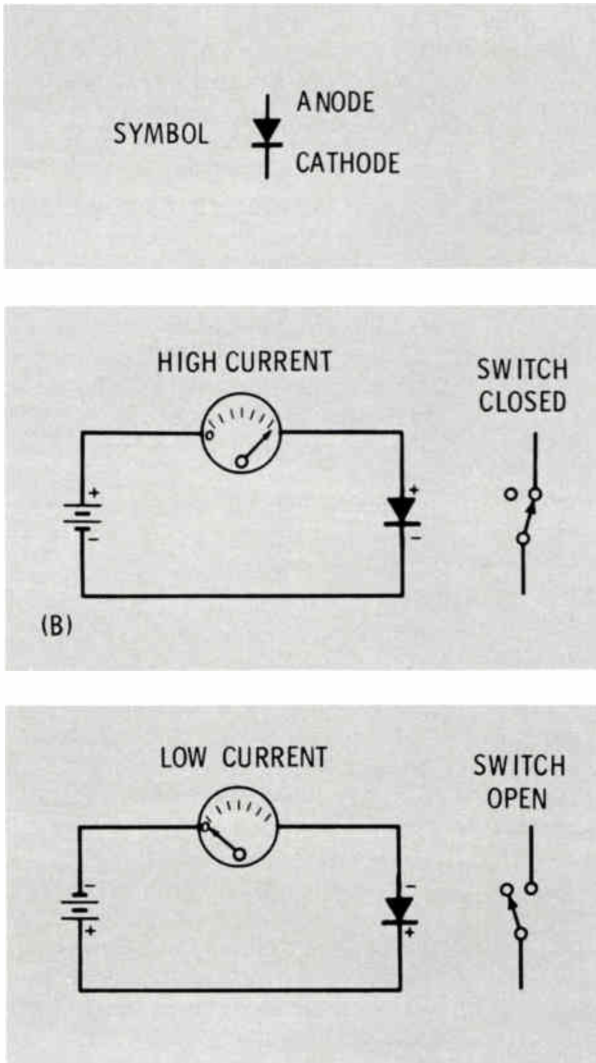
Perfect diodes do not exist. A tube diode can have zero reverse current, but the forward resistance is relatively high. A silicon diode might have very low forward resistance but measurable reverse current. At this time, silicon diodes have the highest efficiency of any used commercially.

All such diode losses produce heat; the less heat, the higher the efficiency. The heat generated by a diode depends, in part, on the length of time it takes to switch from a completely "on" state to a completely "off" state, or visa versa. Between these two operating states, internal resistance is relatively high. The quicker this switching action, the less heat generated. The ultimate in efficient switching is the conventional on-off switch. These facts explain how SCR's and triacs can switch large amounts of power and remain relatively cool. They are either completely on or completely off—the two conditions where heat dissipation is minimum.

Evolution of Rectifier Circuits

The most simple rectifier circuit, consisting of a source of voltage, a diode and a load resistor, is shown in Fig. 3A. The output waveform is produced by the positive half of the incoming sine wave, as pictured in the double-trace scope waveform in Fig. 3B. Diode conduction occurs only when the anode is positive, and because there is a pulse of positive voltage for each positive side of the sine wave, the frequency of the rectified output is 60 Hz. If you don't have a dual-trace scope, check the frequency by connecting the vertical input probe of your scope to the positive end of the load resistor, and the scope ground lead to the power supply ground. Reset the scope controls for internal 60-Hz horizontal (sine-wave) sweep. Adjust the vertical and horizontal gain controls for equal height and width; the waveform should look like that of Fig. 3C, if the output of the power supply is a positive-going pulse. If your scope does not have internal 60-Hz horizontal sweep, change the controls for external horizontal sweep, then attach the horizontal input probe to the anode of the diode, X1. Adjust width as needed. This kind of rectification is often called "half-wave", because only half of the sine wave is used. The DC voltage produced will be low because VOM's and VTVM's **average** any rapid variation in voltage, and this half-wave voltage is present only part of the time, thus making the average very low.

"Full-wave" rectification is illustrated in the schematic of Fig. 4A. The center-tapped transformer provides 180-degree, out-of-phase voltages to X1 and X2, which causes them to conduct alternately when their anodes become positive. Comparison of the full-wave output with the sine-wave input in Fig. 4B verifies that the output pulses of the full-wave voltage are 120 Hz. Or, use the 60-Hz horizontal sine-wave deflection on your scope, as detailed before, and the "V" waveshape (like that in Fig. 4C) will prove the output pulses (if they are positive) to be 120 Hz.

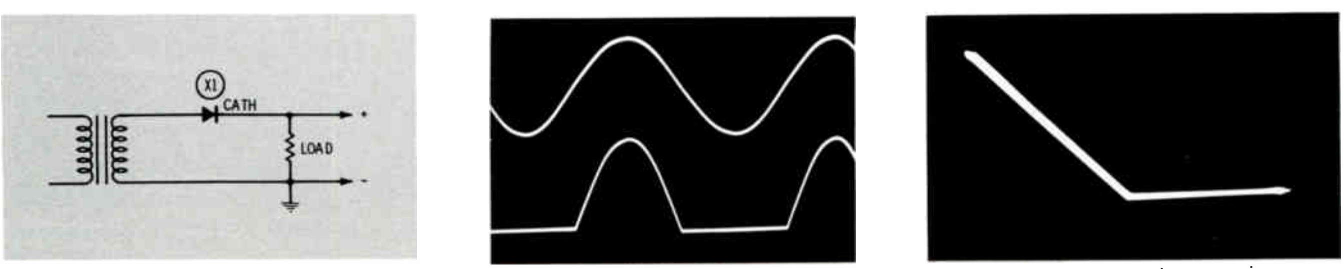


(A) Schematic symbol of a diode.

(B) A diode is switched "on" when the anode is positive relative to the cathode.

(C) A diode is switched "off" when the anode is negative relative to the cathode.

Fig. 2 A diode is a voltage-controlled switch.



(A) Schematic of the half-wave circuit. Input voltage is 150 volts rms, DC output is +67 volts, AC output is 205 volts p-p and the load is 4.7K ohms.

(B) Double-trace scope waveform of the input sine wave and the output rectified pulse; both are 60 Hz.

(C) Scope waveform with the output pulse applied to the vertical amplifier of the scope and a 60-Hz sine wave used for horizontal deflection.

Fig. 3 Simple, unfiltered, half-wave rectifier circuit.

Rectifier circuits without capacitors are not typical in the power supplies of consumer electronic equipment. A half-wave rectifier with an input filter capacitor of 20 mfd is shown in Fig. 5A. The output waveform (hum or ripple) is a 60-Hz sawtooth, as shown in Fig. 5B. It is important for us to know, and remember, that the output is actually 95 percent pure DC with about 5 percent of sawtooth riding on top. The frequency of the sawtooth can be determined with a scope by the method given previously; the correct waveform is shown in Fig. 5C.

Compared to the basic circuit voltages in Fig. 3, the voltages of Fig. 5 show a substantial increase in DC voltage, and an equally substantial decrease in p-p AC (hum). These differences are produced by the capacitor.

An Input Capacitor Causes "Peak-Reading" DC Voltages

Fig. 6 shows the relationships of p-p, peak and rms voltages. Since rectification uses no more than one peak for one diode, the peak voltage is the one of interest to us. Peak voltage equals the rms voltage multiplied by 1.414.

In the rectifier circuits of Figs. 3A and 4A, each diode conducts current and voltage for a complete half cycle, because this is the time the anode is positive relative to the cathode. Adding a capacitor in parallel with the load resistance (Fig. 5A) causes the diode to supply power to the load, and charge the capacitor, during the time of conduction. In between diode conduction pulses, the capacitor partially discharges, to furnish power to the load. This partial discharge results in a sawtooth ripple, or hum, across the capacitor, as shown in Fig. 7B.

Diode conduction cannot occur until the anode becomes more positive than the cathode. With the cathode connected to the positive end of the storage capacitor, only the tip of the input sine wave is more positive than the cathode/capacitor voltage; therefore, diode conduction occurs for a short period of time, as shown in the waveform of Fig. 7A. The dotted lines in Fig. 7B were added to show the part of the sine wave during which the diode current flows, while Fig. 7C shows the relationship between the rising edge of the sawtooth and the diode current (the scope width was expanded for better visibility).

The voltage at the top of the sawtooth is the peak voltage (rms times 1.414) of the applied AC sine wave, less any losses. The amplitude of the sawtooth depends principally on the capacitance and the load. If the load is very light and the capacitance large, the output DC voltage will measure almost exactly the peak of the input AC voltage. This is the meaning of the old phrase "peak-reading".

A 20-mfd capacitor added to the full-wave circuit, as shown in Fig. 8A, produces more DC and less AC (hum) at the output, and the hum is 120 Hz (see Fig. 8B). Frequency of the hum is verified on single-trace scopes by using 60-Hz, sine-wave horizontal sweep and applying the sawtooth to the vertical input. A "bow tie" waveform, as shown in Fig. 8C, indicates the frequency is 120 Hz.

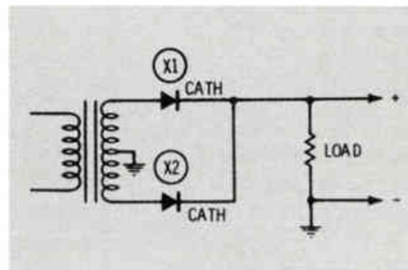
If negative voltage is desired from any of these four types of rectifier circuits, merely reverse the diode(s) and the polarity of the filter capacitor.

Many variations of these basic circuits are possible. For example, Fig. 9A shows a rectifier circuit which supplies a positive output voltage, yet one side of the rectifier is grounded. This circuit was used to produce the waveforms of the capacitor current and diode current (Fig. 9B) by adding small resistors in series between anode and ground, and the negative plate of the capacitor and ground. The common ground necessary for operation of a dual-trace scope inverted the polarity of the pulse of the diode current.

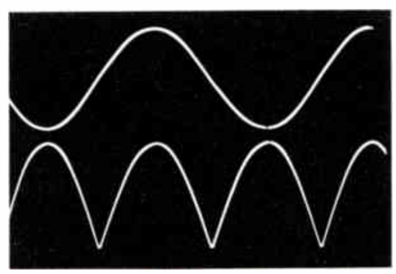
Any rectifier circuit is a closed loop, and the basic operation is not changed by repositioning the ground connection. The ground is there only for the external circuits that constitute the load. Take the schematic of Fig. 9C as an example. It is the same as that of Fig. 5A, except for the grounding point.

Some power supplies have negative output, others have positive output, and some equipment (particularly solid-state types) might have both positive and negative voltage outputs. One model of solid-state TV receiver stacks one power supply on top of another. To determine what the polarity of a power supply should be, follow this helpful rule:

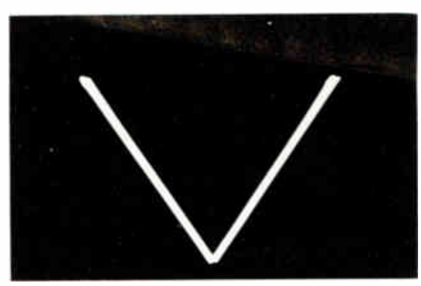
When rectified DC is obtained from a diode, the polarity of the voltage will be negative if it is taken from the anode, and positive if it is taken from the cathode. In Figs.



(A) Schematic of the full-wave rectifier circuit. Input voltage is 150 volts rms on each side of the center-tap, load resistance is 4.7K ohms, DC output is +135 volts and the AC output (hum) is 210 volts p-p.



(B) Scope waveform of the 60-Hz input sine wave and the 120-Hz full-wave pulse.



(C) The 120-Hz output pulse applied to the vertical amplifier of the scope and a 60-Hz sine wave applied to the horizontal amplifier.

Fig. 4 A full-wave unfiltered rectifier circuit, using a center-tapped transformer.

3A, 4A, 5A and 8A, the output voltage is obviously obtained from the cathode of the diode, and consequently is positive. The output voltage of Fig. 9A is from the cathode, through the transformer winding, and is also positive.

A rectifier circuit with both positive and negative voltages is diagrammed in Fig. 10A; the associated waveforms are shown in Fig. 10B. To change this circuit to one that produces twice the normal amount of positive voltage (voltage doubler), it is necessary only to switch the ground to the –output terminal, as shown in Fig. 10C. The same circuit is redrawn in a more familiar configuration in Fig. 10D. It is very odd to see a diode connected from one side of the transformer winding to ground and a filter capacitor connected from the other side of the winding to ground, but Fig. 10C shows that the double voltage is obtained by connecting the negative and positive supplies in series. This is verified when the full-wave, 120-Hz output waveform in Fig. 10E is compared to the two 60-Hz, half-wave, alternate-conduction waveforms in Fig. 10B.

Shunt Rectifiers

All of the rectifier circuits described previously were "series" types; which, incidentally, function just as well if the transformer shown is actually the one on the power company pole.

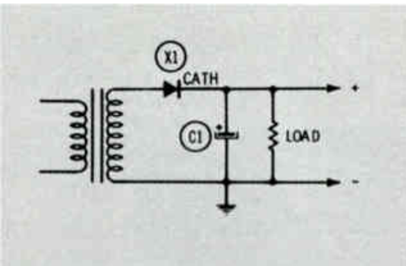
The other basic rectifier circuit is the shunt, or parallel, type. Although it requires a resistive path somewhere across the input terminals, the rectifier diode and load are separated from the source voltage by the input filter (storage) capacitance. The other distinctive characteristic is that the entire input AC voltage also appears across the output, as shown in Fig. 11A.

Fig. 11B illustrates an unsuccessful attempt to filter out the huge amount of hum from the output. Even when fed through a strong filter system consisting of a 680-ohm resistor and a 40-mfd capacitor with no DC load on the output, the hum measured 45 volts p-p. Because of the inherent hum, this circuit is useless for powering radios or TV receivers.

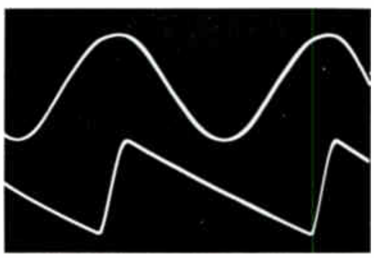
One very successful adaptation is to combine the shunt with a following series rectifier, as shown in Fig. 12. DC and nearly full line voltage are the output of the shunt rectifier. The series rectifier rectifies the AC sine-wave output of the shunt rectifier and adds the DC on top of the DC from the shunt stage to produce voltage doubling.

The output hum of this circuit is 60 Hz. Notice the polarity of diodes X1 and X2 in Fig. 12. X1 conducts on the negative side of the sine wave, and X2 conducts on the positive peak. In many doubler circuits such operation would double the frequency, but not in this case. Because the large sine-wave output from the shunt rectifier circuit completely swamps any small amount of ripple that might be present, the hum output of X2 is 60 Hz.

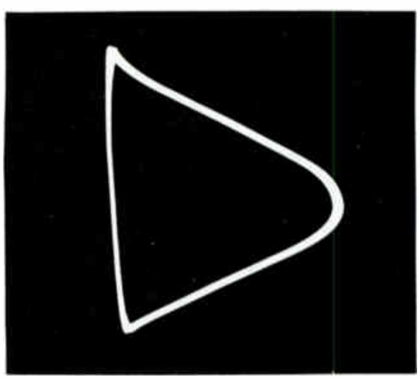
The voltage charts in Table 1 provide the values of the DC and hum voltages obtained from the circuit of Fig. 12 when the size of the



(A) Schematic of the half-wave rectifier with capacitor circuit. Input AC voltage is 150 volts rms, C1 is 20 mfd, load is 4.7K ohms, DC output is +175 volts and AC output is 17 volts p-p.



(B) Input sine wave and the output sawtooth AC; both are 60 Hz.



(C) Scope waveform with the output sawtooth applied to the vertical amplifier and a 60-Hz sine wave applied to the horizontal amplifier.

Fig. 5 An input electrolytic capacitor is added to the half-wave circuit to make it "peak reading".

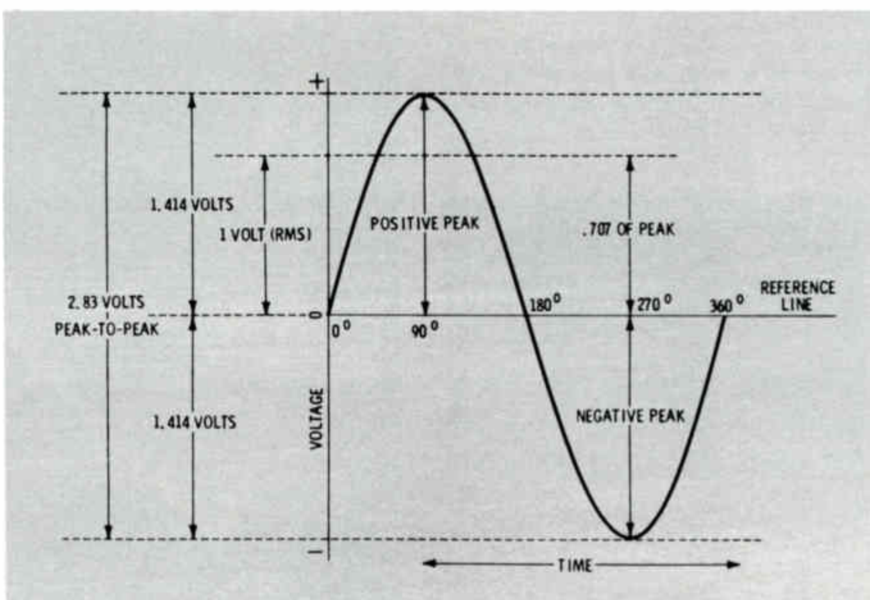
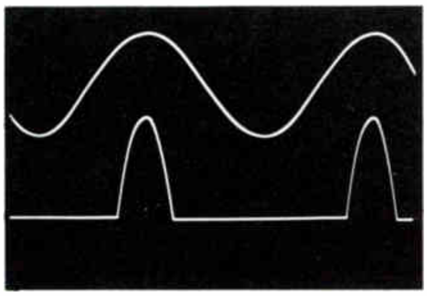
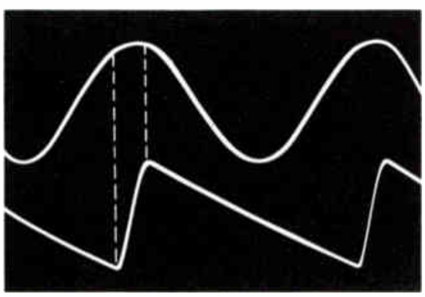


Fig. 6 Peak and rms voltages are enough to evaluate sine-wave AC voltages; p-p voltages are necessary to measure correctly square waves or non-symmetrical waveforms.

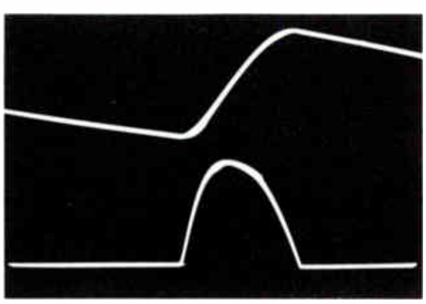
two input capacitors and the value of the load resistor were changed. I have known for many years that the capacitance of C1 and C2 would radically change the output DC voltage and hum. Even so, two items in the table surprised me: One was the reduced output hum voltage as the capacitance of C1 was decreased. The explanation is simple: Hum voltage is dependent on the series rectifier circuit—and it is sup-



(A) Top waveform is the 60-Hz input sine wave and the bottom waveform is the diode current (slightly broadened by the resistances in the circuit).

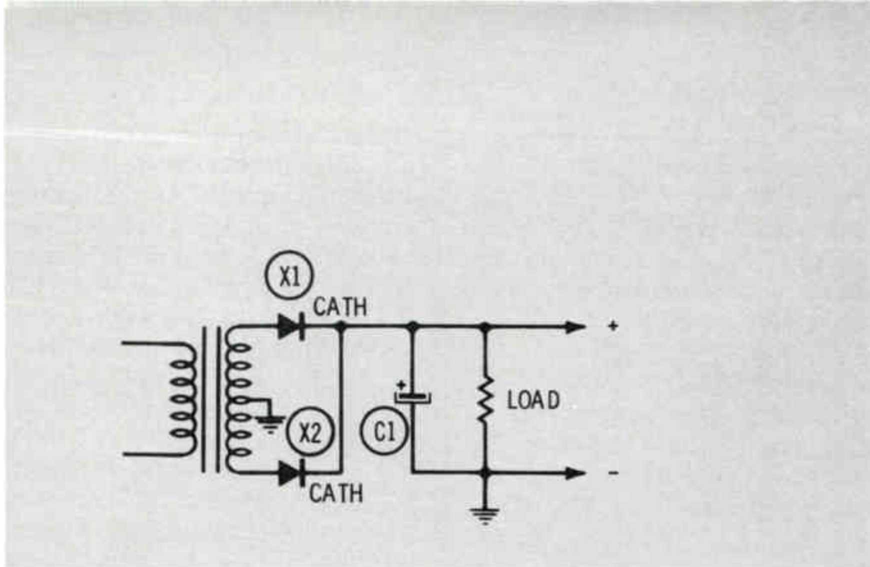


(B) The relationship of the input sine wave to the output sawtooth hum. The dotted lines were added to show the part of the sine wave during which diode current flows.

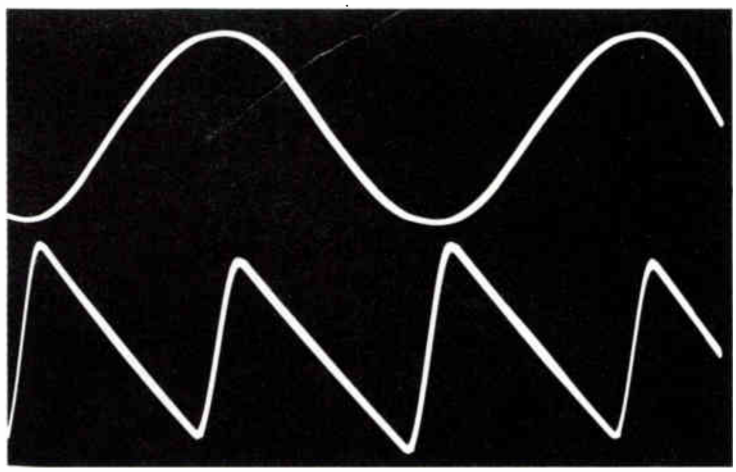


(C) Horizontal sweep width of the scope is increased to make the relationship between the sawtooth hum (at top) and the diode current more clear.

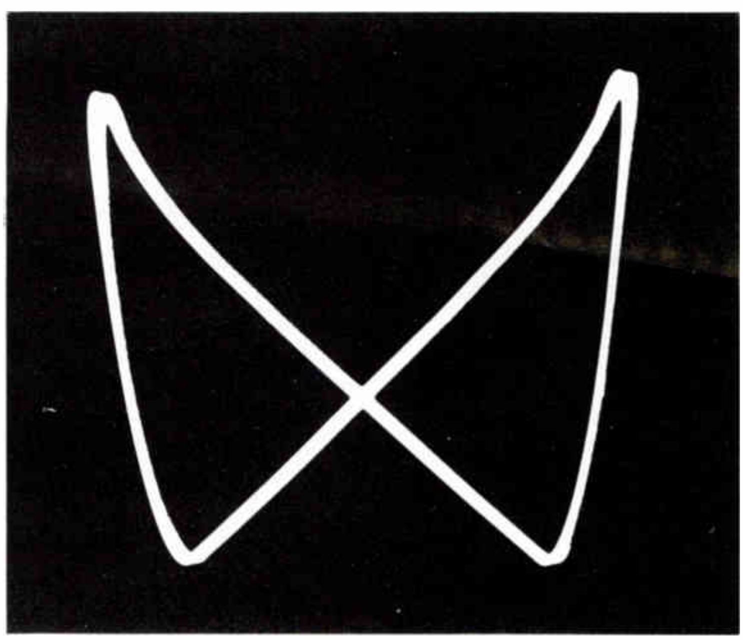
Fig. 7 Dual-trace scope waveforms of current and voltages in the schematic of Fig. 5A.



(A) Schematic of the full-wave circuit using two diodes, a center-tapped transformer secondary and a peak-reading input capacitor. AC input voltage is 150 volts rms each side of center-tap, C1 is 20 mfd, load is 4.7K ohms, the output DC voltage is +195 and the output AC hum is 8 volts p-p.



(B) Waveforms of the 60-Hz input sine wave and the 120-Hz output sawtooth hum.



(C) "Bowtie" waveform obtained with the sawtooth hum applied to the vertical input of the scope and a 60-Hz sine-wave horizontal sweep.

Fig. 8 A frequently used full-wave rectifier with capacitor input filter.

plied with less input DC and AC when the capacitance is decreased.

The other surprise was the result when the capacitance of C2 was changed. When C3 is 0 mfd, and C2 is changed to 0 mfd, the resultant output is +165 DC and 325 volts p-p 60-Hz sine wave, exactly the same as the output of the shunt rectifier. The only explanation is that the anode of X2 is positive relative to its cathode at all times; the peak DC and AC from the X1 circuit are the same.

Other applications of the shunt/series type of voltage doubler are shown in Fig. 13. The load and quadrupler circuit is used during alignment of single- or over-coupled pairs of IF transformers in TV receivers, and it consists of two shunt/series doublers with the DC output voltages connected in series for increased output.

Fig. 13B shows the p-p rectifier circuit of the RCA WV98C VTVM. Other VTVM's and FET meters use solid-state diodes instead of the 6AL5, but the principle is the same. A p-p rectifier circuit must rectify both the positive and negative peaks, regardless of waveshape, and add the two voltages together for the complete reading.

Someone might question the practicality of this circuit, because it was previously stated that the output hum is the same frequency as the input voltage. However, it also was explained that one of the diodes conducted on the positive peak and the other diode conducted on the negative peak. Thus, the requirements for p-p measurements are fulfilled.

Negative Voltage Made From Positive Peaks

To understand how it is possible to obtain negative voltage by rec-

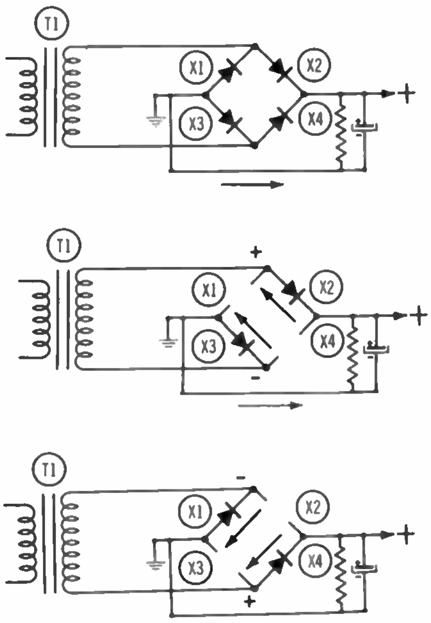
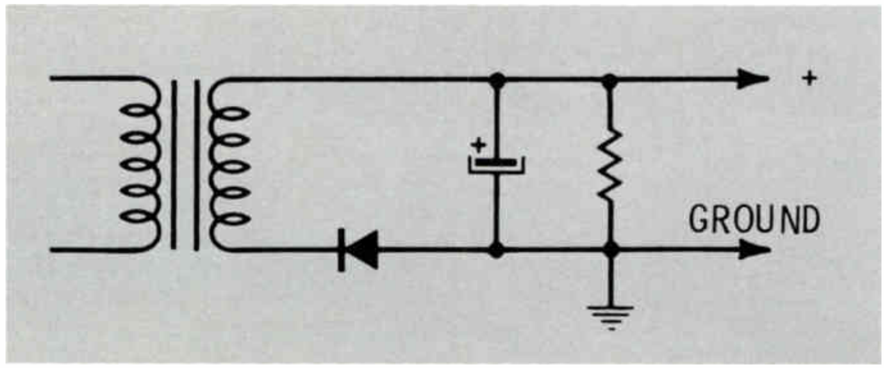
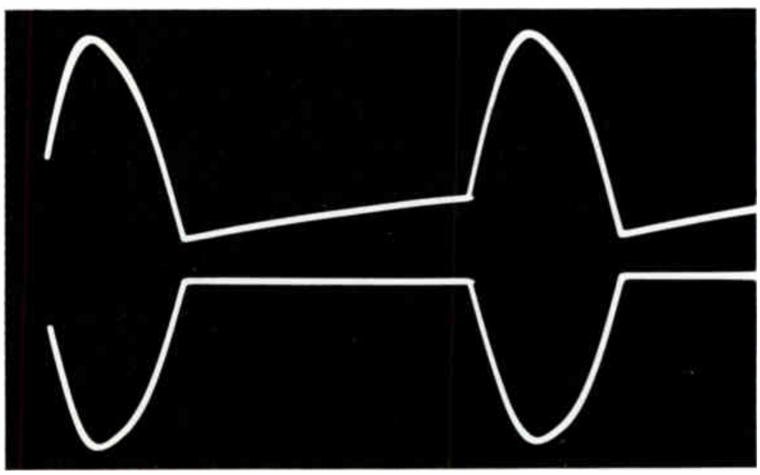


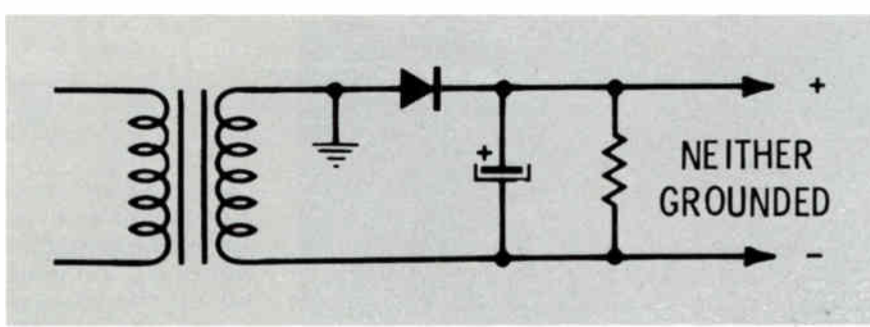
Fig. 8 (D) Schematic of a full-wave bridge rectifier circuit with peak-reading input capacitor. Circuit action is similar to the fullwave circuit in Fig. 8A, except that the diodes switch at both ends of the transformer winding, and the single non-tapped winding supplies power for both positive and negative peak rectification.



(A) Schematic of a rectifier circuit with the rectifier grounded. The output voltage is positive in polarity.

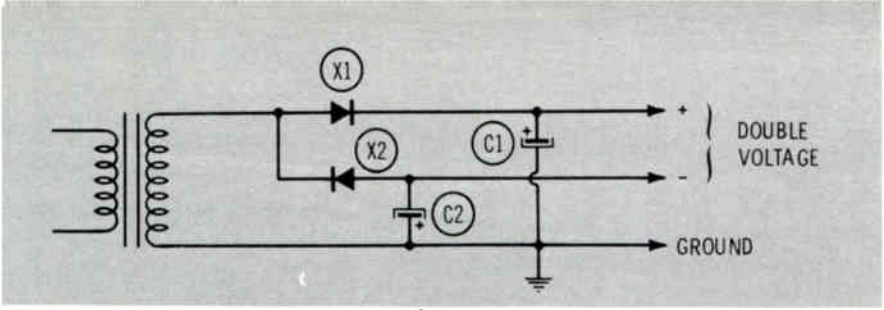


(B) Capacitor current and diode current can be seen on the scope screen by adding small resistors (27 ohms or smaller) between capacitor and ground, and between diode and ground. Attach the scope leads across the resistors one at a time (both, if the scope is dual-trace type.) The slope in the base line of the capacitor current waveform is the discharge of the capacitor into the load. Heavier discharge between cycles increases this slope and might indicate a capacitance that is too small for the value of the load.



(C) Schematic of a rectifier circuit with the rectifier-transformer point grounded. Operation is the same as that of Fig. 5A, except the load cannot be grounded.

Fig. 9 Operation of a rectifier circuit is not affected by location of the ground point.



(A) Schematic of the positive/negative voltage supplies.

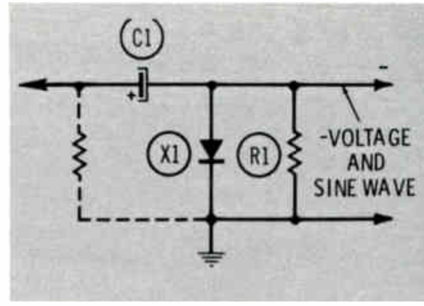
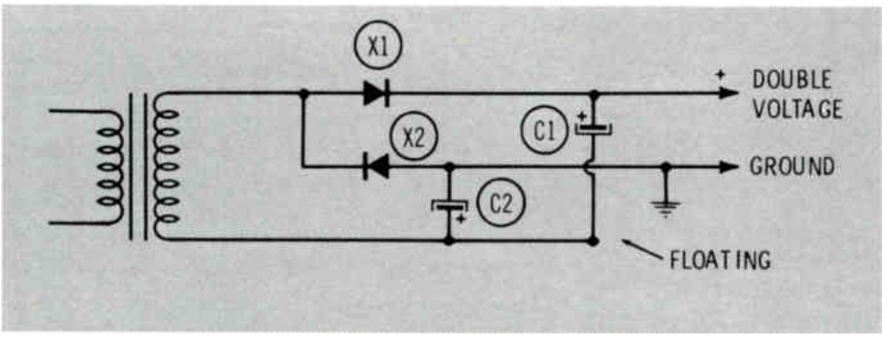
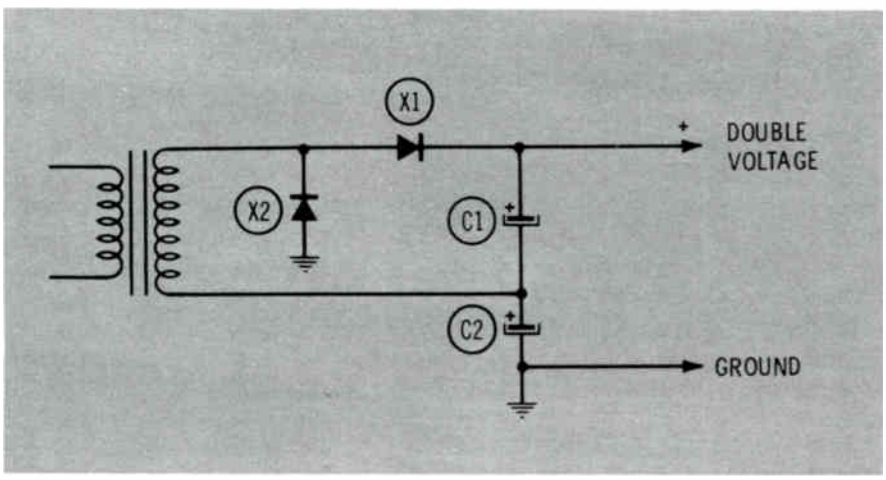


Fig. 11 (A) Schematic of a simple shunt rectifier with negative output.



(C) The schematic of (A) with the common transformer wire floating and the − terminal grounded to produce voltage doubling.



(D) Schematic of (C) redrawn as it often appears in service data. The circuit is much harder to understand in this form.

(E) Scope waveform of the input sine wave and the output sawtooth of (C) and (D). The hum is 120 Hz; this circuit is both a voltage- and frequency-doubler.

Fig. 10 Two half-wave, peak-reading circuits can produce both positive and negative voltages from one transformer winding.

tifying positive peaks, consider the following facts:

- For diode conduction, the anode must be positive in relationship to its cathode.
- When rectified DC is obtained from a diode, the polarity of the voltage will be **negative** if it is taken from the **anode,** and **positive** if it is taken from the **cathode.**
- Analyze the voltages and the electron current path, as shown in Fig. 15.

During the time the positive peak of the sine wave is present at the peak-reading capacitor, the capacitor charges through the low resistance of the diode, which is forward biased by the capacitor current. When the positive peak is not maximum, the diode is no longer forward biased and is virtually an open circuit. The high positive end of the capacitor is grounded through the transformer winding (power wiring or circuit resistances in the case of VTVM's), and the capacitor partially discharges the stored power into the load. This end of the capacitor is highly negative relative to the plate that is connected to the transformer. The capacitor is replenished with power for the short period of time during each cycle when the anode of the diode becomes slightly positive, but the anode of the diode is negative for a much longer period of time (the rest of the cycle). Any DC meter will read this as a negative voltage.

Base and Emitter of a Transistor Used as a Diode

The junctions of a transistor also exhibit diode characteristics. Fig. 16 shows two examples of rectification by the base/emitter junction.

The base of the transistor in Fig. 16A rectifies the pulse from the vertical output stage. A PNP-polarity

(B) Schematic of a shunt rectifier with positive output and an extra RC filter section. Input voltage is 120 volts rms, C1 is 20 mfd, R1 is 4.7K ohms, R2 is 680 ohms (1 watt) and C2 is 40 mfd. Output voltages obtained were: +160 DC and 330 volts p-p AC at the cathode of X1; +150 volts DC and 45 volts p-p AC at the output and C2. **NOTE:** R2 becomes very hot; also, the hum is too large for most uses.

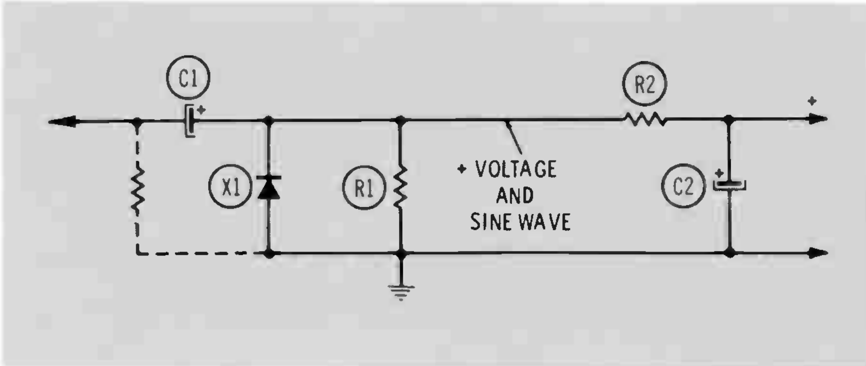


Fig. 11 Shunt rectifiers produce DC and full AC output.

120 volts rms input, C2 is 20 mfd, load across C3 is 9.4K ohms

C1 (mfd)	Output Voltage at C2	Hum at C2
40	+318	18 PP
20	+310	17 PP
10	+295	16 PP
7	+280	14½ PP
1.5	+160	7½ PP
0	0	0

120 volts rms input, C1 is 20 mfd, C3 is 0, load is 9.4K ohms

C2 (Mfd)	Output Voltage at C2	Hum at C2
40	+315	10 PP
20	+310	17 PP
10	+300	37 PP
7	+295	50 PP
0	+165	325 PP (60 Hz sine)
0	+240	255 PP when C3 is 40 mfd (choke input)

120 volts rms input, C1 is 20 mfd, C2 is 20 mfd, C3 is 40 mfd,

Load	Load Current	Voltage at C2	AC at C2	AC at C3
inf.	0 mills	+340	¼ PP	———
39K	8 mills	+330	5 PP	.1 PP
9.4K	33 mills	+310	17 PP	.5 PP
4.7K	62 mills	+285	30 PP	1.1 PP
2.3K	104 mills	+245	50 PP	1.7 PP

Table 1 DC voltages and hum obtained with different sizes of capacitors and load resistors.

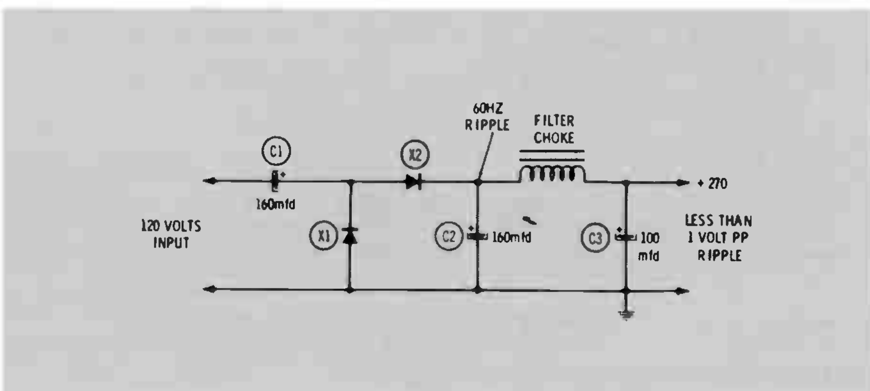
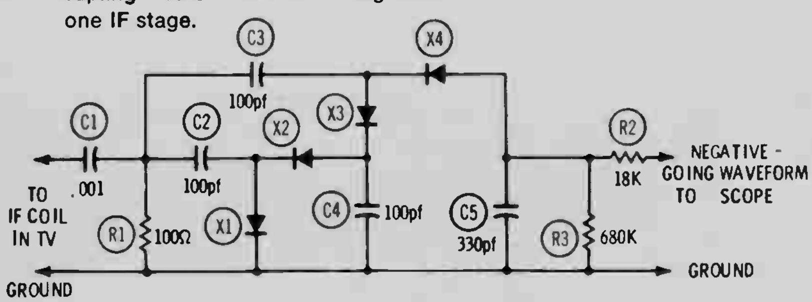
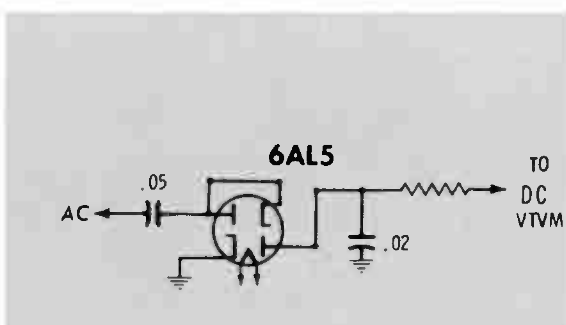


Fig. 12 Schematic of a typical voltage-doubler using both the shunt and series rectifier circuits. The hum frequency is 60 Hz even though the rectifiers conduct on opposite peaks.

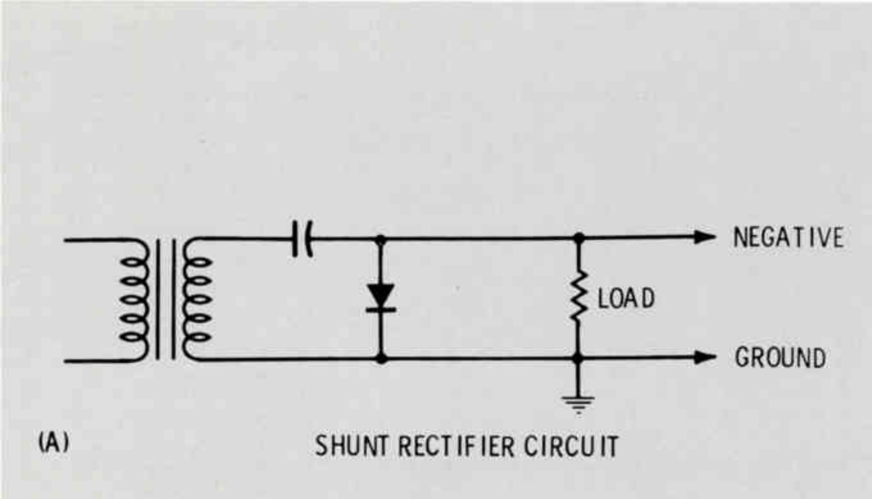
(A) Typical IF load and voltage quadrupling detector used for alignment of one IF stage.



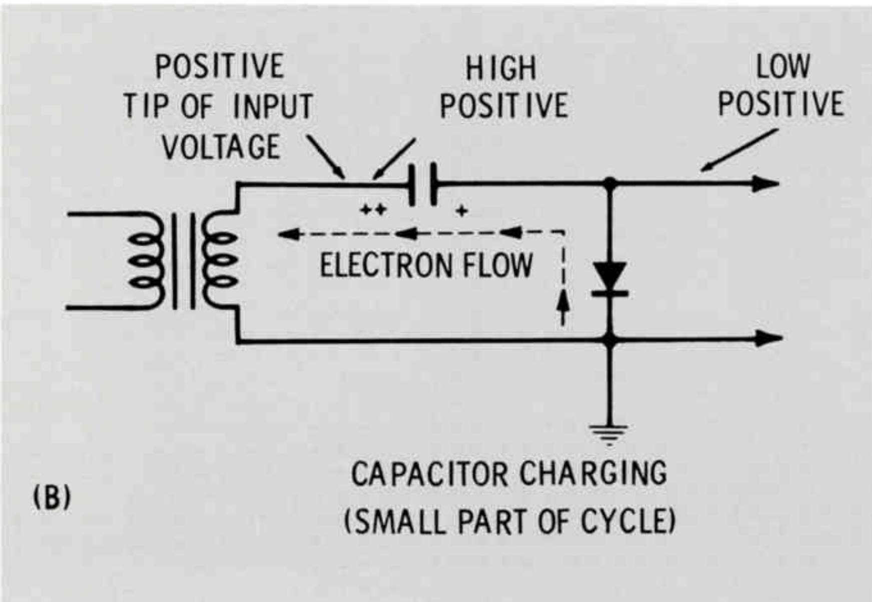


(B) Tube diodes used as p-p rectifiers in the RCA WV98C VTVM.

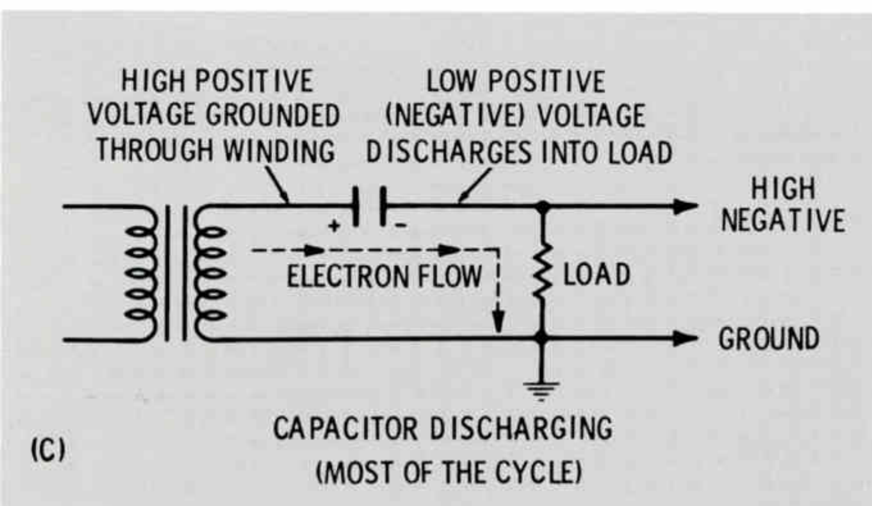
Fig. 13 Other uses for shunt and series rectifier circuits.



(A) Schematic of the shunt rectifier.



(B) Electron flow during the small part of the cycle when diode current is charging the capaictor.

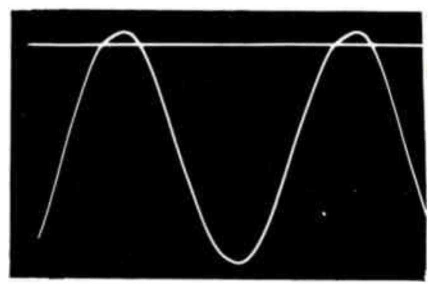


(C) Electron flow during the long part of the cycle when the capacitor is partially discharging into the load.

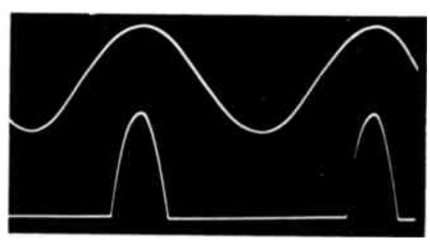
transistor is used, and a meter reads the base voltage as a reversed bias of 1.4 volts. At the right is a transistor equivalent, symbolized as diodes; included are the normal voltages relative to the emitter. From this, it is clear the negative peak of the incoming waveform forward biases the base-emitter junction and causes diode-type conduction. Because the DC produced by this rectification is obtained from the "cathode" of the transistor used as a diode, the polarity is positive.

Fig. 16B shows the voltages on a VHF oscillator transistor of NPN polarity; and on the right, the transistor drawn with diode symbols and normal voltages relative to the emitter. Base-emitter rectification produces negative voltage, which is reversed bias for an NPN transistor. Many similar circuits provide a small forward bias to initiate oscillation, after which the much larger rectified voltage becomes more predominent.

If a transistor stage measures reverse bias, yet according to symptoms on the screen or other accurate tests, the stage is functioning normally, it is nearly a certainty that



(D) The anode of the diode must become positive relative to the cathode for conduction to occur. Only the positive peak of the input sine wave fulfills this requirement. The horizontal line shows the part of the sine wave during which diode current flows. Consider the line zero, and below it as negative.



(E) Dual-trace waveforms of the input sine wave and the diode current.

Fig. 15 Explanation of how a positive peak creates negative voltage in the shunt rectifier circuit.

the transistor is operating as an oscillator or a class "C" amplifier. The reverse bias must become forward bias for a short period during each cycle.

Troubleshooting Power Supplies

The primary factors which affect the output voltage and residual hum of any power supply are:

• Input voltage and waveform (always should be checked).

• Diode condition, including forward voltage drop and reverse current leakage. (Be sure an open in the wiring or a circuit board has not changed a full-wave circuit to a half wave.)

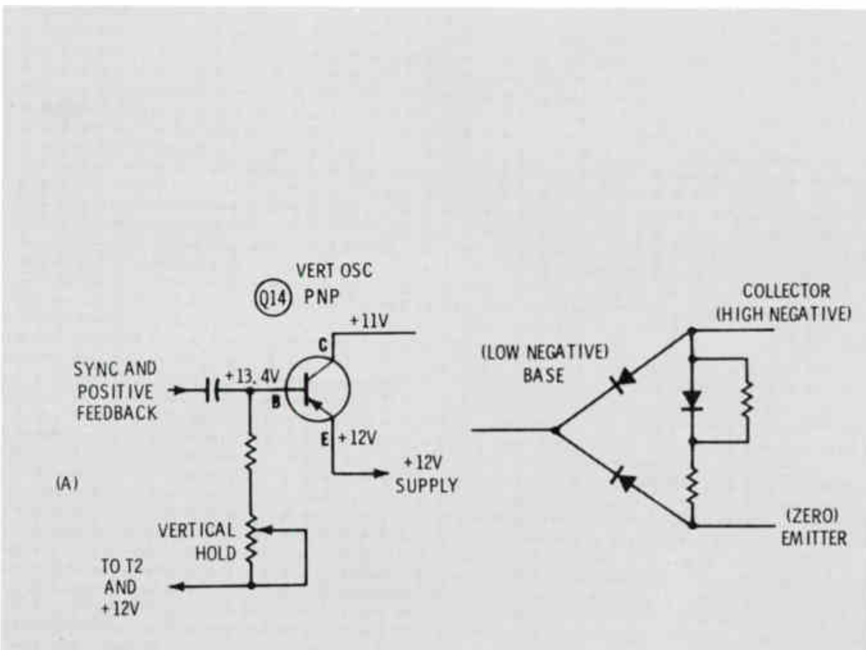
• Capacitor characteristics, including leakage and power factor.

• Load current (should be nearly normal).

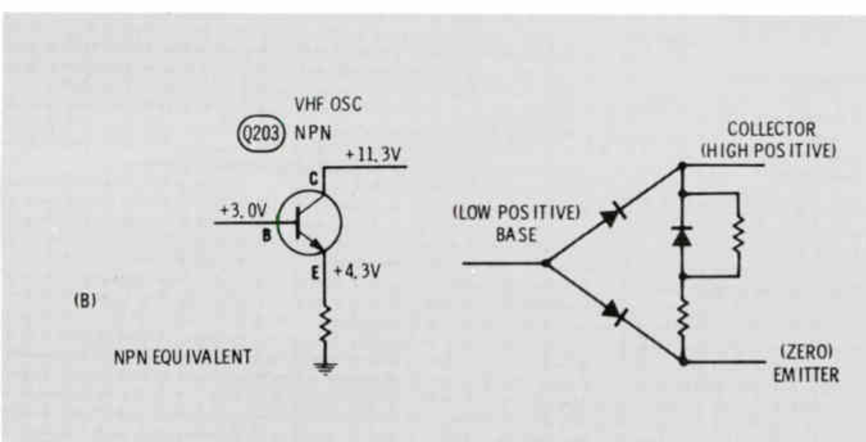
Many variations in symptoms and the extent of the defect are inevitable, but the cause of any power supply problem will be found in this simple list of four basic factors.

One open diode in the circuit shown in Fig. 8A or Fig. 8D will not stop all operation, but the DC voltage will be low and the hum level high, because a full-wave circuit has been changed to a half-wave configuration by the defect.

A scope, VTVM or FET meter, and perhaps an accurate line-voltage meter, should be your primary test equipment for power supply problems. Fig. 17 shows some of the

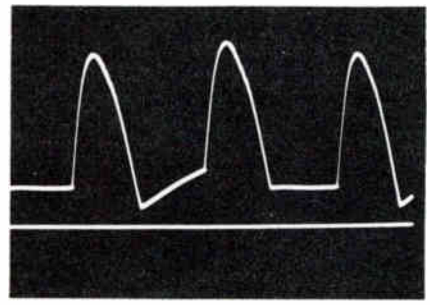


(A) Shunt rectification of the vertical pulse by the base and emitter produces reversed bias. The transistor equivalent, with the junctions shown as diodes, shows why this is true. Shunt rectification creates a positive voltage because the base is the same as the cathode in a diode.

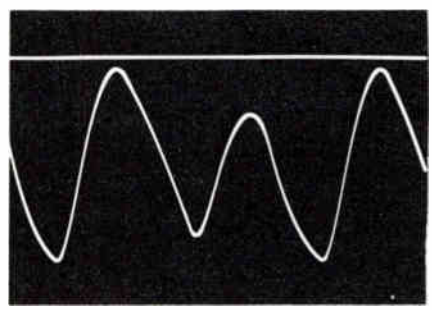


(B) The VHF oscillator transistor shunt-rectifies its own feedback signal and, because the base is the equivalent of the anode of a diode, the resulting voltage is negative, which measures as reverse bias.

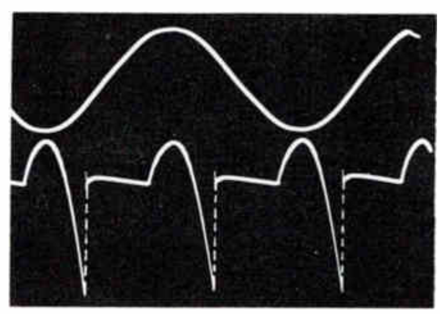
Fig. 16 The base and emitter of transistors also can function as diodes. Both examples are from the RCA KCS157 chassis.



(A) A leaking diode rectifier in the full-wave circuit of Fig. 8A causes alternate capacitor charge/discharge waveforms to have an excessive amount of tilt between pulses.



(B) A leaking diode rectifier in the full-wave circuit of Fig. 8A causes alternate hum waveforms to differ greatly in amplitude.



(C) An open C2 in Fig. 12 changes the circuit from peak-reading to choke-input and produces the lower waveform at the cathode of X2 when the load is light. With a heavy load, the waveform is damped to become a 120-Hz parabola, as shown in Fig. 4B.

Fig. 17 Scope waveforms aid in diagnosing trouble in the power supply.

visual signs of defective parts. Fig. 17A is the capacitor current in the circuit of Fig. 8A when the load is light but one of the diodes has excessive leakage. When the capacitor is part of a multiple unit can, it is difficult to look at the capacitor current, but Fig. 17B shows the difference in size of the alternate hum waveforms when a diode is leaking. Fig. 17C shows the peculiar waveform produced on the cathode of X2 in Fig. 12 when C2 is open. The sharp spike is an inductive kickback from the choke and C3. At higher current, the waveform becomes more like that of Fig. 4B.

In TV receivers, a pulse from the vertical output stage might be seen in some parts of the filter system. Often this is normal. The source can be identified by making the vertical roll; if the extra 60-Hz pulse rushes across the screen of the scope, it is from the vertical sweep. Or, disable the vertical and the pulse should be gone.

Practice measuring the hum frequency on several normal receivers until you can do it rapidly and accurately. This one technique might save you many hours of troubleshooting time. ▲

Chapter 5

Zener diodes—operation, testing and replacement

Zener diodes are solid-state voltage regulators. They are used often as DC voltage regulators in the voltage supplies to low-level stages in FM receivers and solid-state television receivers, and as the source of a reference voltage in transistor-regulated power supplies. Because so many zeners are used in modern equipment, we need fast and accurate methods of testing them, and strong guidelines for selecting replacements.

Zener Diode Actions

A zener diode, when forward biased (anode positive, cathode negative), acts as a normal rectifier diode and provides a low internal resistance. When only slightly reverse biased (anode negative, cathode positive), the diode is nearly an open circuit. This action is identical to that of a normal rectifier diode.

If the reverse bias is gradually increased, as shown in Fig. 1, current flow increases very suddenly at a voltage called the "avalanche" point. A graph of this action is shown in Fig. 2. The voltage at which avalanche takes place is determined by the internal construction and the active materials used during the manufacturing process. One supply catalog lists general replacement zener diodes with nominal voltages ranging from 3.3 to 120 volts DC.

In addition, zener diodes are rated by maximum wattages, which should not be exceeded, if premature failures are to be avoided. A higher wattage rating should not be used for replacement zeners, for reasons which will be given later in this article.

Ohmmeter Tests

Test a zener diode with an ohmmeter exactly as you would a power supply diode. The only precaution is that the voltage of the ohmmeter battery should be less than the rating of the diode (most are).

Pre-set the ohmmeter for a low scale—we suggest X10—and measure the forward resistance by attaching the positive meter lead to the anode and the negative meter lead to the cathode. A low reading should be obtained. Reverse the diode leads. Any deflection of the needle now indicates a short or excessive leakage. Try a higher scale, perhaps X1000, for a more sensitive reading of the leakage.

If they have previously operated satisfactorily in the circuits under test, most zener diodes which pass this simple test will not be defective.

A more complete test is required to find the operating voltage for a zener, the ratings of which are not known.

A Variable-Voltage Test

Zener diodes for use in experimental circuits or diodes of unknown "avalanche" voltage rating can be tested by operation in the circuit shown in Fig. 1. The series resistance (which might, in some cases, be the internal resistance of the power supply) is necessary to prevent overload of the power supply and accidental burnout of the diode under test. The resistor also assures current regulation at the nominal voltage of the individual zener. Replacement zeners are usually available in ±10-percent or ±5-percent tolerances.

Connect the zener diode in the correct polarity and increase the supply voltage until a "plateau" is reached, as shown in Fig. 2. The nominal voltage rating is about the center of the plateau. Of course, the current should never exceed the maximum rating of the zener diode.

Many manufacturers test zeners at 20 percent of the rated current. The diode which yielded the graph shown in Fig. 2 was rated at 4.7 volts and 1 watt. The maximum current was not listed, but was computed using the Ohm's law formula: Power (in watts)=EI. Because the power is 1 and the voltage (E) is 4.7, the maximum current (I) is .2128 amps, or 212.8 milliamps. Twenty percent of 212.8 milliamps is 42.6 milliamps, or approximately 40 milliamps, which should be the test current for the zener used in this example.

If you are testing zener diodes which are original components, the current meter reading can be omitted. Just do not increase the voltage any more than the minimum necessary to establish the plateau.

A fixed power supply voltage and a resistor substitution box or a variable resistor of the proper size to vary the current also can be used to test zeners. However, a smooth variation of current is more difficult to obtain, so this method should

The rounded top corners of the waveform in Fig. 4A were caused by the high internal impedance of a one-watt zener diode. Also, the amplitude changed somewhat as the input voltage was varied. When the top corners are rounded, a minimum resistance setting of R1 is recommended, because it sharpens the corners and minimizes amplitude changes. However, the more rounding of the corners, the less accurate the reading of the zener voltage.

The diode graphed in Fig 2 measured 5.6 volts in the clipping test. After subtracting .7 volt, the corrected zener voltage rating was 4.9 for this diode, rated by the manufacturer at a nominal 4.7 volts. I would rate it from the graph in Fig. 2 as 4.7 volts (the middle of the plateau at 80 milliamps). Rounding of the top corners caused the slightly inflated reading; however, the 4.9-volt reading is more than accurate enough for all normal servicing.

Even more accurate results were obtained during the tests of an exact

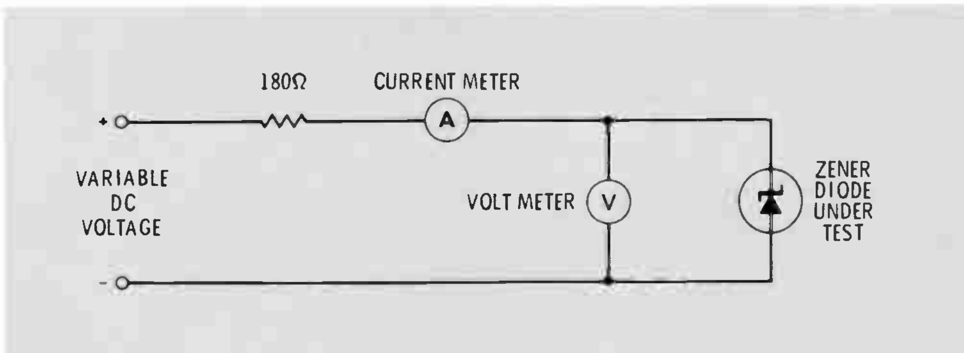


Fig. 1 Schematic of a circuit which can be used to test zener diodes by the voltage-current method.

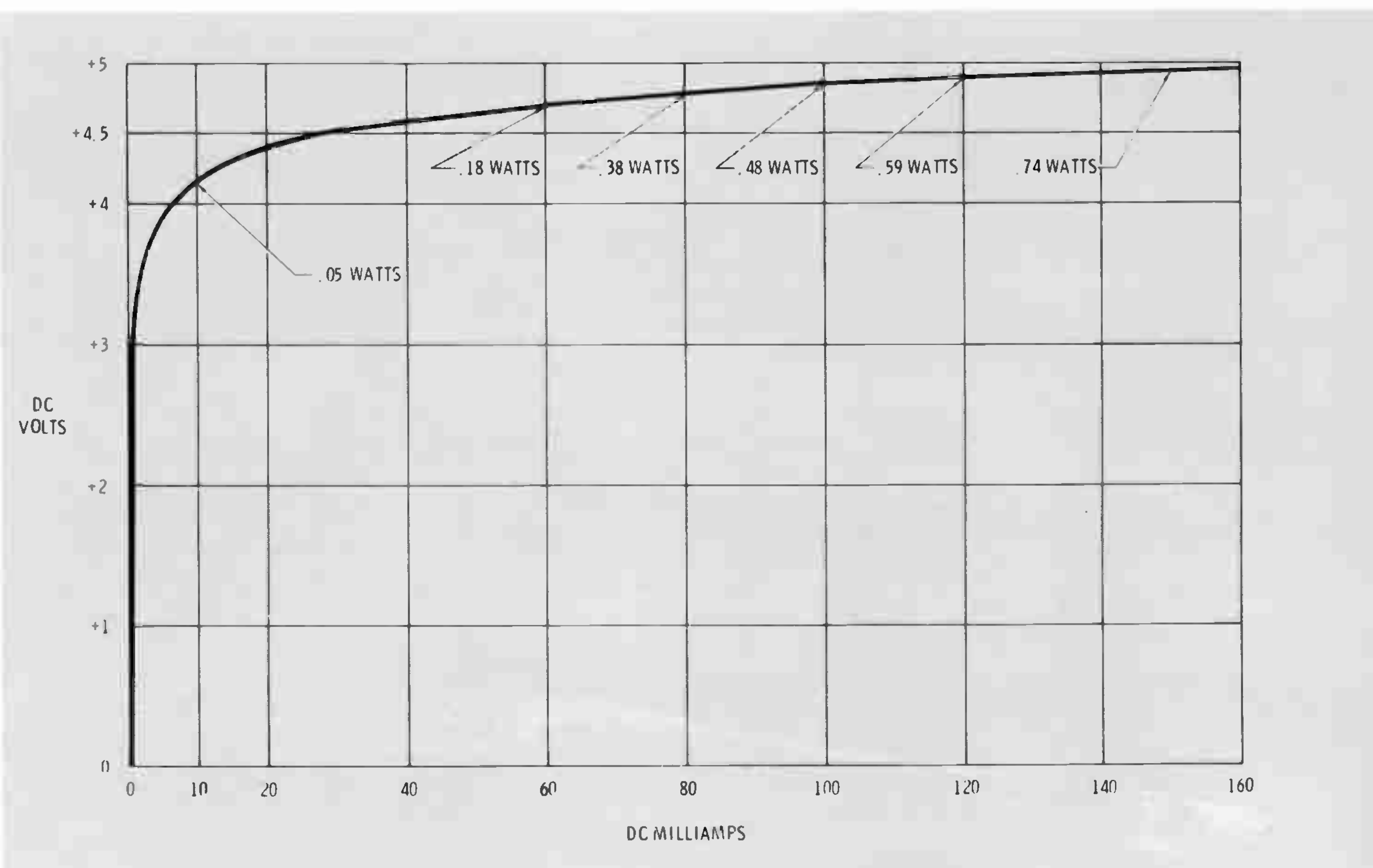


Fig. 2 Results of the voltage-current method of measuring zener diodes can be graphed. Shown here is the graph of an International Rectifier Z1102-C 1-watt zener diode. The nominal voltage rating is approximately in the center of the "plateau".

replacement zener which was rated at 10 volts and 2 watts, although the current/voltage graph showed 8.7 at the usual test current (40 milliamps in this case) and 8.9 at the center of the plateau of the curve. The peak-to-peak reading during the clipping test was 9.7, from which was subtracted .7, to give a zener voltage of 9.0 volts. Although this differs .1 volt from the nominal rating obtained from the center of the voltage-current plateau, because of the higher voltage, it is a smaller **percentage** of error than the error of previous zener diode readings. Also, the amplitude or shape of the corners did not change with variations in R1 or the input voltage.

We recommend the clipping test to determine the true nominal rating of all zeners of one-watt rating and larger. Remember, the applied AC must be at least twice or more the voltage of the zener that is under test. The values given in Fig. 4D are sufficient for testing zeners

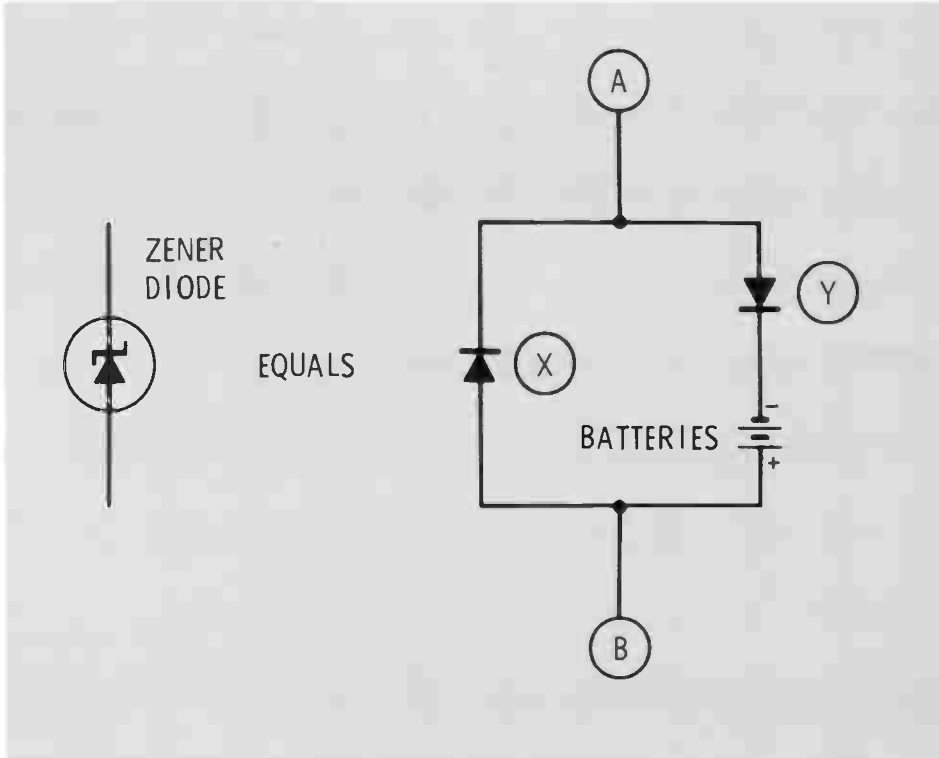


Fig. 3 A zener diode can be visualized as two rectifier diodes of opposite polarity connected in parallel, with a battery, used to provide a voltage delay, in series with one of them. Conduction can be obtained in either polarity, but at different voltages.

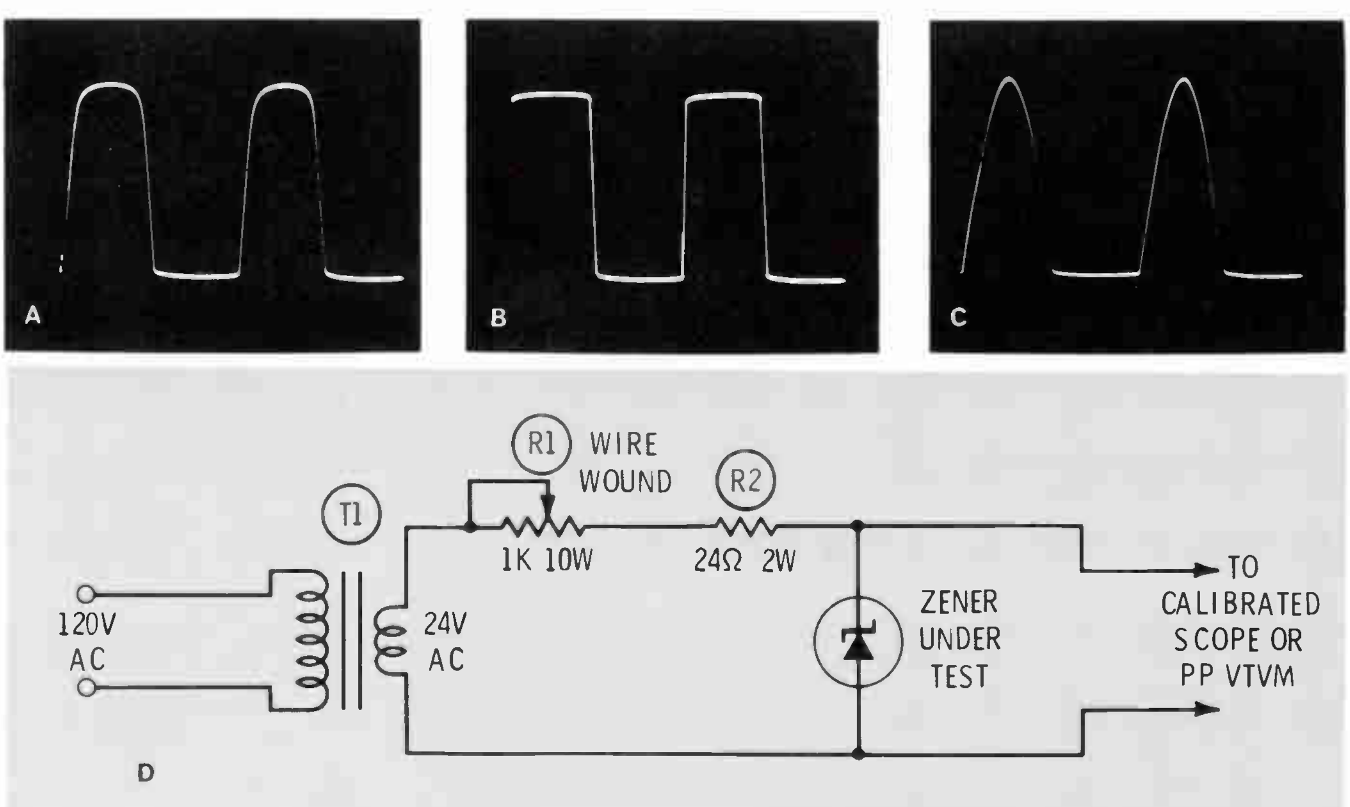


Fig. 4 Waveforms obtained when a zener diode is used to clip a sine wave. **A)** The high internal resistance of a 1-watt zener caused rounding of the corners of the waveform shown here (clipped by the zener action). **B)** A 2-watt zener diode, which has lower internal resistance, clipped the sine wave more symmetrically and gave a more accurate reading. **C)** A power supply diode clipped just one peak of the sine wave. **D)** Schematic of the circuit used to test the zener avalanche voltage by the clipping method.

up to a rating of approximately 12 volts.

Troubleshooting Zener-Regulated Power Supplies

The schematic of a typical zener-regulated voltage source is shown in Fig. 5. If the normal load current does not vary excessively and the zener current is near the center of the plateau, the regulation will be adequate for any normal line voltage variation or normal aging of components. However, as practical technicians, we are concerned with the effects and symptoms produced when these components become defective.

When the circuit is normal, an increase of 20 percent in the input voltage to R1 should cause an increase at the zener of about .1 volt. However, the current in the zener might double. There is no certainty that such a voltage increase would cause any of these components to fail, unless the zener current is raised above the maximum rating or R1 is heated enough to cause it to change value.

A lower value of R1 causes the same conditions as an increase in input voltage or line voltage. Such a change, in combination with an actual voltage increase, is likely to destroy the zener (cause it to short).

A higher value of R1 decreases slightly the voltage at the zener, but no change in performance should be noticed before the voltage at the zener drops 10 percent or more. At that point, regulation is nearly gone.

An open zener diode will cause an increase in the DC voltage to the load. In some cases, the supply voltage to R1 also will increase excessively and cause problems in related circuits. This can cause serious symptoms, for example, if a voltage to the AGC keyer is changed.

More important, in many cases, an open zener diode regulator can cause a primary symptom of hum or sweep instability because of signal and sweep voltages present on the B+ lines. A zener regulates voltage changes, and hum or sweep voltages on the supply voltage are reduced in the same way DC variations are minimized.

In one circuit, removal of the zener and substitution of a fixed resistor to restore the correct DC voltage increased the hum ripple by a factor of five.

Substitute The Zener With A Resistor

Because a zener is a "resistor" whose resistance changes according to the applied voltage, a variable or selected fixed resistor often can be substituted temporarily for the be considered a second choice.

Curve Tracer Tests

Tests of diodes and zener diodes using the Jud Williams and Eico transistor curve tracers were described in the March, 1971 issue of ELECTRONIC SERVICING. Accurate results demand that the gain of the horizontal amplifiers in the scope be adjusted to a known calibration.

Zener Tests By Clipping

By bending the truth slightly, we can visualize a zener diode as two rectifier diodes of opposite polarity in parallel, and with a battery, whose voltage is equal to the zener voltage, connected in series with diode "Y", as shown in Fig. 3. Let's imagine that we connect this zener-equivalent in series with a DC circuit which has 50 milliamps flowing in such a way that terminal "A" is negative. About .7 volt will be measured between terminals "A" and "B", because diode "X" is conducting and this is the voltage drop across it. Diode "Y" is reverse biased, and, therefore, non-conducting.

Imagine now that the terminals "A" and "B" are interchanged in the circuit. Diode "X" is reverse biased and non-conducting. Because the battery voltage is a constant reverse bias for diode "Y", it cannot conduct until the voltage drop across terminals "A" and "B" exceeds this voltage.

Assuming zero resistance in the battery and a large current, such as 50 milliamps, flowing through the circuit, the voltage drop across terminals "A" and "B" will be equal to the battery voltage plus the .7 volt barrier potential voltage of diode "Y". This sum is the zener voltage.

If the analogy stated previously is correct, a zener diode should clip both peaks of a sine wave to produce a square wave whose peak-to-peak voltage is equal to the zener voltage plus .7 volt (the forward voltage drop). We tested several zener diodes in the ELECTRONIC SERVICING laboratory to verify this asumption, and were pleased with the simplicity of the test and the accuracy of the results.

Results of The Clipping Tests

Figs. 4A and 4B show the waveforms produced by two individual zener diodes of different types. The circuit used to obtain these clipped waveforms is shown in Fig. 4D.

A good diode which is not a zener produced the waveform shown in Fig. 4C.

zener, to prove the condition of the zener. If the circuit functions better with a resistor which has been se-

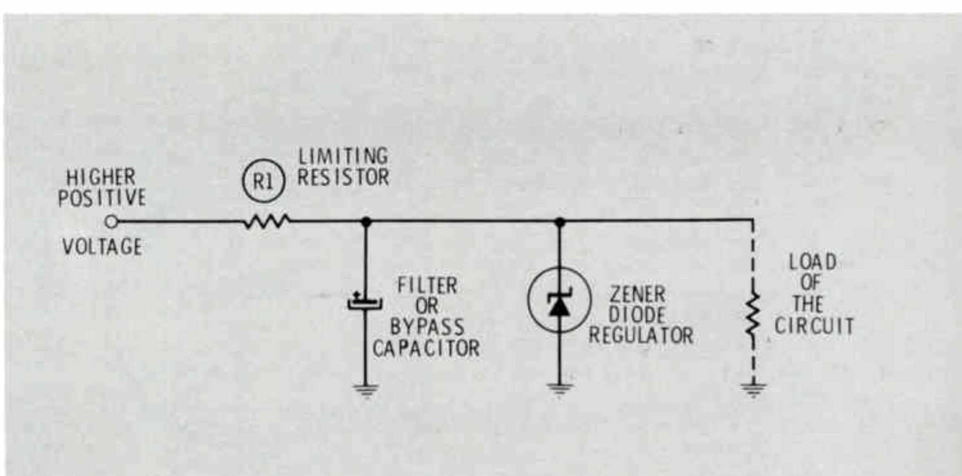


Fig. 5 Schematic of a typical power supply regulated by a zener diode. R1 limits the maximum current which can be drawn by the zener. The voltage across the load is regulated against input voltage changes or changes of the load current.

lected to provide the correct DC voltages, it is likely the zener is defective.

Summary

Four general methods of testing zener diodes have been presented. These methods include:

- Ohmmeter tests for forward conduction and reverse leakage (fast test)
- Current-vs-voltage measurements (slow but accurate)
- Curve tracer patterns (relatively fast; requires equipment)
- Clipped sine-wave measurements (fast and accurate).

In addition, defective zeners can often be found in-circuit by voltage and resistance measurements, or, when one is open, by the increase in both DC voltage and ripple.

All zener characteristics, except two, can be tested accurately enough, for all practical service operations, by these previously described methods.

There is no easy test to determine maximum wattage, or no convenient rule to specify what wattage zener to purchase for replacement in any particular circuit. Of course, it is best to follow the original specifications when they are known.

Do not replace a zener with another that has a **larger** wattage rating. It will operate on a wrong part of its curve and cause poor performance.

Internal impedance can be measured, but by a method too complex for service use. If one universal replacement zener fails to operate correctly and all other components are normal, it is possible that the internal impedance of the zener is wrong. Try a different type or brand. ▲

Chapter 6

SCR's and Triacs—operation and testing

Conventional diodes effectively are voltage-controlled switches. When the anode voltage is made more positive than the "barrier voltage", relative to the cathode, the diode becomes a conductor. Voltages of opposite polarity cause the diode to become an open circuit.

SCR's (silicon-controlled rectifiers) and triacs (see Fig. 1) have more than the one "PN" junction employed in semiconductor diodes. One of these added sections, called a "gate", has the ability to block conduction through the device.

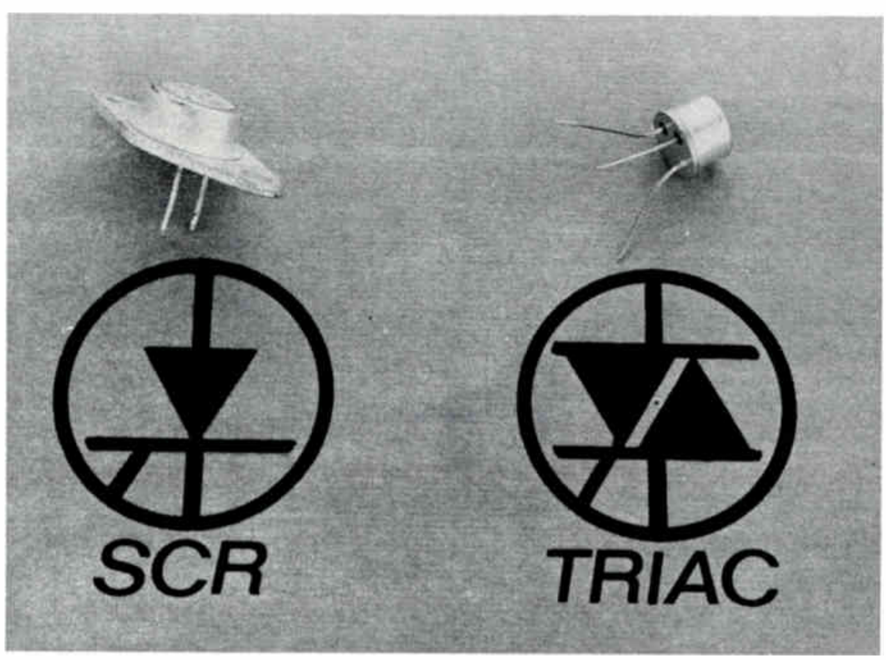
SCR's and triacs are available in many of the case dimensions and lead arrangements commonly used for transistors. The lead locations of two popular types are shown in Fig. 2. Because

Testing LDR's

The maximum resistance of an LDR can be determined accurately only by maintaining the cell in complete darkness for several minutes before measuring it with an ohmmeter. Because many circuits, including the one in Fig. 8, do not utilize the high-resistance characteristic of the LDR, this reading usually is not critical.

The minimum resistance of an LDR can be determined by subjecting it to bright light. A rough test can be made by shining a flashlight at the cell from the same distance each time. I would guess that the LDR shown in Fig. 8 would measure less than 1000 ohms if a 2-cell flashlight beam were directed at it from a distance of 2 feet.

Fig. 1 Shown here are an SCR and a triac and their respective symbols. Note the physical similarity to transistors.



this similarity of outward appearance can cause costly mistakes and wrong identification during servicing, tests which indicate whether a device in question is a transistor, SCR or triac will be explained in this article.

Basic Characteristics of SCR's

An SCR can be visualized as a diode in series with a switch, as shown in Fig. 3A. Conduction is controlled both by gate action and by the polarity and amplitude of the anode voltage.

Following are some of the normal responses of an SCR with the listed voltages applied:

- Anode voltage negative relative to the cathode—No conduction, regardless of the voltage applied to the gate. This is normal diode action.
- Anode voltage positive and the gate zero or negative relative to the cathode—No conduction. This is gate action.
- Anode voltage positive and the gate sufficiently positive—Full conduction. The change from non-conduction to full conduction is a regenerative effect which occurs instantaneously when the gate-cathode voltage is increased slightly above the breakover, or "trigger", point.
- After conduction has started, a "latching effect occurs and the gate loses control and cannot block conduction, which continues until the anode voltage and/or current are reduced below the "holding" point.

The resistance between gate and cathode of an SCR is about a few hundred ohms. Resistance indications should be similar to those produced by two conventional semiconductor diodes paralleled front-to-back. About the same ohmmeter reading should be obtained when the test leads are switched. Also, the lower the range used, the lower will be the reading obtained. The resistance between the anode and either the cathode or gate should be nearly infinite.

Basic Characteristics of Triacs

A triac effectively functions as two paralleled front-to-back diodes in series with a switch, as shown in Fig. 3B.

Some of the responses of a non-defective triac when operated under different voltage conditions are as follows:

- Anode voltage negative and the gate zero relative to the cathode—No conduction. Diode action.
- Anode voltage positive and the gate zero relative to the cathode—No conduction. Gate action.
- Anode voltage negative and the gate voltage sufficiently negative—Full conduction.
- Anode voltage positive and the gate voltage sufficiently positive—Full conduction.
- The change from non-conduction to conduction is a regenerative effect, which occurs when the gate-cathode voltage is increased slightly above the "trigger" point, just as in SCR's.
- After conduction has started, a "latching" effect occurs, in which the gate loses control and the conduction continues regardless of subsequent changes in the gate voltages. Conduction continues until the anode voltage and/or current are reduced below the "holding" point.

The junction resistances of triacs are nearly identical to those of SCR's. The gate-to-cathode readings should be similar to those produced by measuring two diodes which are paralleled front-to-back. Infinite resistance should exist between the anode and either the cathode or the gate.

A Tester You Can Build For Checking SCR's And Triacs

An SCR or a triac should be tested first by use of an ohmmeter. An open circuit between gate and cathode, or a short circuit or leakage from anode to gate or from anode to cathode proves the device is defective, and no other testing is required.

Shown in Fig. 4 is a tester which checks SCR's, triacs and power transistors by applying 6 volts DC that is limited to 150

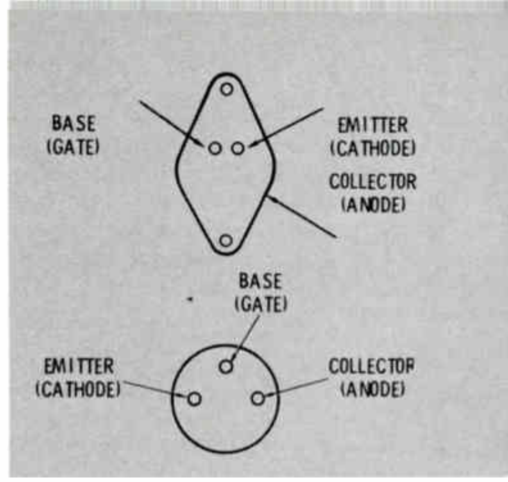


Fig. 2 Because the typical base configurations of SCR's and triacs, shown here, are almost identical to those of transistors, specific tests, described in the text, are required for positive identification.

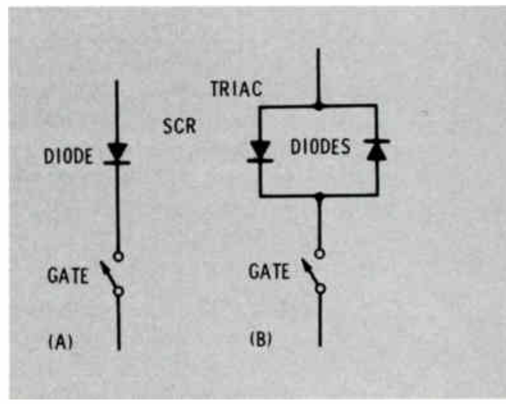


Fig. 3 These circuits illustrate the effective action of SCR's and triacs. **A)** An SCR is the equivalent of one diode in series with a switch. **B)** A triac is the equivalent of two diodes, connected back to front in parallel, in series with a switch. When properly triggered on, a triac conducts in both directions.

milliamps. This is a good operational test for these devices, and provides the operator visual evidence of SCR, triac and diac triggering and holding actions. The tests also indicate whether the device is a transistor, an SCR or a triac.

To test an SCR, triac, or power transistor:

- Adjust the polarity switch (S1) to the SCR-NPN position, the toggle type on/off switch (S2) to "off", and the gate-voltage control (R1) to minimum.
- Connect the tester to the device through color-coded clips and test leads.
- Turn the on/off switch to "on". If the bulb lights, the

device being tested is shorted, or the test leads are touching.

- Gradually turn up the gate-voltage control. At a certain critical voltage (measured by a meter for the most detailed information) the bulb should light, indicating conduction of current through the device.
- A gradual brightening of the bulb when the control is turned up, and a gradual decrease in brightness as the control is turned down indicates that the device is an NPN transistor.
- A sudden lighting of the bulb to full brilliance at one point on the gate-voltage control, and no reduction in brilliance when the gate-voltage control is turned down, indicates that the device is an SCR or a triac. Subsequent tests will determine which. The bulb should remain lit after the control is turned down until a momentary open in S3 extinguishes it.
- Slide the polarity-reversing switch (S1) to the TRIAC-PNP position, and, starting at minimum, turn up the gate-voltage control.
- A gradual brightening and darkening of the bulb when the gate-voltage control is increased and decreased indicates that the device is a PNP power transistor.
- If the bulb does not light when the gate-voltage control is increased, the device is an SCR.
- If the bulb suddenly lights to full brilliance at one position of the gate-voltage control, and the brilliance does not decrease when the control is turned down, the device is a triac.
- Turn the on/off switch to the "off" position, to minimize battery drain.

Tips About Using The Thyristor Tester

The first version of this thyristor tester was designed and built about three years ago, when the RCA CTC40 chassis, which uses two SCR's in the horizontal sweep circuit, was introduced. The original version of the tester used two 67½-volt batteries, a neon bulb, and several more switches to test for leakage, which might occur only at higher voltages. Such a sensitive leakage test was found to be unnecessary and was discontinued in favor of simple ohmmeter tests.

Another useful variation of the tester circuit used 6 volts AC for the anode supply, but retained the DC gate-voltage control. A scope connected across the light bulb displayed the curret waveform. One difference in operation was readily evident: After the gate-voltage control was turned up enough to light the bulb, decreasing it extinguished the bulb. The reason is that the anode voltage decreased to zero 60 times per second, and unlatching could occur during any of these "zero" times.

An SCR conducts during only the positive alternation of a sine wave applied to its gate, as shown by the current waveform in Fig. 5B. No conduction through the SCR occurred when negative voltages up to –5 volts were applied to its gate.

Triacs conduct during both alternations of a sine wave, as shown in Fig. 5C. The crossover-type distortion at the mid, or zero, points on the waveform is produced because the voltage must increase from zero to .8 volt DC or more before conduction can occur. Also, conduction ceases during the .8 volt DC just preceding zero voltage. Together, these areas of non-conduction caused a measured voltage drop of .6 volt RMS across the triac (from main terminal 1 to main terminal 2).

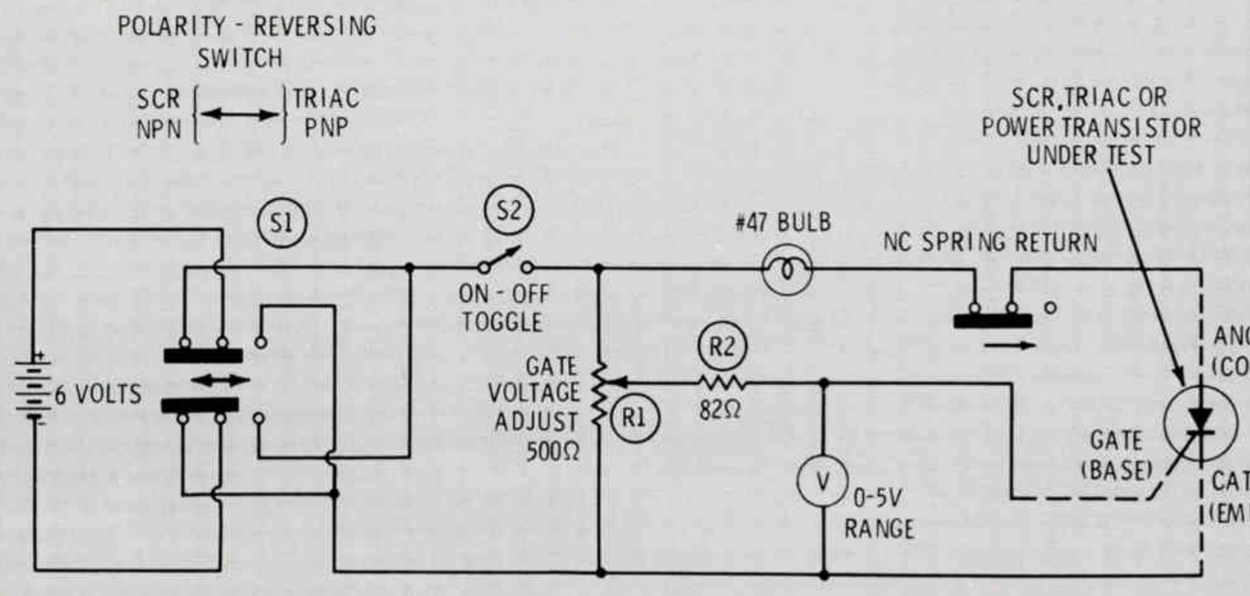


Fig. 4 Schematic diagram of a tester which helps determine whether a device is a transistor, an SCR or a triac and indicates whether or not it is operating correctly.

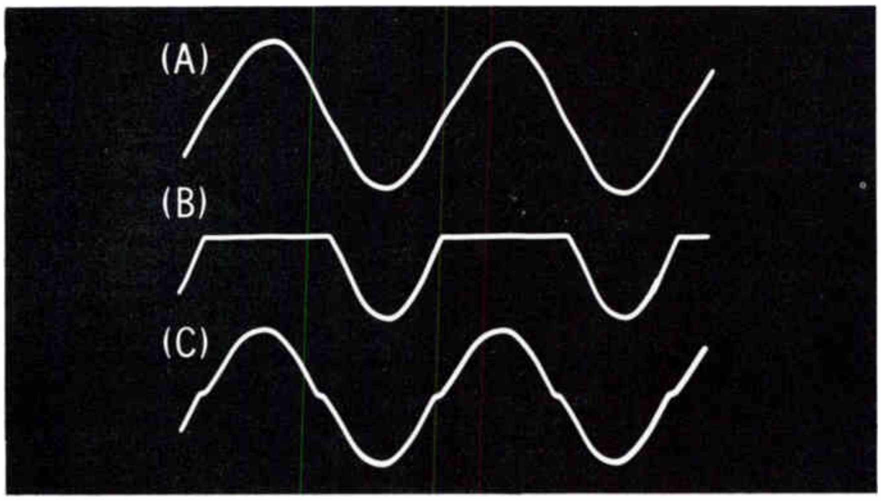


Fig. 5 Waveforms of the load current produced when SCR's and triacs are operated from an AC anode supply. **A)** Waveform of the input 60-Hz sine wave from a heater transformer. **B)** Waveform of the current (voltage across bulb) when 6 volts AC was supplied to the anode of the SCR in the schematic shown in Fig. 4. **C)** Waveform of the conduction current when 6 volts AC was supplied to the anode of a triac connected to the tester diagramed in Fig. 4. The voltage drop across the triac measured .6 volt RMS.

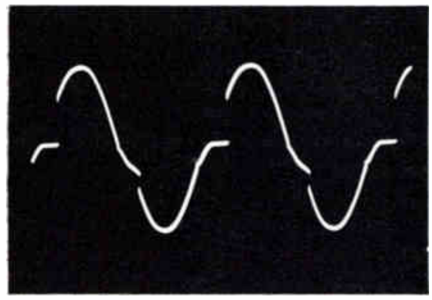


Fig. 6 Partial conduction that occurred when insufficient negative gate voltage was applied to an SCR of higher voltage rating than the one which produced the waveform in Fig. 5C.

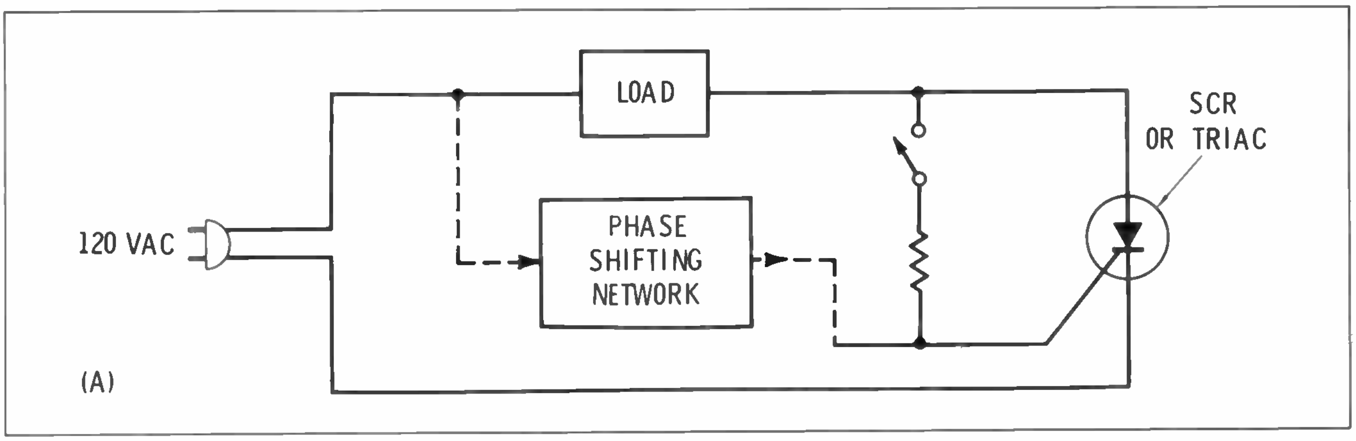
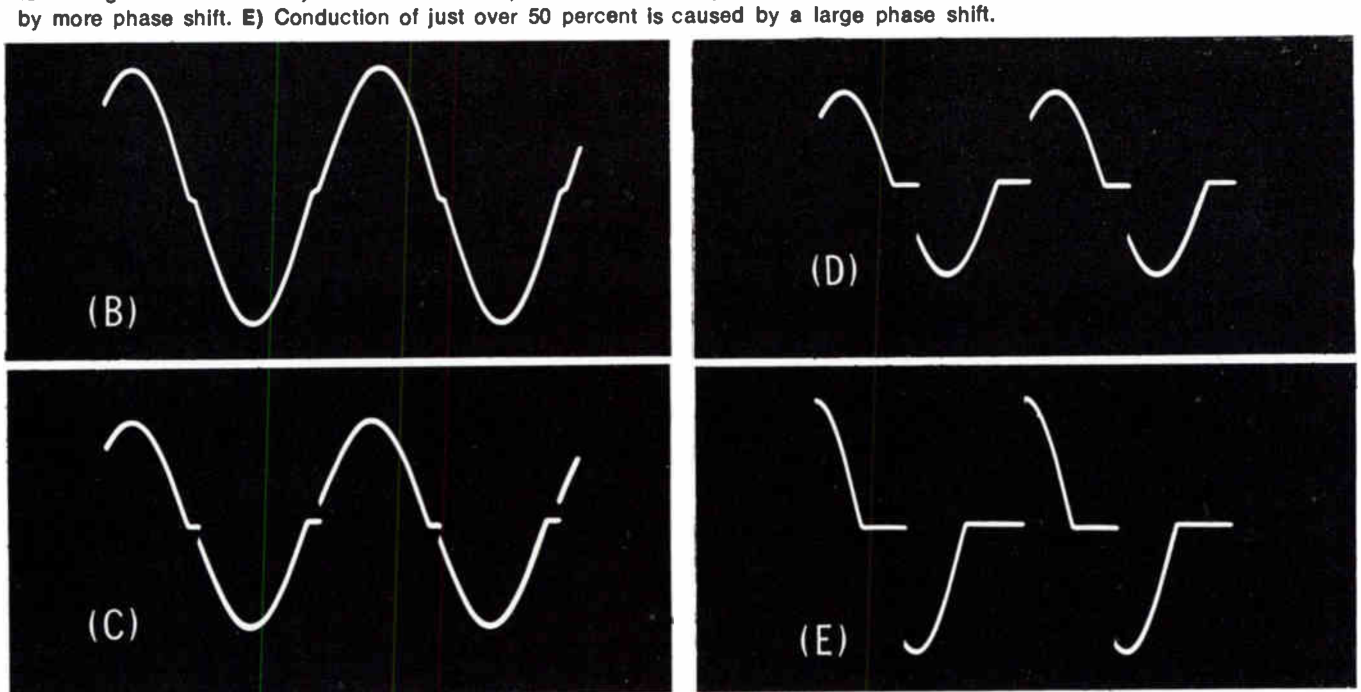


Fig. 7 SCR's and triacs can be triggered on by a resistor connected between anode and gate, or by a sample of the input voltage that has been phase shifted. **A)** Block diagram of the triac circuit. **B)** Conduction current produced with AC supplied to both gate and anode. **C)** Effect of a small phase shift in the gate voltage. **D)** The triac is triggered into conduction later by more phase shift. **E)** Conduction of just over 50 percent is caused by a large phase shift.



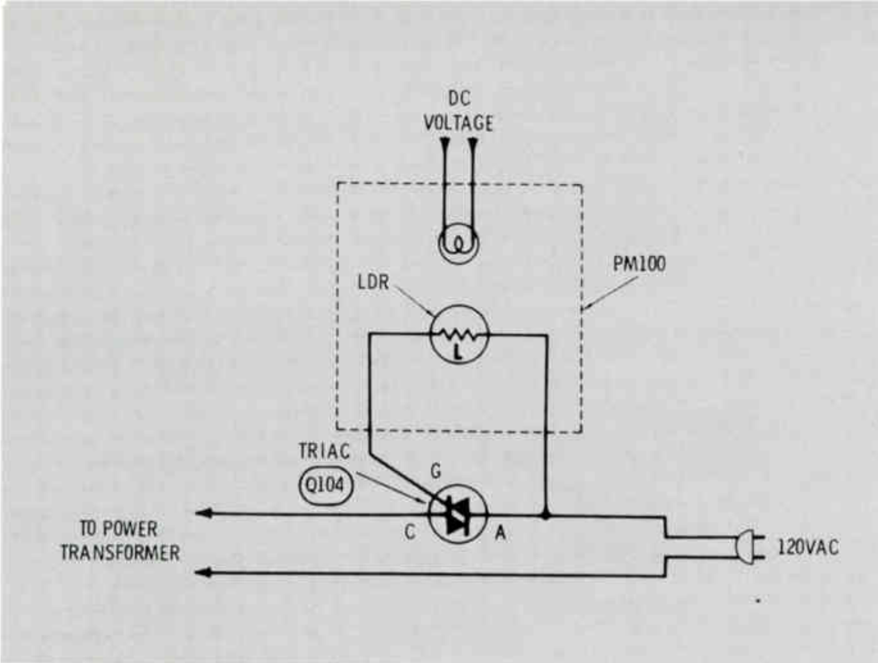


Fig. 8 Remote power on/off circuit of RCA CTC54 color TV chassis. The lamp is lighted by action of the remote control. The light reduces the resistance of the Light Dependent Resistor (LDR), or cadmium-sulfide cell; this triggers on triac Q104, which applies AC to the receiver power supply.

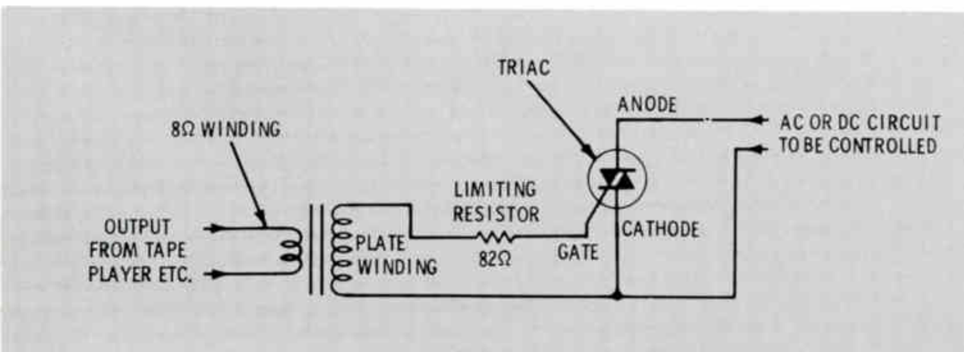


Fig. 9 Schematic of a triac circuit which will start the change cycle of a slide projector, or will turn lamps on and off according to the amplitude of the audio input.

When the gate voltage was positive and the gate-voltage control was advanced very slowly, the triac triggered first into half-wave operation (See Fig. 5B) when the potential on the gate was +0.8 volt. This voltage instantly dropped to +0.7 because of the increase in gate current. The gate-voltage control was advanced further and triggering for conduction of both peaks (see Fig. 5C) occurred at +0.85 volt, after which the gate voltage dropped to +0.4 volt. These three modes of operation were very distinct, as if a 3-position switch were used. The bulb was unlit, then was lighted to partial brilliance and, finally, to full brilliance, with no variation between.

The action when negative voltage was applied to the gate was somewhat different. Triggering into the full-wave mode occurred at –0.98 volts, which promptly dropped to –0.6. However, there was a tendency for the bulb to light dimly and then brighten. The current waveform shown in Fig. 6 helps explain the reason: Because conduction was triggered on late, during the peak, the bulb was supplied with less total current. Increased gate voltage produced normal conduction.

When tested in the thyristor tester, different brands of triacs with higher voltage ratings required higher gate voltages, than did the smaller sizes. The scope waveforms of the larger triacs generally were less smooth than those produced by smaller ones.

Uses For SCR's And Triacs

A triac or an SCR can be used to turn on and off resistive loads or to provide variable lighting or motor speed. Two alternate methods of controlling the conduction of these devices are shown in Fig. 7. For example, a 56-ohm resistor connected between the anode and gate will dependably trigger on a triac operated from 6 volts AC. A higher value should be used for 120-volt operation, to avoid gate damage. Use the highest value that will dependably trigger on the triac.

A variation of this method is employed in the RCA CTC54 color TV chassis, to turn on and off the power to the entire receiver when remote control is used. The circuit is shown in Fig. 8. The remote control supplies power to the bulb, which is located inside a light-tight assembly. When the bulb is lighted, the illumination decreases the resistance of the Light Dependent Resistor (LDR) enough so that the triac conducts and applies 120 volts AC to the power transformers. (LDR's are also called cadmium-sulfide cells.)

One simple triac-equipped circuit I have used for several years to initiate the change cycle of an automatic slide projector is shown in Fig. 9.

The narration or sound effects which accompany the slide presentation are recorded on one channel of a stereo tape recorder. The speaker is connected to this channel during playback. A short audio tone, of perhaps one second, is recorded on the other channel at any interval where a slide change is desired, so that the narration and the slide changes are in perfect synchronization. The frequency of this tone is unimportant; even 60 Hz is okay. The volume of the stereo unit is at the minimum level required for dependable operation. ▲

Chapter 7

Integrated circuits in TV—construction, applications and testing

Although the home entertainment electronics industry is still in the process of changing from vacuum-tube circuitry to the use of transistors, another revolution also is in the making. The new gadget causing all the stir is the integrated circuit (IC), sometimes simply called a "chip."

Incorporating this new device into a television receiver might appear as just another way for the manufacturers to make life miserable for servicing technicians, but in reality there are some pretty sound reasons why we are going to see more and more IC's in today's and tomorrow's TV.

One of the advantages of using IC's is that they require so little space. This equates into smaller instruments, for consumer appeal, and also smaller chassis frames, less circuit board area, less weight, etc. Along with this goes the saving in assembly costs. Obviously, it is cheaper to mount a single unit on a board than it is to mount the dozen or more components which an IC replaces. Whether or not the IC itself is cheaper than the separate components which it replaces would be hard for us "outsiders" to know at the moment; but it is probable that improved manufacturing techniques will bring down the cost of IC's as their use becomes more general.

The IC retains most of the good characteristics of the transistor—low power consumption and the attending coolness of operation, no consumption of the material of which it is made (as contrasted with a tube filament and cathode), resistance to physical shock, etc.

The IC also has about the same poor qualities as the transistor, including wide variations in characteristics as the ambient temperature is changed, susceptibility to damage from electrical overloads and arc transients, and susceptibility to damage from excessive heat when it is installed or removed from soldered circuits.

There are some limitations which are peculiar to IC's, but more on that later.

Construction of an Integrated Circuit

The construction of IC's has become literally a science, and certainly no complete description of the processes involved could fit into this magazine. But a few simple drawings can, at least, provide an understanding of the basic construction technique.

Suppose that we take a slab of P-type silicon material and diffuse into it some N-type impurities, as shown in Fig. 1. The depth of the diffusion will depend on the length of time the slab is exposed to the N impurities and the temperature at which it is diffused. The area of diffusion will depend on the amount of surface which is exposed and the amount which is covered with a protective mask, which can be removed later. If leads are welded to the slab and to the N region, a useful diode has been produced.

The next step is to mask all but a portion of the N surface and subject the device to another diffusion, but this time with P material. As illustrated in Fig. 2, a transistor is produced as a result of this second process. Obviously, if one transistor can be made in this manner, it is simply a matter of repetition to form a number of transistors on the same slab and then cut them apart. (As a point of interest, transistors produced simultaneously on the same slab will be quite uniform in characteristics, for reasons which should be obvious.)

Just as two or more vacuum tubes often share the same glass envelope, there are many times when it is desirable to form several transistors in a single package. If the transistors produced in the manner just described were not cut apart, we would have such a "packaged" device. But there is one problem: All the collectors would be connected together. Consequently, the device would not be very useful.

To provide a means of isolating the transistors from one another, and also to provide an inactive mounting for them, one more process of masking and diffusion is

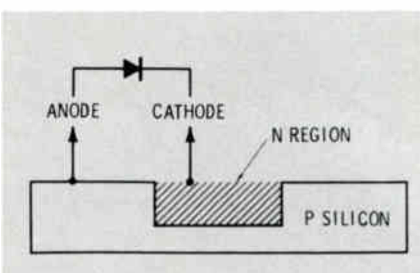


Fig. 1 The first step in construction of an integrated circuit is the formation of "N pockets."

employed, the end product of which is shown in Fig. 3.

Note that in Fig. 3 the original slab is no longer used as one of the elements of the transistors but, instead, forms a mounting base called the substrate. Because the substrate is made of P material, the junctions of the substrate and the collectors of the NPN transistors are reverse biased and, consequently, no conduction can take place between the substrate and collectors of the transistors. There is capacitance between these elements; however, it can be compensated for in much the same way that the stray capacitance of a vacuum-tube is either used to advantage or compensated for by the external circuitry.

Although an array of closely similar transistors is sometimes useful, it is more often desirable to interconnect a pair of transistors within the unit, as in the Darlington pair configuration, for example. This can be accomplished by the following additional manufacturing processes.

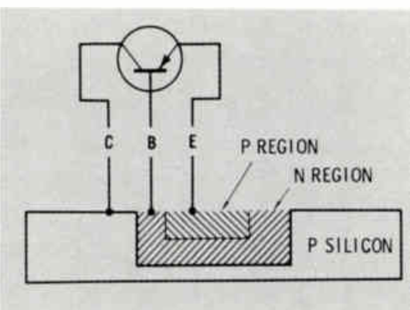


Fig. 2 By diffusing P material into the N region, the elements, or junctions, of a transistor are formed.

After the transistors are formed, the points which are to be used for connections are masked. The unmasked surface then is exposed to an oxygen atmosphere and baked. This forms a layer of silicon dioxide, better known as glass, which is an excellent insulator.

Next, another masking operation covers all the surface except those points at which connections are desired, and some type of metal, perhaps gold, then is deposited on the unmasked areas.

Finally, leads are welded to the metal-covered points, for external connections. The completed circuit is shown in Fig. 4. (The interconnection between the two collectors cannot be shown in the same cross-section with the emitter-to-base connection, because it must take some other path across the surface of the chip.)

Forming resistors and capacitors in the integrated circuit is somewhat simpler in concept, although not necessarily in actual practice. Fig. 5 shows diagrammatically how it can be done.

On the left of the chip in Fig. 5 a resistor is formed by utilizing the resistance of a block of P material, which is isolated from the substrate by an intervening layer of N material. The size and shape of the P material determines the resistance; a long, narrow strip has higher resistance than a short, wide one.

The capacitance between the deposited metal and the N material beneath the insulation forms the capacitor at the right. As with any capacitor, the value can be increased by increasing the area of the plates.

In manufacturing integrated circuits, a great number of them, perhaps a hundred or more, each having the equivalent of many transistors, diodes, resistors, and capacitors, are formed simultaneously on a single wafer, or substrate, a couple of inches in diameter. Obviously, the more IC's produced on the wafer, the lower the price per IC. As a rule of thumb, a 1000-ohm resistor requires about twice the area of a transistor and a 10-pf capacitor requires about three times as much area as a transistor. For this reason, integrated circuits are designed to use as many transistors and as few passive components (resistors, capacitors and coils) as possible. This is just the opposite of conventional circuitry, in which the transistors usually are the most expensive of the four devices.

Also because of cost, the values of resistance and capacitance are kept as low as possible, and often external components are used, if space permits. A common trick used to reduce the values of resistors is to stack diodes and use their junction potentials to drop voltage. For example, if 3000 ohms is required to drop 2 volts in a certain bias circuit, an area of the chip which could accommodate six transistors is required. But, by using three diode junctions in series, approximately the same voltage drop can be obtained using only the area of three transistors. Possibly a zener will be used, reducing the required area to that of a single transistor (see Fig. 6).

At the present state of the art, the tolerance of resistors and capacitors in IC's are very broad, although the ratio of two resistances or capacitances can be held to relatively close specifications. Consequently, circuits are normally designed so that absolute values of R and C are not critical. In practice, this equates, more or less, to "lots of gain and lots of negative feedback."

Integrated circuits are packaged in about the same fashion as transistors, except, of course, there are many more leads coming out of the device. A common package is similar to the TO-5 transistor, but with eight to a dozen leads. They also are packaged in flat, rectangu-

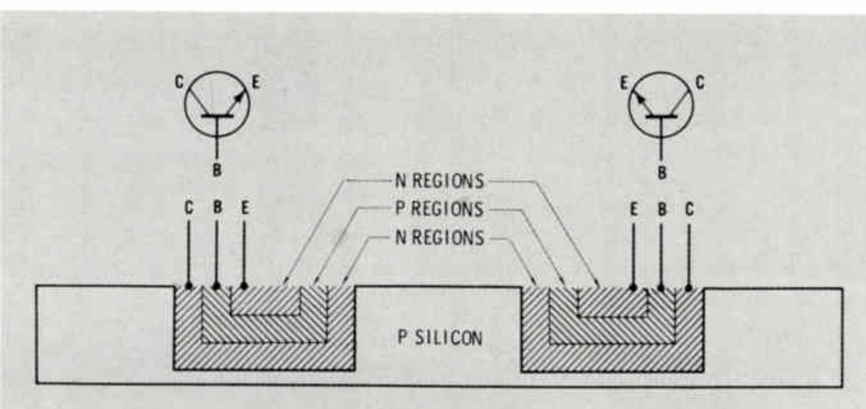


Fig 3 Formation of NPN transistors on a P substrate. The substrate can be cut to yield individual transistors, or additional processing can be performed to make an IC.

lar enclosures made of plastic or ceramic with conductors extending from both long edges. The conductors are either flat or round, and sockets are available for either type.

Applications in Television

The IC first appeared in television about five years ago. That first IC functioned as a combined 4.5-MHz amplifier, FM detector, and audio preamplifier.

At present, we know of the following applications, which illustrate the design sophistication already achieved:

1) 4.5-MHz amplifier/FM detector/audio preamplifier with voltage-operated variable gain and an audio output of more than 1 volt P-P.
2) Video IF amplifier/discriminator/differential DC amplifier, with integral voltage regulator. This type is used for automatic fine tuning.
3) Chroma demodulator and color-difference amplifiers, with voltage-operated phase shift of the 3.85-MHz reference signal, to allow tint control.
4) Chroma-bandpass amplifier/reference oscillator/burst amplifier/color killer/ACC/burst blanking, with voltage-operated gain control.
5) Complete IF amplifier with integral AGC, sound and video detectors, and video amplifier with a 6-volt output.

Naturally, some of the IC's in current usage might not perform all of the functions listed above; or different combinations of functions may be performed by a certain IC. For example, a circuit designer might choose to include the reference oscillator in the same IC with the chroma demodulators. (The IC's used in the electronic tuner control of RCA's CTC 47 are simple logic devices which do not reflect the present state of the art.) Fig. 7 shows an early model IC used as a 4.5-MHz amplifier, FM detector, and audio preamplifier. It, too, is relatively simple by today's standards.

As technology advances, it is likely that more integrated circuits will be developed for use in television. On the other hand, there are three limitations of the IC which make the all-IC receiver seem unlikely for quite some time.

First, it is difficult to build an IC which will operate with much more than 10 volts of supply, and this limits the usable output amplitude of an IC to about this peak-to-peak amplitude.

Secondly, heat dissipation becomes a problem in IC's, and so they are essentially low-power devices.

Third, large values of capacitance (in excess of perhaps 20 pf) are undesirable in an IC because of the size requirement and additional cost.

These limitations pretty well exclude IC's from the deflection systems and the audio and video output circuits of TV receivers.

Troubleshooting

As most technicians who are servicing solid-state television have discovered, there are fewer failures in them than in vacuum-tube receivers. Of course, a transistor failure might require more time to replace than a tube failure, because so many transistors are soldered in, and also because there are so few standard-type transistors. Still, transistors are the most frequent cause of failure; but not because transistors are bad.

For most applications, ½-watt resistors are used in circuits, even though the actual dissipation might be only a fraction of this rating. Smaller resistors are no cheaper, and much of the equipment (or people, for that matter) which inserts components into circuit boards can handle the ½-watt resistors more easily than smaller ones. Because of this oversizing, burned-out and off-tolerance resistors (usually caused by overheating) occur less often in solid-state circuits, particularly circuits using IC's.

Capacitor failures also are rare because capacitors in low-power, solid-state circuits often are operated far below their voltage ratings. Also, there has been a lot of im-

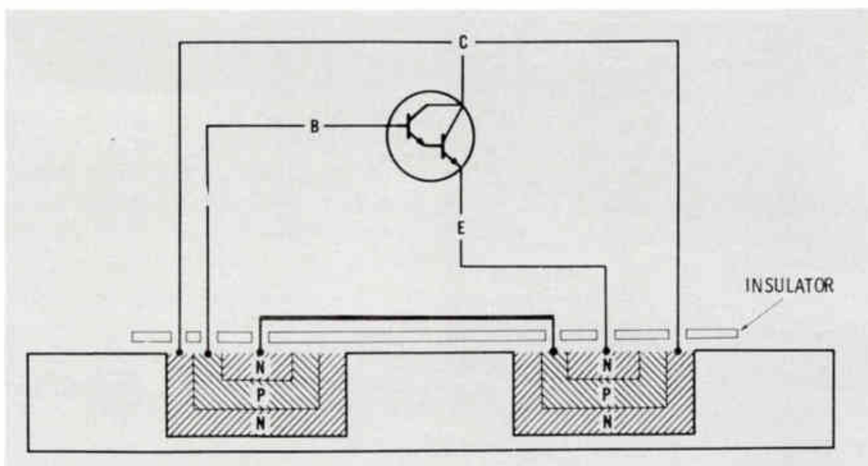


Fig. 4 The interconnections are made by covering the devices with an insulating layer having aperatures in the desired locations and then depositing metallic conductors on top.

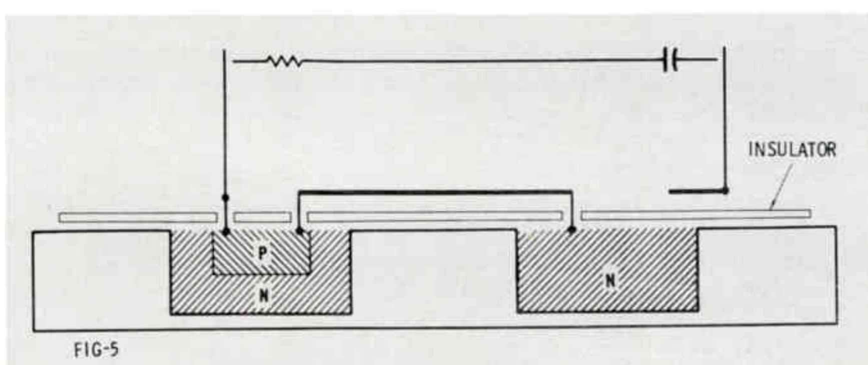


Fig. 5 Capacitors and resistors are formed in this manner.

provement of capacitors in recent years.

Because of these factors, the incidence of failure in solid-state equipment has been reduced to a level below the failure rate of comparable tube-type circuits. However, most of the failures in solid-state equipment result from faulty transistors. There haven't been enough integrated circuits used in television receivers to permit definite conclusions, but it appears that we are faced with the same situation that has prevailed in tube-type equipment—many failures will be caused directly or indirectly by the active component, the IC.

Transistors are relatively cheap, simple to test, relatively easy to change, and often can be substituted.

IC's are more expensive, practically impossible to test, and cannot normally be replaced by some substitute type. Also, unless they are plugged in, which is rare, it is possible that the original will be destroyed when it is removed from the board. (Incidentally, plug-in IC's function normally in a computer operating in an air-conditioned environment; but contact contamination definitely has been experienced in television receivers employing plug-in IC's).

Before you decide to replace an IC, several checks should be made. Just how extensive these checks are will depend on your equipment, your knowledge of the circuit in which the IC is located, and the trade-off between your labor cost and the cost of the IC.

First of all, be sure that the IC actually is receiving the supply voltage it is supposed to receive. A shorted zener diode used as a regulator, or an off-tolerance power-supply bleeder, might be supplying insufficient voltage; IC's are rather critical in this respect. Also, an open zener or some other fault external to the IC might increase the supply voltage to a level that will destroy the new IC as soon as it is installed.

The next item on the pre-replacement check list seems obvious, but it is too important to be ignored. Be sure that the input signal actually is getting to the input terminal of the IC. It is possible that a coupling capacitor has opened, or that there is a defective solder connection or a cracked board. Defective solder connections have been known to turn up months, or even years, after manufacture. Plated-through holes in circuit boards are still a bit new, and it is not uncommon for the through plating to be open.

Usually there will be several terminals of the IC which are connected to ground via a resistor and bypass capacitor. It is fairly certain that a transistor emitter inside the IC is connected to this terminal. If either of these components is open or shorted, the transistor to which they are connected will develop little or no gain.

Another item to be checked is the circuit which the IC is driving. If it uses a transistor, perhaps it is the one which has failed. Inject a signal at a convenient point near the output of the IC; if the test signal doesn't pass through the rest of the system, it is a safe bet that the output of the IC cannot either.

IC Replacement

If the IC is mounted in a socket, replacement is simple, but there are a few tips which might save you time and money:

- First, don't plug in another IC until you are certain that the supply voltage is correct. Excessive supply voltage seldom ruins a tube immediately, but it is likely to "zap" a transistor or IC before you know what happened.
- Don't forget that the trouble might be socket and pin corrosion. It is possible that a new IC will fix the trouble, but the old one might too, if it is reinserted. If you do not have a replacement, try removing and inserting the suspected IC a couple of times before ordering a new one. Since IC's have come along, we have added another subject to our "do-not-argue-about-these-things" list. How to get an IC off the board is almost as inflammatory as discussions of religion and politics. Everybody has a pet method which he is prepared to defend against all others. Here are some of the leading contenders:

One approach is simply to cut off all the leads and then remove the ends which are soldered through the board, one at a time. This works rather well with IC's which have long leads, but not so well with the plastic, in-line types which are mounted tightly to the board. As a rule, the IC is destroyed; but this is unimportant unless the IC was actually good, or if it is a warranty item and the manufacturer wants it back. (As a point of interest, I have always maintained that the customer rightfully should pay for any parts which are destroyed through no fault of the technician, or as a calculated risk—but it does run up the repair bill.)

Another popular method of IC removal involves using braided ground strapping as a wick to draw off molten solder from around the terminals of the IC. Braid designed specifically for this purpose also is available. However, extreme caution is needed, because it requires a lot of heat to melt the solder and also get the braid hot enough to carry the solder away. It is easy to get the printed wiring on the board so hot that the bonding between the copper and the board melts and the two separate. Nevertheless, some technicans become very adept and can perform a very neat job with this method.

The flat-surface soldering iron, which is designed to heat all the contacts simultaneously, works well for removing AFC-diode packs having three leads. But this method sometimes gets difficult with IC's having up to 14 heads. Either the iron is too large or not large enough. Of course, if all integrated circuits had the same lead configuration there wouldn't be any problem with this method.

Another approach uses a soldering iron with a tube and squeeze bulb attached. The idea is to get the terminal hot and then pump the bulb to blow away the solder. The one we tried didn't seem to work too well, but maybe with more practice we could have mastered the trick.

One tool that seems to be relatively effective consists of a spring-loaded piston inside a small cylinder which has a teflon nozzle on one end. The piston is pushed down and the nozzle is held as near as possible to the connection to be unsoldered. When the solder melts, the piston is released and, hopefully it draws up the solder. If there is room to operate, it works fairly well, but usually one has to repeat the process on some of the IC terminals.

An uncle of mine has had a small

air compressor in his shop for the past twenty years. He uses it to blow the dust out of cabinets, clean off the bench, etc. Now he uses it to blow the solder out of holes in boards. To prevent spraying solder all over the chassis, he wads a paper towel around and beneath the reverse side of the area where he is working.

Summary

In the next few years, it can be assumed that the IC will be applied to many more circuits in television receivers. The reasons for this assumption are: simplified assembly, smaller and lighter chassis, reduced cost and performance equal to, or better than, tube and transistor circuits.

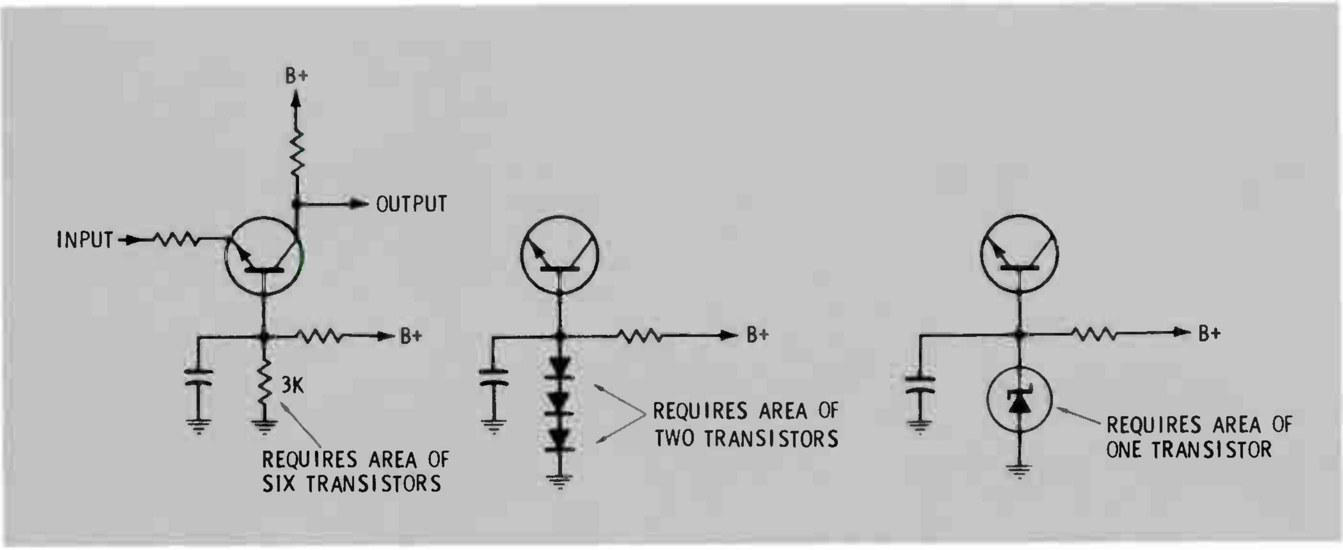


Fig. 6 A voltage drop can be obtained by forming a resistor, a series of diodes, or a zener. Cost is a major consideration in determining which method is used.

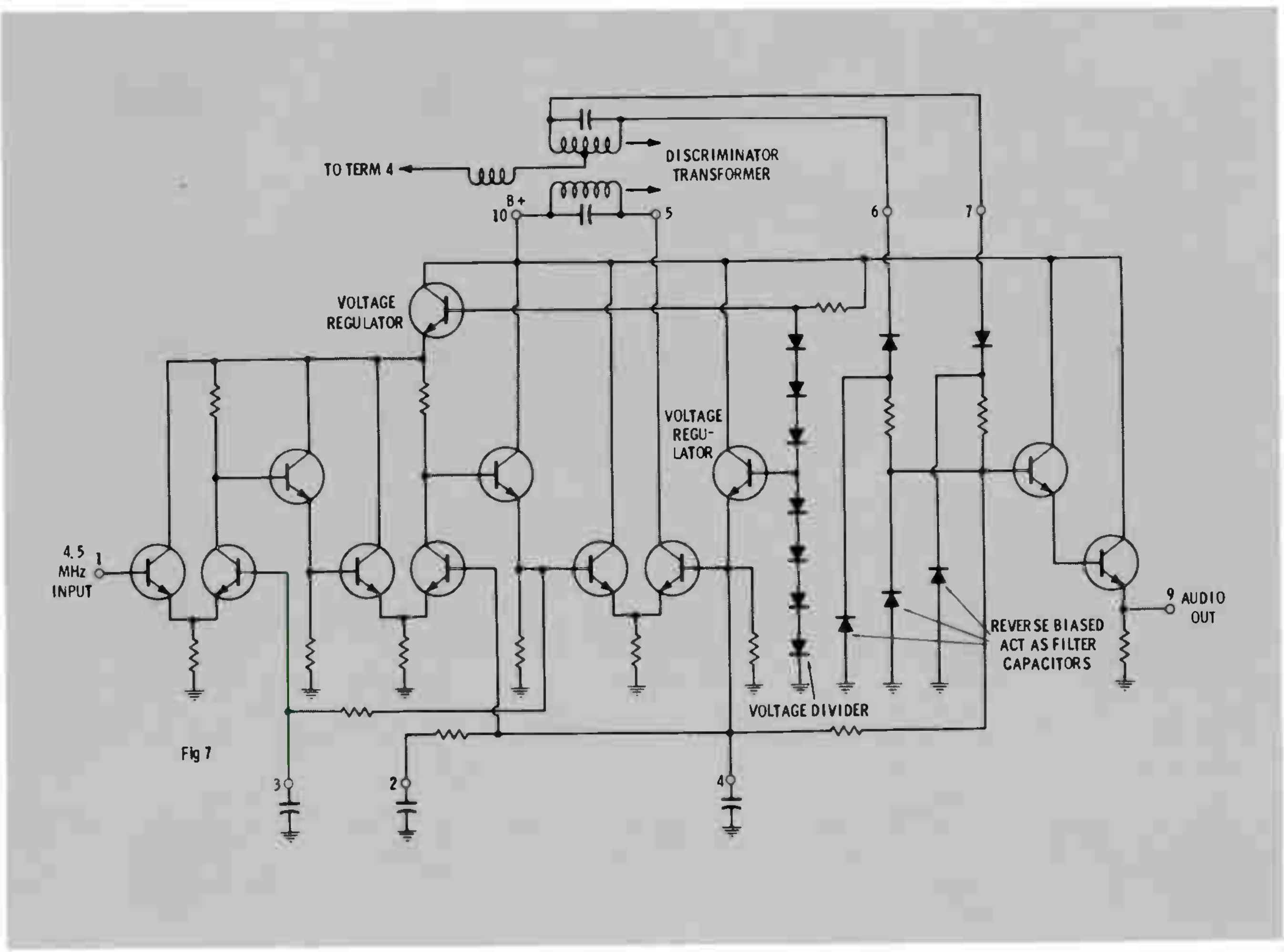


Fig. 7 The RCA type CA 3013 amplifier and discriminator, with typical external circuitry.

At the moment, the production of the types of IC's suitable for most TV applications is, relatively speaking, in its infancy. The techniques for manufacturing IC's are being constantly revised; however, basic construction techniques probably will remain similar to those described in this article.

From the servicing angle, it isn't really necessary to know precisely how an IC is made, or for that matter, precisely how it functions. It is important, however, to know thoroughly what each IC in a receiver **does.** Equally important, the technician must know the purpose of each component connected to an IC. If he does not, he will make a lot of wrong guesses, replacing good IC's needlessly and damaging new ones by installing them in defective circuits.

Good soldering techniques must be employed when you are removing IC's. Whether or not an IC found to be good should be reinstalled is questionable—putting it back might be more costly than leaving the new one in place. But ruining the circuit board while removing it is another matter! A patched up board can lead to future failures, and the alternative—replacing the board—is too costly even to consider in most cases. A sign we noticed in a shop not too long ago sums it up. "If you're too busy to do it right the first time, how will you find time to do it over?" ▲

Chapter 8

Quick testing of transistors using the scope and ohmmeter

Most transistor failures are of the catastrophic type, such as open or short circuits, and can be found without guesswork by use of the simple tests described in the following paragraphs, each of which has been tried and proven in ELECTRONIC SERVICING'S lab.

Use Your Scope to Check Transistors

One method of using an oscilloscope as a read-out device to test transistors is shown in Fig. 1.

All base-emitter or base-collector junctions of a transistor exhibit diode characteristics. That is, when the element made of "P" material is positive relative to the other element made of "N" material, electrical resistance of the junction is at minimum. Conversely, negative voltage applied to the "P" element and positive voltage applied to the "N" element will cause a near-open circuit between the two elements.

These junctions also will rectify. The emitter-collector path involves a series connection of two dissimilar and opposite-polarity "diodes"; because of this, emitter-to-collector rectification is very inefficient, and related test results indefinite.

Interpretation of the scope waveform is the only difficult part of this test; photographs of typical waveforms are shown here to guide you. Signals supplied to both the vertical and horizontal amplifiers in the scope are changed by the condition of the transistor junction.

A horizontal line, as shown in Fig. 2A, indicates an open circuit; a vertical line (Fig. 2B) indicates a short across the test leads. (In fact, the scope is pre-set by shorting and opening the transistor test leads before the test is started. The "H" input on the scope in Fig. 1 is the external horizontal sweep input, and the sweep selector must be set to the "EXT" position. With nothing connected across the test leads, adjust the horizontal gain control for a horizontal line of about one-half the width of the scope screen. Short the test leads together and adjust the vertical gain control and range switch for a vertical line of about the same height as the length of the horizontal line in the previous step. Focus and beam intensity of the scope should be adjusted normally.)

Typical waveforms for a good germanium transistor tested out of circuit are shown in Fig. 3. As shown, connection of a specific test lead to a specific transistor element produces a definite and individual pattern; this characteristic enables you to identify the polarity of diodes or transistors. Otherwise, it is not necessary to observe polarity in connecting the test leads; the right-angle waveform will face the opposite direction if the leads are reversed or if a transistor having opposite polarity is tested.

In the base-emitter and base-collector tests, silicon transistors produce the same waveforms as germanium types (except for the Zener effect shown in Fig. 4A, which has been evident in all the base-emitter tests of silicons I have made so far), but emitter-collector tests of silicons (Fig. 4B) indicate an open circuit.

Sharp corners on the scope waveforms are the hallmark of a good diode or a good transistor junction. This also is true during in-circuit tests. If there is a doubt, remove the transistor for a more definite test.

Waveforms produced by resistance, capacitance or inductance alone, without a transistor or diode, are shown in Fig. 5. Comparable waveforms produced by these characteristics and transistor junctions, as might happen in-circuit, are shown in Fig. 6. Two actual in-circuit waveforms are shown in Fig. 7 (the 3.3K-ohm out-of-circuit resistor was used to intensify the obscuring effect of the circuit components). Be certain the power is turned off

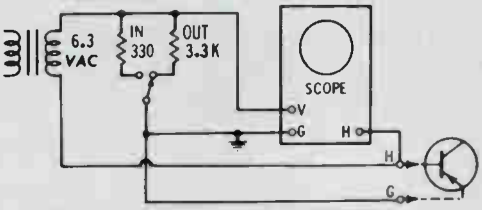


Fig. 1 Schematic of a transistor testing adapter for use with almost any oscilloscope. Both vertical and horizontal deflection voltages are supplied by the adapter, and no locking of the scope is needed. Two values of resistors are shown: 330 ohms for in-circuit, and 3.3K ohms for out-of-circuit transistor or diode tests.

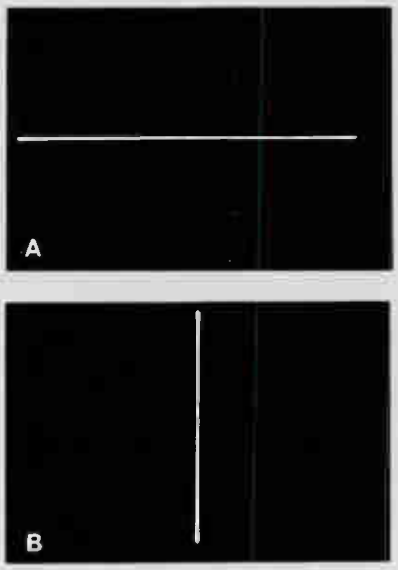
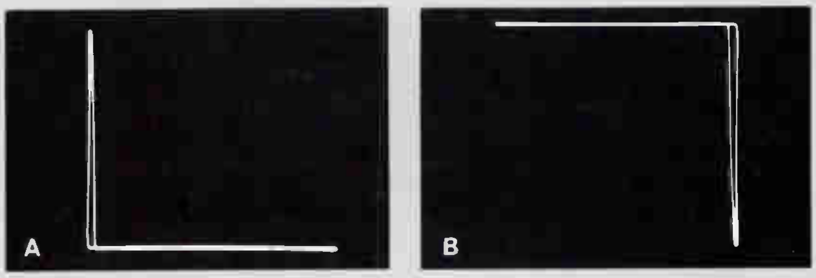


Fig. 2 Single straight lines produced by open or shorted transistors (following the simple preadjusting explained in the text).
(A) A horizontal line indicates an open across the test leads.
(B) A vertical line indicates a short across the test leads.



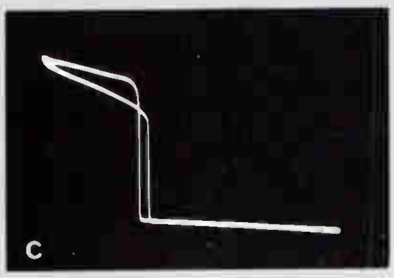


Fig. 3 Waveforms typical of most normal germanium transistors.
(A) PNP polarity transistor with base connected to "H" and emitter (or collector) to "G". A diode with the cathode connected to "H" and the anode to "G" will produce the same waveform.
(B) The same PNP transistor with the base connected to "G" and the emitter (or collector) connected to "H". A diode with cathode connected to "G" and anode to "H" produces the same waveform.
(C) A PNP transistor with the emitter connected to "H" and the collector to "G". Rectification is inefficient, and scope gain must be increased to obtain a large waveform.

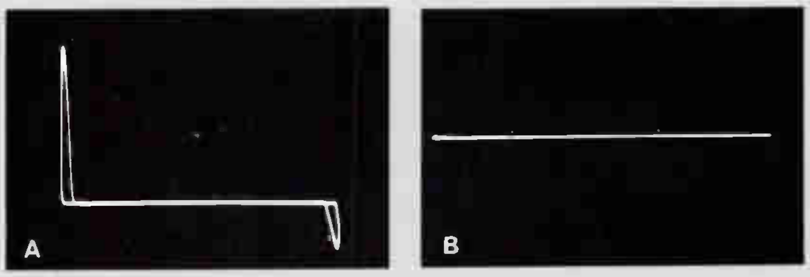


Fig. 4 Silicon transistors present further problems.
(A) One type of NPN-polarity silicon transistor with the base connected to "G" and emitter to "H". The negative-going tip on the right is caused by Zener effect (actually, zener diodes produce a longer tip)—it is not scope overload, nor does it appear in the base-collector waveform.
(B) Collector-emitter tests indicate an open circuit when the transistor is a silicon type.

to any circuits being tested.

Some of the advantages of this method of testing transistors as though they are rectifying diodes are as follows:

• Extreme speed. Just attach the test leads in sequence to the base-emitter, base-collector and emitter-collector. A short or open "result" indicates a defective transistor.

• No charts or scales. Just select the value of resistor for in-circuit or out-of-circuit tests; that's all.

Disadvantages of this test method are as follows:

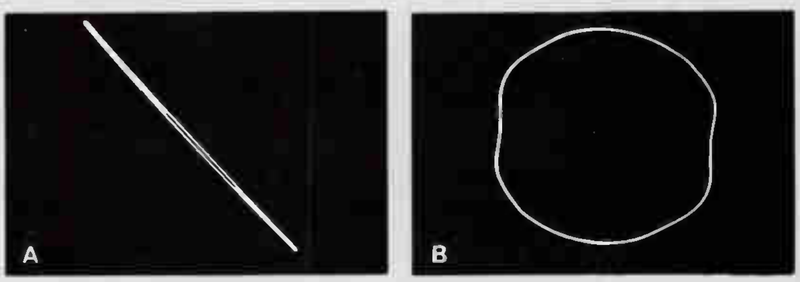


Fig. 5 Waveforms produced by resistance, capacitance or inductance alone, without a transistor.
(A) A 3.3K-ohm resistor across the test leads produces this tilted waveform.
(B) A .47-mfd capacitor or a filter choke across the test leads produces a near-circle.

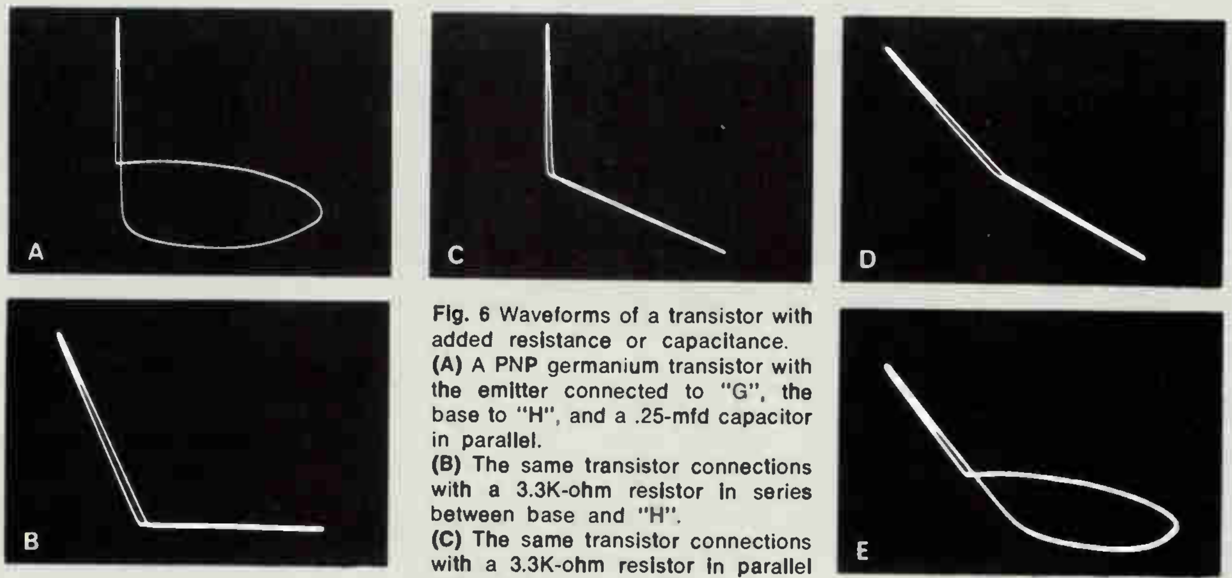


Fig. 6 Waveforms of a transistor with added resistance or capacitance.
(A) A PNP germanium transistor with the emitter connected to "G", the base to "H", and a .25-mfd capacitor in parallel.
(B) The same transistor connections with a 3.3K-ohm resistor in series between base and "H".
(C) The same transistor connections with a 3.3K-ohm resistor in parallel between base and emitter.
(D) A PNP germanium transistor with the emitter connected to "G", the base to "H" through a 6.8K-ohm resistor, and a 6.8K-ohm resistor in parallel with the base and emitter. The waveform approaches that of a pure resistance, but the "diode" corner is still visible.
(E) The same transistor in **(D)** but with emitter connected to "G", the base to "H" through a 6.8K-ohm resistor, and a .068-mfd capacitor in parallel with base and emitter.

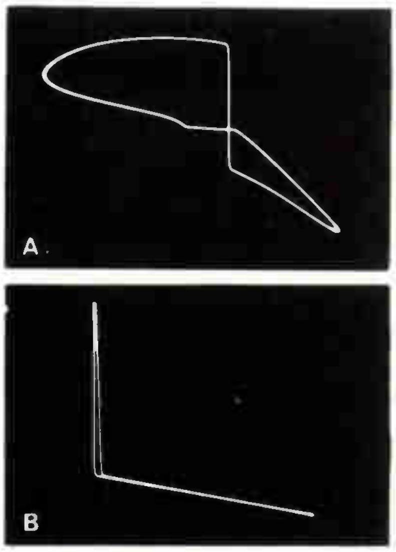


Fig. 7 In-circuit waveforms.
(A) Emitter-to-collector waveform produced by a PNP germanium transistor connected to an unloaded audio-output transformer.
(B) Emitter-to-base waveform produced by the same transistor, including bias resistors and electrolytic coupling capacitor.

• There is no indication of moderate leakage.

• The emitter-collector path of silicon transistors always tests open; consequently, this test is limited to shorts.

• No numerical ratings for reference can be found.

Ohmmeter and Beta Tests of Three Power Transistors*

2N408 germanium PNP—low power/low voltage output transistor; DC beta 150—all leakages normal on transistor tester

Test	negative lead to:	positive lead to:	meter scale:	reading in ohms:
forward	base	emitter	X10	31
forward	base	collector	X10	29
leakage	emitter	base	X10K	1meg
leakage	collector	base	X10K	700K
C/E forward	collector	emitter	X100	6000
C/E leakage	emitter	collector	X1K	200K

2N301A germanium PNP—high power/medium voltage transistor; DC beta 130—slight, normal ICEO leakage

Test	negative lead to:	positive lead to:	meter scale:	reading in ohms:
forward	base	emitter	X10	16
forward	base	collector	X10	15
leakage	emitter	base	X1K	45K
leakage	collector	base	X1K	33K
C/E forward	collector	emitter	X100	70
C/E leakage	emitter	collector	X100	8K

NPN silicon—medium power/high-voltage transistor; DC beta 70—all leakages normal on transistor tester

Test	negative lead to:	positive lead to:	meter scale:	reading in ohms:
leakage	base	emitter	X1meg	500meg
leakage	base	collector	X1meg	200meg
forward	emitter	base	X10	110
forward	collector	base	X10	104
C/E leakage	collector	emitter	X1meg	21meg
C/E forward	emitter	collector	X1meg	180meg

*Ohmmeter function of a VTVM used for measurements; battery 1.5 volts.

Using A Curve-Tracer To Test Transistors

More sophisticated tests of transistors can be made with curve tracers. We presently are conducting evaluation tests on curve tracers manufactured by Eico and Jud Williams, and hope to have our report ready for the December issue of ELECTRONIC SERVICING.

Transistor Beta Testers

No shop should be without a transistor beta and leakage tester. In addition to the accuracy of the reading, the equipment makes a favorable impression on your customers who see you use one.

DC beta is the ratio of collector current versus base current. Most commercially built transistor testers vary the base current until a predetermined amount of collector current is read on the meter, then the meter is switched to read the base current. The meter scale is calibrated as DC beta.

To avoid interpreting wrongly the DC beta reading a tester might accurately give us, we should have some understanding about the significance of such tests. Because so many transistor types have been manufactured, a transistor testing manual which would give the control settings of the tester for each transistor, to permit the use of a good-bad scale, is not practical. Also, the beta reading varies with the collector current used during the test. We, the technicians, must decide the limits that are acceptable in beta readings—often without sufficient information on which to base this judgement.

A transistor with a DC beta of 150 does not automatically produce twice the AC gain of another transistor of the same type which, when tested, indicates a beta of 75. There are several reasons why this is true. The same circuits that stabilize against undesired changes caused by heat variations also partially stabilize against variations in average emitter current. Consequently, the more effective the heat stabilization of the circuit, the less AC gain variation will be observed when transistors of different DC beta are used. A transistor with a low DC beta might produce normal gain if the circuit can supply the added

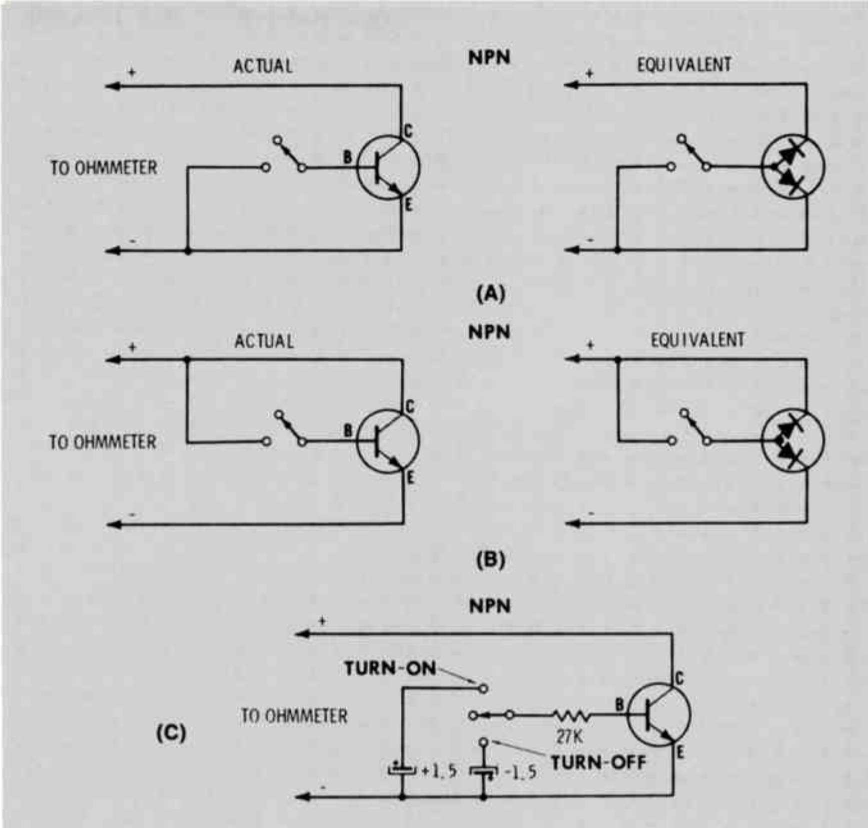


Fig. 8 Simple turn-off and turn-on tests of transistors.
(A) The collector-emitter resistance increases when the base is connected to the emitter—a fairly good test.
(B) The collector-emitter resistance decreases when the base is connected to the collector—a false test of no value.
(C) A switch, resistor and two batteries permit accurate turn-off, turn-on and ohmmeter tests—accurate indication of the transistor condition can be obtained, but leads must be changed during the test.

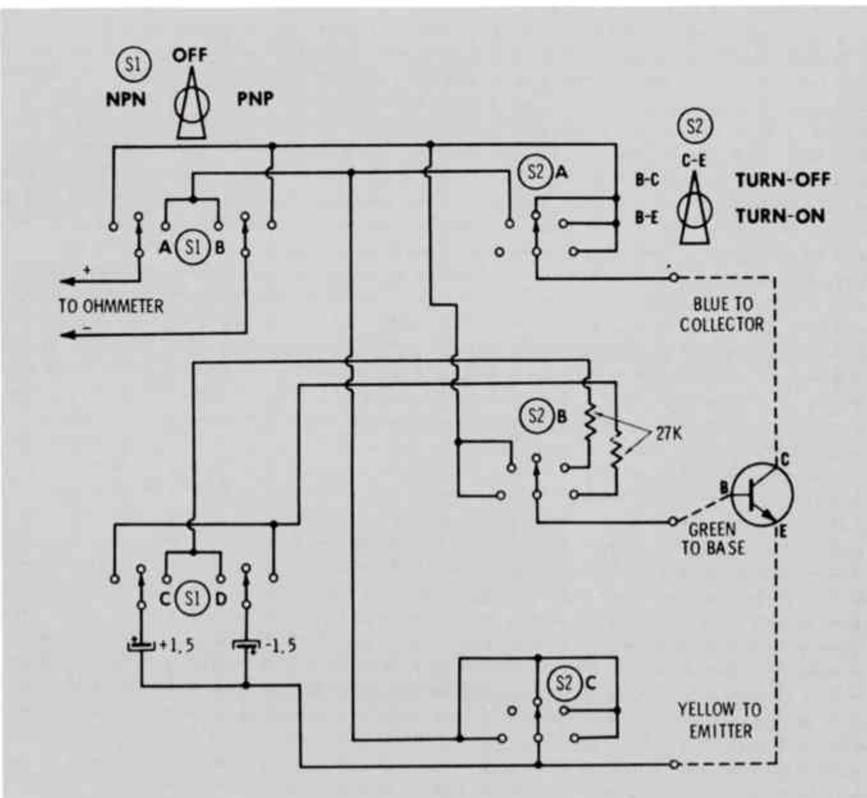


Fig. 9 Complete schematic of an adapter you can build which permits quick and accurate turn-off, turn-on and ohmmeter tests without moving ohmmeter or transistor clip leads—a very good method.

base current. However, the input resistance of the transistor will be lower, and this could have a noticeable effect on AC gain because of the change in impedance matching.

Ohmmeter Tests

Ohmmeter tests of germanium type transistors and diodes are quite informative, but such tests are of questionable value for checking silicon devices, for which most ohmmeter readings normally indicate a nearly open circuit.

The accompanying table compares the ohmmeter readings of **individual** transistors and **not** those representing average conditions. Notice that only the forward bias readings of base-emitter and base-collector of the silicon transistor are low enough to have any significance in an ohmmeter test. Some of these ohmmeter readings will change from the heat of a persons fingers. Also, the table does not show the completely different readings obtained if another ohmmeter scale is used, or if a meter with a different value of ohmmeter battery voltage is substituted.

Despite all these limitations, nearly all germanium and many silicon transistor defects can be found with ohmmeter tests; because most failures are absolute, borderline or questionable results are seldom obtained.

Turn-Off and Turn-On Tests

Ohmmeter readings combined with simple turn-off and turn-on tests provide an easy method of determining the ability of the base to control collector-emitter current, plus adequate leakage checks.

The collector-emitter resistance (in the forward-bias polarity) increases when the base is connected to the emitter, as shown in Fig. 8A. This is true, but not complete, transistor action, because a small amount of voltage is developed between base and emitter when the base is floating, and this voltage acts as forward bias on the base, which reduces the collector-emitter resistance. Connecting the base to the emitter is the simplest type of turn-off test.

Logic indicates that the circuit of Fig. 8B should be a simple, but good, turn-on test. A low reading on the ohmmeter is produced when the base is connected to the collector. But examining the diode-equivalent schematic reveals that the positive ohmmeter lead now is connected to the base, which is forward biased relative to the emitter and, consequently, will be indicated as a low resistance. This is a **false** turn-on test, and is of no value.

True transistor action can be tested by the circuit shown in Fig. 8C, which keeps the collector isolated from the base as the base is supplied with forward bias, no external bias or reverse bias. Experience has proven the test results to be very good, but the operational drawback of changing leads increases the possibility of poor connections, not to mention loss of time.

A complete adapter that provides all connections for ohmmeter turn-off and turn-on tests is shown in Fig. 9. Neither the transistor nor the ohmmeter leads require reversing or changing, and a transistor can be identified as a PNP or a NPN by the readings obtained when those two positions of S1 are tried.

The same 2N408 used to obtain the readings in the accompanying table measured 200 ohms on the turn-on position of S2, 6K-ohms on the C-E position, and about 100 megohms on the turn-off position. No hair-splitting decisions are necessary to conclude that this transistor is normal. ▲

Chapter 9

Checking transistors with the in-circuit transistor tester

The amount of solid-state units that have to be serviced is increasing, and, as a result, more and more service shops are turning to the in-circuit transistor tester to reduce the time required to service these units.

At present, there are more than 30,000 electronic service shops using the in-circuit AC beta transistor tester. Many more would use this time saver if they knew more about its operation and applications.

The following paragraphs explain how the in-circuit transistor tester operates and how it is applied to reduce servicing time.

Operation

With the tester connected to the transistor, the BETA CAL control is adjusted to the BETA CAL line on the meter. This sets the collector current to a normal level of about 2 milliamps, as shown in Fig. 1. When the TEST or GAIN button is depressed, the meter is transferred to the base circuit, as shown in Fig. 2, and the amount of base current it took to give the 2 milliamps of collector current is read on the meter.

Because beta is the ratio of input current to output current, the meter can be calibrated directly in beta. This is an extremely simple explanation, but the operation is just as simple and easy to perform.

Parameters

Beta is a very important parameter in a transistor because it indicates whether or not the transistor has enough gain (the ability to amplify a signal). As can be seen, the less base current it takes to produce the "set-up" collector current, the higher the beta or amplification of the transistor. This is the reason for the reverse-reading beta scale on these testers.

There is one more parameter that is just as important: leakage, or ICBO. Leakage is the reverse current that flows between the base and collector of a transistor, and is measured with the emitter lead open, as shown in Fig. 3.

Leakage in a transistor is important because it can affect the total operation of the circuit. Since the leakage current is in opposition to the normal current flow between the emitter and collector, it will lower the beta of the transistor. In many cases it may not lower the beta below the general beta spread of the transistor and, therefore, may not be detected during the beta test. The leakage measurement must be made out of circuit because any resistors or coils in the circuit will provide a path for the DC current and produce a false reading.

To measure leakage, a voltage of the opposite polarity is applied between the base and collector leads, and the resultant base current is measured on the meter. Normal leakage of a germanium transistor will be about 2 to 10 microamps in low-power types and up to 3 milliamps in power-output types. The leakage in silicon transistors is much lower and, in many cases, may not even be indicated on the meter of the tester.

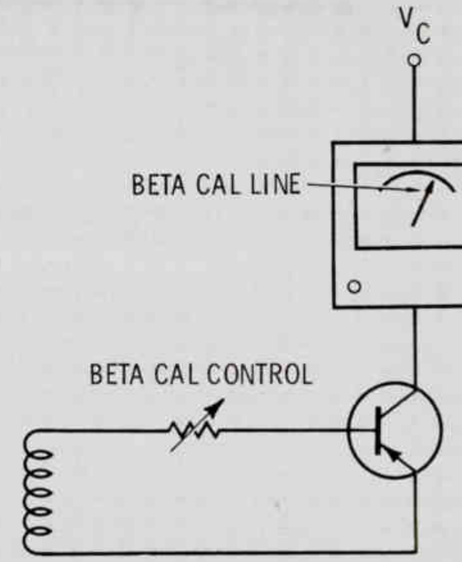


Fig. 1 BETA CAL control sets the collector current to a normal, or reference, level of about 2 ma.

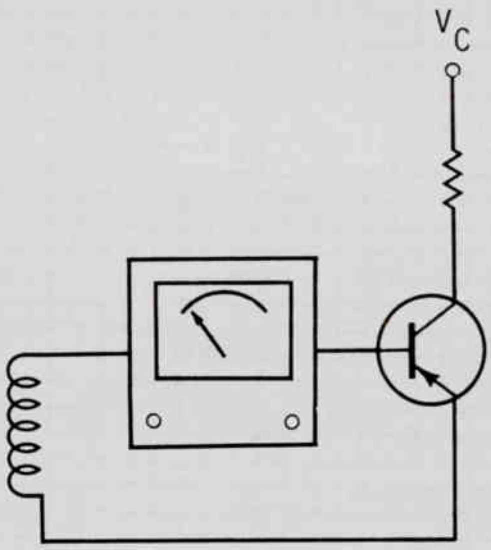


Fig. 2 Depressing TEST or GAIN button switches meter to base circuit. Meter indicates amount of base current it took to produce 2 ma of collector current, although meter scale is actually calibrated in terms of beta.

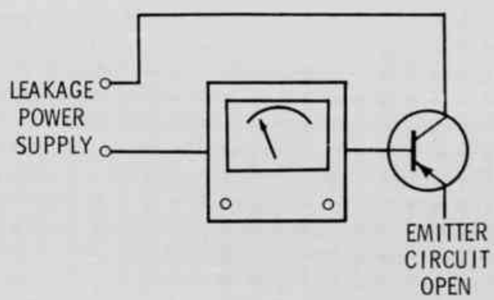


Fig. 3 Reverse current flowing between base and collector (ICBO) is measured with this basic test setup.

Connecting the Leads

The leads from the tester must be connected correctly to the transistor to be tested. With the transistor out of circuit, this is simple because the leads are easy to get to. The only difficulty that may be encountered is identification of the base, emitter and collector leads. Fig. 4 shows some of the more common base diagrams of transistors. When there is some doubt about lead identification, consult a transistor manual, such as Howard W. Sams Transistor Specification Manual, or Sencore's FET and Transistor Reference Book. Look up the transistor by number and refer to the base diagram indicated.

Testing transistors in-circuit may be a little difficult. In many cases, transistors are soldered to the circuit board, and the leads are either too short or non-existent so that the test leads cannot be attached to them. To overcome this, connect the tester leads to the leads of a component that is connected to the different elements of the transistor, as shown in Fig. 5. A small light under the board will help trace out the leads and printed circuit for making the right connections.

After the transistor tester has been connected properly to the transistor, either in or out of circuit, rotate the BETA CAL control on the tester until the meter pointer rests on the BETA CAL line on the right hand side of the meter. As explained earlier, the collector current is now being set to a 2-milliamp reference level. With the meter calibrated, depress the BETA TEST or GAIN button, and read the beta direct from the meter scale. Most testers have two ranges of beta. In most cases, the high range will be used. The lower range will be used mostly for older transistors and many of the audio output transistors, since they have a lower beta figure than the low-power audio-driver transistor.

Checking for Defects

The chart on page 28 shows the meter indications for different transistor defects. For example, if one of the transistor elements is open, the tester will not calibrate out of circuit, but may appear to calibrate in-circuit due to current paths created by the circuit impedances. When the gain or test button is depressed, no beta reading will be obtained. For various other defects the tester will not calibrate or will not give a beta reading, indicating that the transistor or the circuit around it is defective. This will be the case in over 85 percent of the circuits that are tested. If the transistor tester can be calibrated and a gain reading in beta obtained on the meter, the transistor is not defective.

This simplicity and ease of testing is the one big reason why the in-circuit AC beta transistor tester has become so popular for solid-state servicing.

Leakage

In some cases, a beta reading will be indicated, but the transistor will still be defective. There are several ways to tell if the transistor is at fault.

First, if the meter needle vibrates rapidly during the beta reading, it indicates that the transistor could be leaky or have excessive ICBO. The vibrating needle indicates that a large amount of current is being drawn from the power supply of the tester. Any time this is indicated, recheck the transistor for leakage out of circuit. (In low-impedance circuits, the circuit itself, or a defective component in the circuit, could also cause this effect.) If the transistor is not found to be defective, check the circuit for the source of the problem. In either case, the defect has been isolated to a given stage or component.

If the beta reading of the transistor being checked is low, it is generally due to leakage of the transistor. It is a good idea to list on the schematic of the various sets that you service regularly, the beta readings taken in-circuit on a normally operating set. These readings can be used for comparison in the future. Also, consult a transistor manual for the values of beta that can be expected from the various types of transistors.

Examples of Application

Using an in-circuit transistor tester and the preceding information, servicing time on solid-state devices can be reduced. Here are a few examples and points that can be used for servicing solid-state devices in the shop.

The customer complained of distorted audio after his radio operated for several minutes. The unit was opened and the audio output transistor was replaced. When the unit was connected to the bench power supply, it operated normally for over 30 minutes without distorting, so it was buttoned up and returned

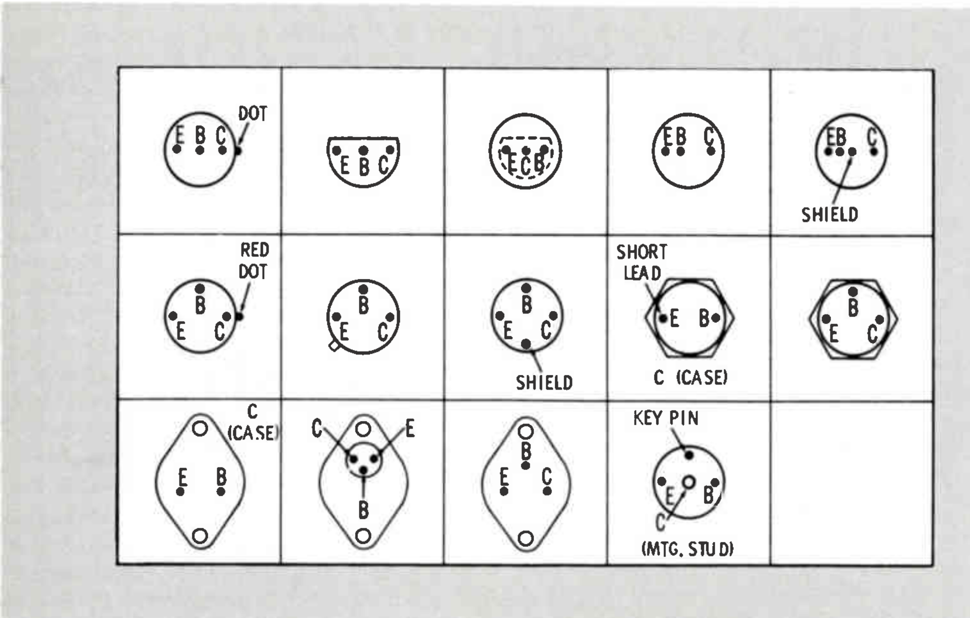


Fig. 4 Base diagrams of common transistor types currently in use.

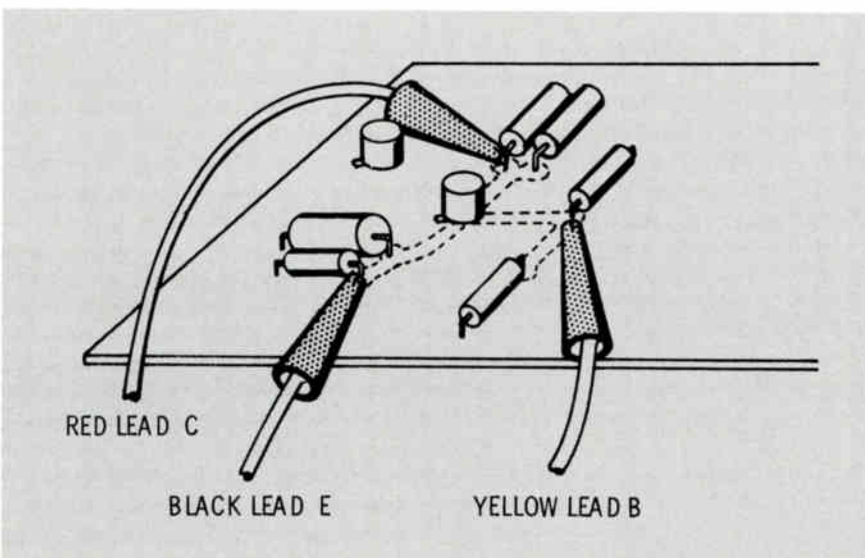


Fig. 5 Tester leads connected to components whose leads are electrically connected to leads of transistor under test.

to the customer. Two days later he returned the radio for servicing.

When asked how long it played before distorting, he said 30 minutes. Without opening the unit, it was allowed to play, and after 20 minutes, the sound became distorted. The output transistor was checked but it registered normal on both beta and leakage.

The audio stages were the most likely suspects, so beta readings of the transistors in the audio were taken and recorded while the unit was cold. The radio then was allowed to play until the distortion became very noticeable, and another beta reading was taken. The reading of the first audio amplifier was almost half the value of the reading taken earlier, and the leakage was high when checked out of circuit.

When the transistor was tapped, the leakage changed, indicating an intermittent problem. The first audio amplifier transistor was replaced, and the radio returned to the customer, who reported much later that the radio played better than ever. The moral: Don't jump to conclusions before having all the facts.

While servicing a small-screen, portable imported TV set, it was found that an exact replacement transistor is not always the answer. The original complaint had been no video. Another technician had discovered that the first video amplifier transistor was defective, and had put in the recommended replacement transistor from a replacement line. The result: a weak and washed-out picture. This prompted him to get an exact replacement transistor for the set, but it produced only slightly better results.

The in-circuit transistor test showed the driver and video output transistors to be high-gain types, while the exact replacement transistor was a low-beta type.

Another transistor in the set had the same markings as the replacement transistor so its beta was measured. It measured high.

The beta of various transistors in the general replacement transistor stock was checked. One transistor out of the group was high, but just under that of the driver and output stage. This was installed and the picture improved. The FET and transistor reference book was consulted, and it was discovered that the general replacement transistor was usable since its beta reading of 75 fell within the indicated normal beta spread of 50 to 180. However, the transistor that finally solved the problem had a beta of 165. Apparently, the design of the video circuit left much to be desired and would work only with high-beta transistors in all three stages.

In most cases, the circuit will operate normally with a transistor whose beta falls within the given beta spread of the general replacement transistor, but don't overlook the fact that some circuit designs are more gain sensitive than others.

Other Tips About Transistors

There is such a thing as an intermittent transistor. The AC beta can be checked hot or cold. Using freeze spray can speed up servicing time.

Connect the in-circuit tester to the suspected transistor, and check the beta. While depressing the TEST or GAIN button, spray the transistor with the freeze spray. If the beta reading disappears, the transistor is defective. Beta gradually decreasing is normal for a transistor operating in cold ambient temperatures. Any sudden or drastic change indicates a thermally intermittent transistor.

Another problem involves the transistor that is not listed in any specifications book. In this case, look for a transistor with markings similar to the defective transistor, and use its beta reading to select a replacement transistor. Usually a similar transistor can be found in the TV set, but if not, look for one with a similar function, such as an audio driver for a video, horizontal or vertical driver.

In the IF there are usually three transistors. Compare the two good ones and average the readings. IF and RF transistors generally have lower beta than audio transistors.

Conclusion

Servicing time can be reduced by using the in-circuit transistor tester. The amount of time saved is dependent on the technician's knowledge of the operation and application of the instrument and his ability to interpret the information it supplies. A thorough understanding of the parameters and peculiarities of solid-state devices is also essential to quicker solid-state servicing. ▲

Transistor Tester Meter Indications For Defective Transistors

TROUBLE	METER INDICATION
Open Base, Emitter or Collector	Cannot BETA CAL when transistor is tested out of circuit. In circuit tester may BETA CAL through circuit impedances but no beta reading can be obtained when GAIN button is depressed.
Base to Emitter short	Tester will BETA CAL, but TYPE switch must be in wrong position. Beta reading will be all the way to left or greater than infinity with meter pointer vibrating.
Base to Collector short	Tester will BETA CAL, but when GAIN button is depressed, meter indication will not change.
Emitter to Collector short	If there is a dead short, testor will not BETA CAL. If there is a low resistance short the tester may BETA CAL, but the meter needle will vibrate rapidly when checking beta.
Collector and Base leads interchanged	Tester will BETA CAL, but meter reads to right (a beta of less than one).
Emitter and Collector leads interchanged	Tester will BETA CAL, but meter may read to right (a beta of less than one). Indicates a very low beta figure. A few transistors may read the same because they are made to have the Emitter and Collector leads transposed.
Base and Emitter leads interchanged	Transistor will BETA CAL as opposite-polarity transistor, and no Beta reading is obtained when GAIN button is depressed.

Chapter 10

Testing transistors, diodes, FET's and SCR's with the curve tracer

Transistor Characteristics Which Can Be Tested

Characteristics of transistors which can be measured include DC beta, AC beta, shorts, leakage, opens, bandwidth, linearity, polarity (PNP or NPN), internal capacitance, noise level, and maximum permissible operating currents and voltages. Only a few of these characteristics can be tested in an electronic service shop, because of practical limits of test equipment and technicians' time.

Several simple methods of testing some characteristics of transistors were given in Chapter 8.

Testing of shorts, leakage and opens is understood best by thinking of the transistor as three interconnected diodes, as shown in Fig. 2. Forward and reverse resistance of the three junctions can be measured with an ohmmeter by testing one junction, then reversing the polarity of the leads and measuring again. This method demands some experience in interpretation, and, unfortunately, when applied to nondefective silicon types, infinite resistance is indicated by most of these tests. However, some opens, shorts and most leakage can be detected using this method.

Each diode junction of a transistor also can be dynamically tested for its ability to rectify, by use of the circuit shown in Fig. 3. The ideal waveform for a good junction is a right angle. A short produces a vertical line, and an open produces a horizontal line. These tests can be made on in-circuit transistors; however, the accuracy will depend upon the circuit characteristics. Also, collector-emitter tests are not as definite as we might desire, and leakage indications are not very sensitive.

Turn-on and turn-off tests in which the collector-emitter junction is measured with an ohmmeter are true measures of transistor actions. Of course, no accurate calibration is possible. The basic circuit foı such tests is shown in Fig. 4.

DC beta testers accurately measure the DC, or static, gain of a transistor by adjusting the base current to achieve a known collector current; the base current then is measured on a meter whose scale is calibrated in DC beta. The smaller the base current required, the higher the beta. A simplified schematic of this method is shown in Fig. 5 In actual commercial instruments, only one meter is used, with switch-

Fig. 1 Jud Williams Model A transistor curve tracer, one of at least three commercially produced curve tracers now available. Unit shown here simultaneously applies one step of a staircase waveform of current to the base of a transistor and a parabolic voltage to its collector. Emitter-collector current (voltage dropped across emitter resistor) is used to drive the vertical deflection of a scope and the collector voltage provides horizontal deflection. The resultant waveform is a "family of curves" which reveals the degree of control the base exercises over emitter-collector current, levels of leakage between junctions and AC gain, or beta (ratio of base and collector currents). Two three-prong sockets on top of unit are for out-of-circuit testing of transistors. Three-prong probe which is plugged into PROBE socket on front panel of unit is used for in-circuit testing. Connections to scope are located at rear of unit.

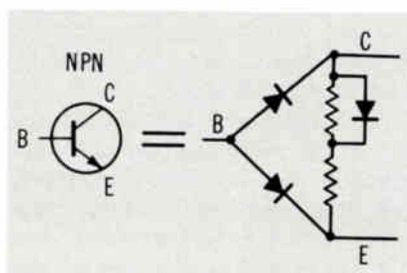


Fig. 2 Equivalent circuit of an NPN transistor shows three interconnected diodes which represent the relationships of the three elements of a transistor—emitter, base and collector. Resistance testing of these "equivalent diodes" reveals positive information about the diode action of the junctions (front-to-back ratios) and the junction-to-junction leakages (reduced resistance). The equivalent circuit of a PNP transistor is the same as that shown here, except the polarity of the diodes is reversed.

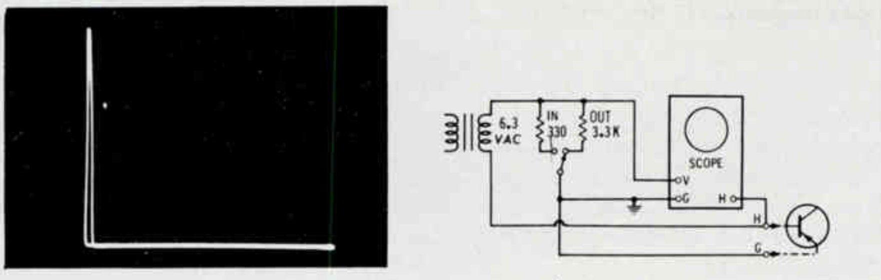


Fig. 3 Schematic of a simple method which permits testing of the diode junctions in a transistor using a scope as the readout. A right angle is the ideal waveform for base-emitter and base-collector junctions.

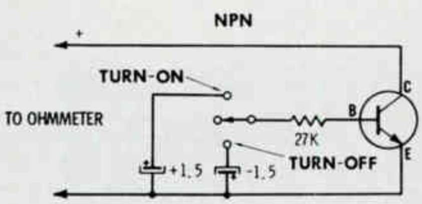


Fig. 4 The ability of the base to control the resistance of the collector-emitter circuit can be tested by this simple test unit, which is connected to an ohmmeter.

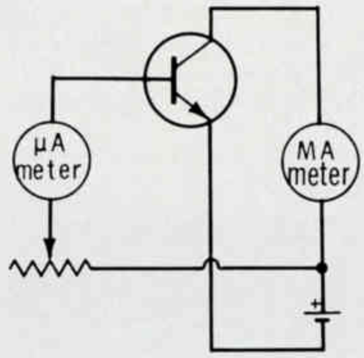


Fig. 5 DC beta is the ratio of static base current to static collector current.

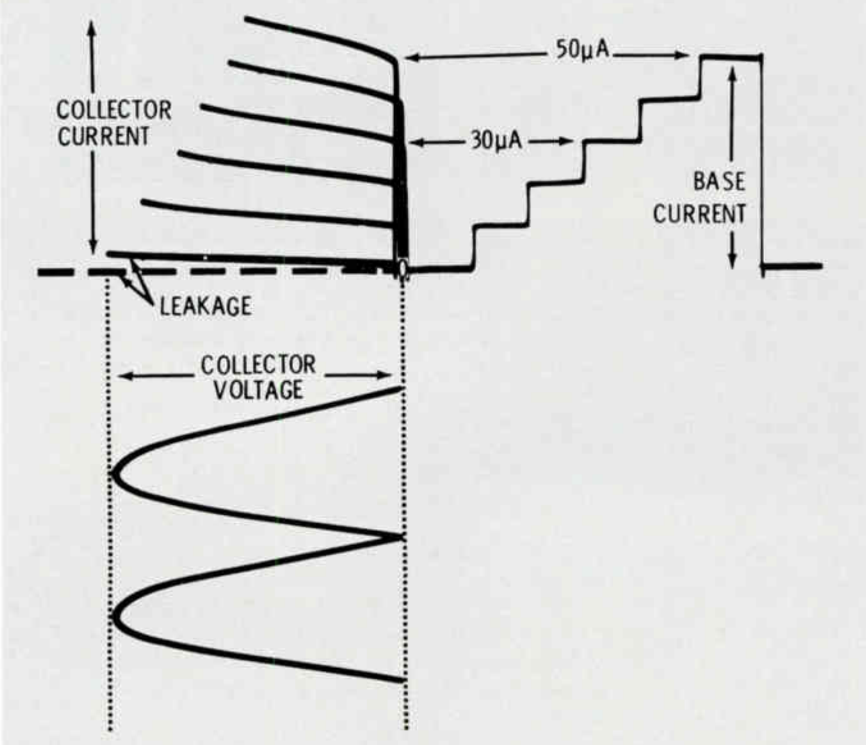


Fig. 6 A typical family of transistor curves showing the relationship between the DC "staircase" base current and the DC parabolic collector voltage. The collector voltage varies from zero volts to maximum and back to zero again during the duration of each step of the staircase. Collector-emitter leakage can be read by the tilt of the zero base current curve compared to the true zero line on the scope graticule.

ing for the various shunts. Other switch functions are used for polarity reversal, leakage, calibration, etc. Also, provision usually is made for the beta tests to be made at various amounts of collector current. This is desirable because transistors provide different betas at different collector currents. For example, one transistor measured a beta of 180 at 1 milliamp and a beta of 240 at 10 milliamps. Many commercial transistor testers have provision for measuring beta in-circuit. I will not comment on this because to date I have not had an occasion to perform these tests.

Testing Transistors With Curve Tracer And Scope

Dynamic transistor curve tracers are beginning to be heralded as the best solution to some of the shortcomings of the preceding tests. Follow with us as we thoroughly check out the performance of the Jud Williams Transistor Curve Tracer, Model A (photo in Fig. 1).

The curve tracer applies a "staircase" waveform of base current to the base of the transistor, and during each step of the staircase a DC voltage that varies from zero to maximum and back to zero again is applied to the collector of the transistor. Collector current vertically deflects the scope beam, and collector voltage provides horizontal deflection.

Fig. 6 shows the relationships between the waveforms applied to the transistor and the resultant "family of curves" produced by a normal transistor. The family of curves

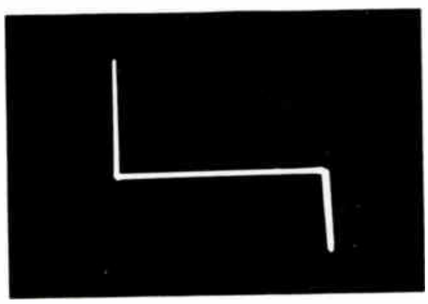


Fig. 7 Curve produced on a solid-state scope as a result of protective zener action in the horizontal sweep circuit of the scope. Many scopes will overload when the COLLECTOR VOLTAGE control is set to produce higher voltages. False curves are the result. See the text for ways of eliminating such horizontal sweep overload.

shows collector voltage and current at zero base current and at five steps of increasing base current. Tilt of the "zero base current" curve (the longest one) is an indication of collector-to-emitter current not controlled by the base. This uncontrolled current is a direct indication of collector-to-emitter leakage.

How To Connect The Scope And Obtain A Curve

Three wires extend from the rear of the curve tracer cabinet. The black lead connects to the ground post of the scope, the white lead to the horizontal input terminal or binding post, and the red lead to the vertical input. Usually, it is more convenient to use the regular scope probe. If the probe has direct and low-capacitance functions, use the direct position, to avoid unnecessary mathematics when measuring transistor beta.

Rotate the horizontal selector knob on the scope panel to the position marked "EXT", "H INPUT" or "HORIZONTAL INPUT". With both the curve tracer and scope turned on and the VOLTAGE control of the tracer turned up partially, a horizontal line should be seen on the screen of the scope. The horizontal width of this line should vary when both the VOLTAGE control on the tracer and the horizontal gain control on the scope are adjusted. Scope intensity, focus and centering should be adjusted normally.

No locking adjustments are necessary, because the scope receives both horizontal and vertical deflection voltages from the curve tracer.

Preset the BASE CURRENT switch to 10 μa, the SELECTOR switch to LEFT position and the VOLTAGE control to about 20 volts. Plug into the left socket on top of the tracer a small three-lead transistor which is known to be good. Be certain the leads are in-

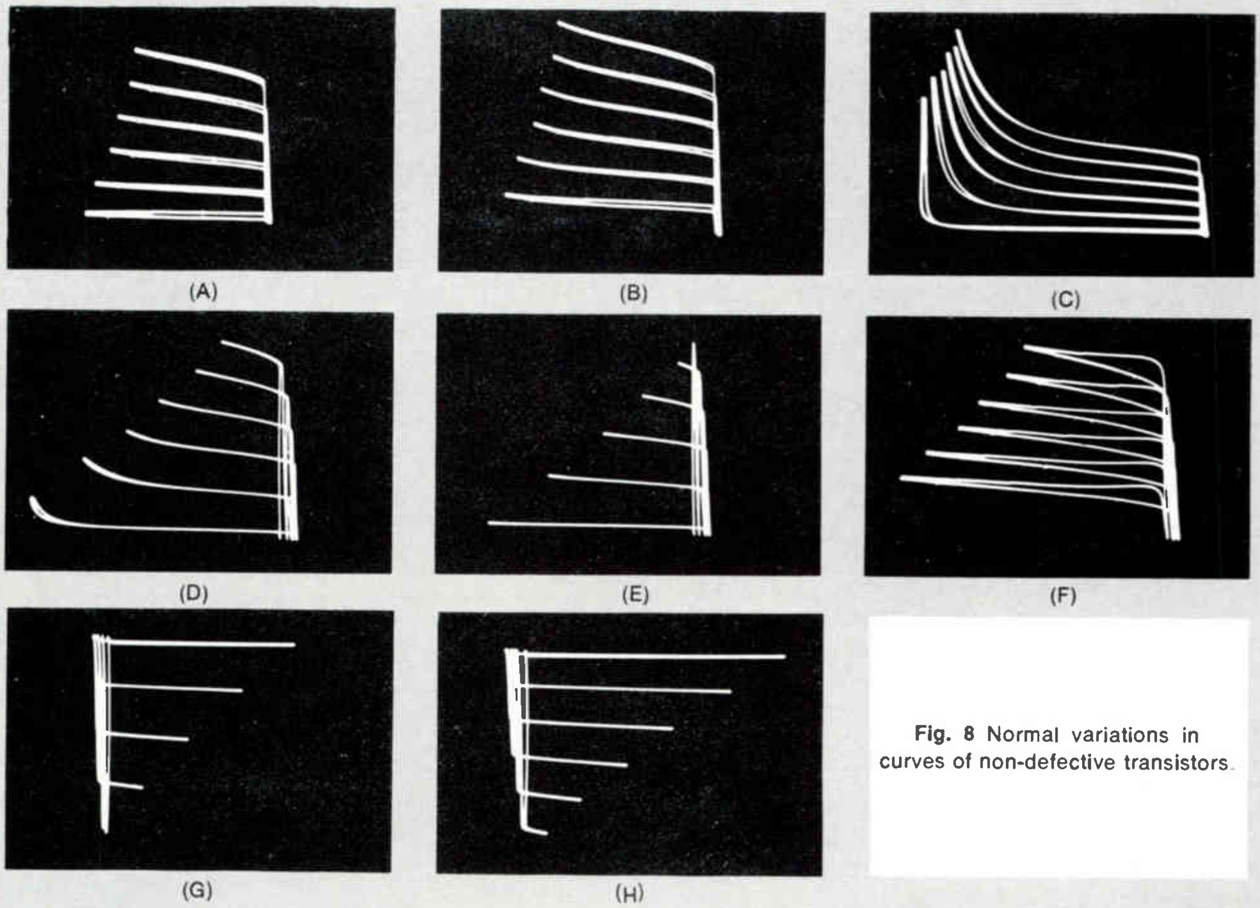


Fig. 8 Normal variations in curves of non-defective transistors

(A) Family of curves for a 2N411 PNP germanium transistor. BASE CURRENT control set for 10 μA per step of the staircase, and VOLTAGE control set at 20 volts PP.
(B) Curves produced by same transistor, but with BIAS switch erroneously set for silicon instead of germanium.
(C) Curves produced by same transistor, but with VOLTAGE control set at 70. Avalanche leakage occurs at about 50 volts.
(D) Curves produced by same transistor, but with BASE CURRENT control set at 50 μA, VOLTAGE set at 30, and scope vertical gain reduced.
(E) Curves produced by same transistor and conditions as in (D), but, because COLLECTOR VOLTAGE is set at only 20, only 5 curves are produced on scope.
(F) Curves of an old type 2N301A PNP germanium power transistor. Notice how leakage tilts the "zero base current" curve. Also note the loops in each curve, which indicate poor frequency response and internal heating.
(G) Family of curves of a small NPN silicon transistor with BASE control set at 10 μA and COLLECTOR set at 15 volts. This transistor produces about 50 percent more gain than the one in (A).
(H) Curves produced by same silicon transistor, but with VOLTAGE control increased to 25, to produce all 6 curves.

serted in the correct socket holes.

Between two and six curves, depending on the transistor, should appear on the scope. Wrong setting of the POLARITY switch will cause an "L" or "J" waveform or a vertical line. Select the position of the POLARITY switch which produces a normal curve; the polarity of the transistor then can be read directly from the position of the switch.

Adjust the vertical and horizontal gain controls and the centering controls for a waveform of sufficient size to be seen easily. Fewer changes in centering will be produced by adjustment of the various controls if the scope vertical circuit is set for the AC function.

Overload of the horizontal deflection circuit in the scope is relatively common when the VOLTAGE control is positioned to high settings. Fig. 7 shows the bent ends of the waveform produced by overload in one brand of solid-state scope (caused by zener protection of the FET used as horizontal amplifier). To test your scope for this possibility: 1) Operate the tracer and scope as usual, except do not plug in a transistor; 2) Progressively increase the setting of the VOLTAGE control on the tracer while reducing the scope width with the horizontal gain control; 3) A vertical corner or a brighter area at either end of the horizontal line indicates scope overload. Such overload cannot be considered a transistor or scope defect, because more input is applied to the horizontal amplifier of the scope than is necessary for full horizontal deflection.

Elimination of scope overload is very simple. The manual for the Jud Williams curve tracer says to insert a 1 meg-ohm (or higher, if needed) resistor between the white wire from the tracer and the horizontal input of the scope. If you are plagued by pickup of a powerful local broadcast station which rides on top of the waveform, as we are in our locality, a 5-to-1 or 10-to-1 fixed voltage divider might minimize the interference. Values of 470K/47K-ohm perform well with the solid-state scope.

Normal Variations Of The Curves

Gain, leakage, avalanche voltages, linearity and many other characteristics of transistors vary widely. Consequently, many variations in the waveshape of curves obtained from individual transistors of the same nomenclature and brand can be expected, in addition to the larger variations obtained from transistors of different types and/or brands.

However, the mere production of a family of curves, regardless of minute variations and/or abnormalities, in most instances can be considered absolute proof that the base of the transistor is controlling the collector current and, consequently, the transistor probably is functioning relatively normally. In other words, presence or absence of the family of curves is, for all practical considerations, a valid "go/no-go" indication.

Many of the normal out-of-circuit curves are shown in Fig. 8. Notice carefully the settings of the curve tracer controls, which are listed for your guidance.

Open Circuits and Leakages

An open in any element, a base-emitter short, or no transistor plugged into the curve tracer will produce a straight horizontal line on the scope, as shown in Fig. 9. A vertical line is caused by a collector-emitter or a base-collector short.

Leakage tilts the horizontal lines of the curves. Fig. 9 shows the curves produced by transistors with various values of leakage.

Mistakes Cause Wrong Curves

Improper curves can be caused by mistakes in plugging in or connecting the transistors or improper adjustment of the curve tracer controls. Some of the resultant snares possible are shown in Fig. 10.

Comparison of Tests Of Defective Transistors

For comparison, I tested several defective transistors with 1) the curve tracer, 2) with a good commercial beta tester and 3) by use of the standard series of ohmmeter tests. The results then were compared for accuracy and speed. The findings are included in the following paragraphs.

Fig. 11 shows the curve tracer waveform and the results of the

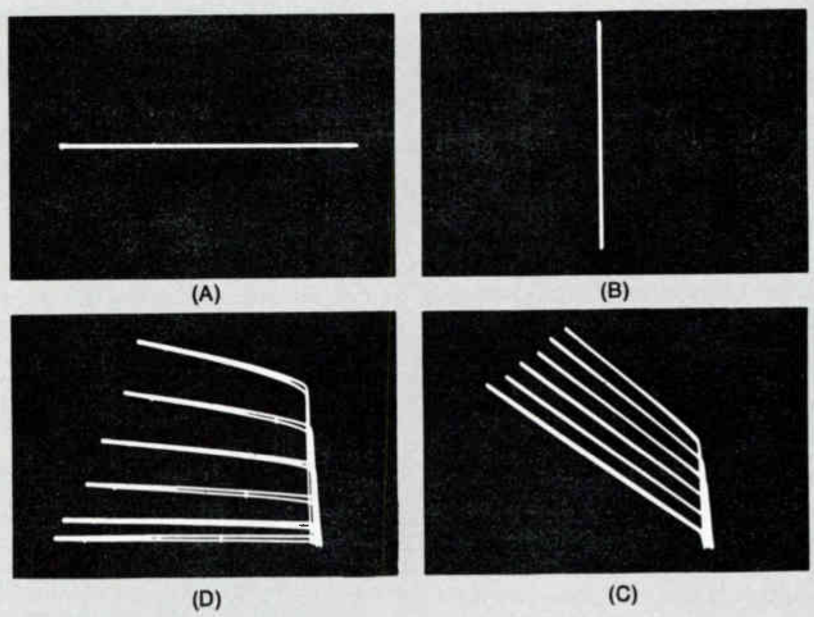


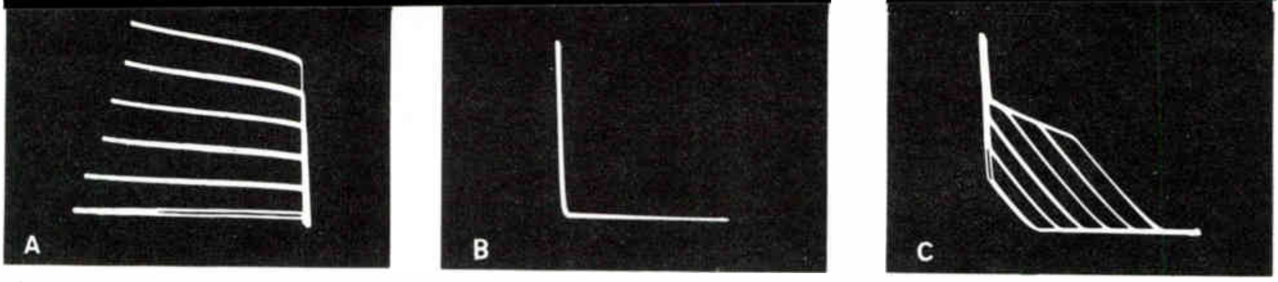
Fig. 9 Curves produced by defective transistors.

(A) A single horizontal line is caused by a base-emitter short or an open element.

(B) A single vertical line is caused by a base-collector or collector-emitter short.

(C) Curves of a 2N408 PNP germanium transistor with a 1.8K-ohm short between collector and emitter, or a 180K-ohm short between base and collector. Notice the tilt of all the curves.

(D) Non-linearity near the "zero base current" curve of a 2N408 caused by a base-emitter short of 10K ohms.



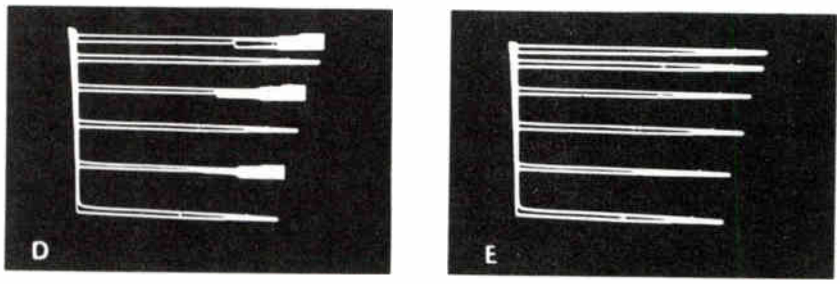


Fig. 10 Abnormal curves caused by improper connections and/or adjustments. **(A)** At first analysis, this is a normal-appearing curve; however, the collector and emitter of the transistor where interchanged. A large base current of 100 μA was required to produce the curve, indicating very low transistor gain. **(B)** Some variation of a right angle is obtained when the POLARITY switch is reversed. **(C)** A right angle and false curves caused by operation of a NPN silicon power transistor with the polarity switch set for PNP and the base current increased to 500 μA. **(D)** The same NPN silicon power transistor operated correctly with BASE CURRENT of 10 μA, but with the SILICON BIAS control turned to one end, causing a "gremlin" on alternate lines. This is a factory adjustment which can be touched up, if needed. Slight adjustment of the bias control eliminated the spurious response. **(E)** Curves produced by same transistor reveals non-linearity, also caused by a wrong setting of the SILICON BIAS control.

other two methods. The beta tester disclosed that the DC beta was slightly low, but the transistor was otherwise okay. Analysis of the ohmmeter readings indicated collector-to-emitter leakage, while the curve tracer revealed low gain and poor linearity. All three methods indicated that the transistor was not completely normal, but the results from the curve tracer were obtained quicker and were more absolute.

The curves in Fig. 12 indicate high transistor beta, or gain; however, the slope of the "zero collector voltage" side of the curves was excessive. Base-emitter forward resistance measured normal (110 ohms) on an ohmmeter, but the base-collector forward resistance was 1.2K ohms, nearly ten times the normal value. The beta tester indicated that the beta was 170 at 1 milliampere, and that the leakage was normal. Both the ohmmeter and the curve tracer revealed a defect in the transistor, but the curve tracer revealed it quicker.

It's possible to try too hard to obtain a curve; in such cases the result usually is a false curve, as shown in Fig. 13. Ohmmeter measurements indicated that the transistor had an open emitter. The beta tester indicated "no collector current." The two curves produced by the curve tracer are false ones obtained by increasing the setting of the COLLECTOR VOLTAGE control which, in turn, increased the **height** of the waveforms.

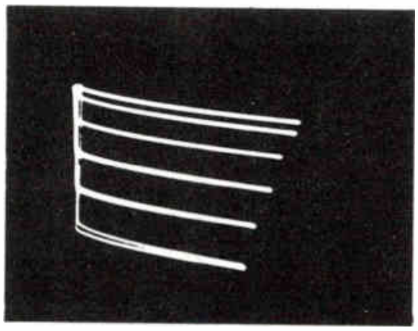


Fig. 11 These curves are nearly normal for a NPN silicon type except for some non-linearity, but low gain was indicated when the base current had to be increased to 20 μA to obtain a waveform of the usual height. Beta measured 42 at 10 milliamperes, with no noticeable leakage. The collector-emitter forward reading was 20K ohms and the reversed reading only 24K ohms.

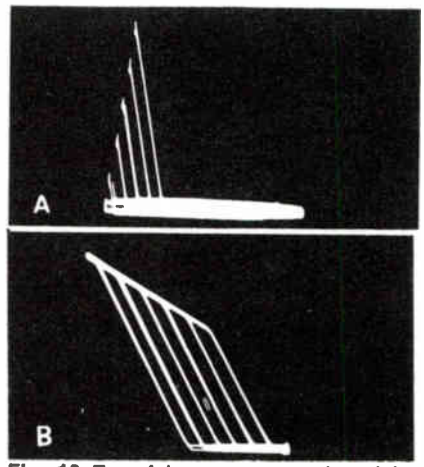


Fig. 13 Two false curves produced by an NPN transistor with an open emitter. Base-collector was 80 ohms; base-emitter indicated infinity on ohmmeter tests.

(A) Tested as an NPN, with base current of 100 μA.

(B) Tested as a PNP, with the base current at 500 μA.

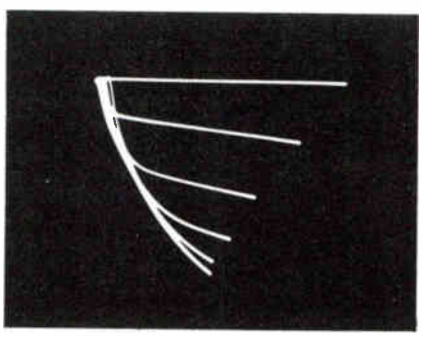


Fig. 12 Excessive slope of the left side of the curve. Beta was 170, with normal leakage. The forward resistance of base-emitter junction was a normal 110 ohms, but the base-collector measured 1.2K ohms.

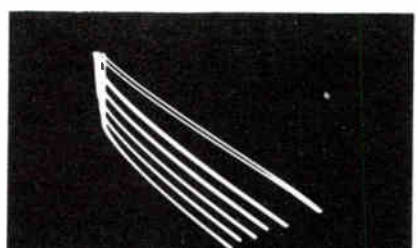


Fig. 14 Curve here shows low gain (base 20 μA) and severe leakage. Beta was 67 with collector-emitter leakage. Ohmmeter tests indicated collector-emitter forward resistance of 1300 ohms; the reverse resistance was 3000 ohms. All three test methods produced accurate indications in this case.

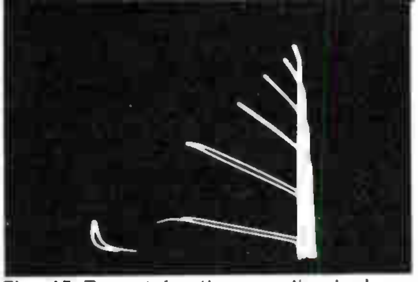
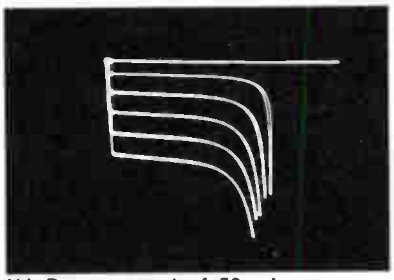
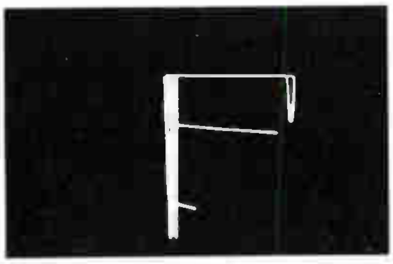


Fig. 15 Except for the peculiar leakage pattern on the "zero base current" curve, these curves indicate a normal PNP germanium transistor. Ohmmeter tests were good, and beta measured a high 300.

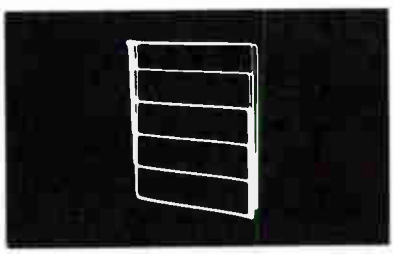
Fig. 16 Three different kinds or degrees of avalanche leakage.



(A) Base current of 50 μA was necessary to produce this normal-size waveform, indicating low gain in this NPN silicon transistor. Ohmmeter tests were normal, except for excessive base-collector leakage. Beta was 37, with normal leakage indicated.



(B) Curves of this NPN silicon transistor indicate very high gain (base current 10 μA) and a sharp avalanche at 10 volts. Ohmmeter readings were normal. Beta was a very high 400 at 10 milliamperes. Only the curve tracer showed any sign of a defect in this instance.



(C) A NPN silicon transistor with an indicated beta of 140 and normal leakages and ohmmeter readings. The transistor had so much avalanche the corner of the curve moved down and touched the bottom curve when the collector voltage was increased to 20 volts.

All three test methods correctly indicated high leakage in another transistor, whose family of curves is shown in Fig. 14. However, tests with the curve tracer required less time.

A "zero base current" curve of a 2N1303 germanium transistor is shown in Fig. 15. This curve indicates leakage with a few volts of collector voltage, no leakage with a relatively higher level of collector voltage, followed by normal avalanche leakage. (Another transistor of the identical type did not produce the unexpected dip in the base line.) The beta reading was a high 300, and leakage was normal. Ohmmeter readings seemed normal. **Only** the curve tracer found this defect.

Two extreme avalanche conditions are shown in Fig. 16. The curve at (A) shows low-gain avalanche leakage on all of the curves except the "zero base current" curve, which usually is the first to bend when the COLLECTOR VOLTAGE control is advanced. A beta of only 37 and normal leakages were indicated by the beta-type tester, while an ohmmeter test indicated excessive collector-base leakage.

The family of curves shown in Fig. 16B reveals a sharp avalanche leakage at only 10 volts PP. Many circuits use more DC voltage than this, and under such conditions the transistor would act as if it had a collector-emitter short. Normal ohmmeter readings and a very high beta reading of 400 at 10 milliamperes with normal leakage would seem to indicate that the transistor was entirely normal. Only the curve tracer revealed the true defect, a voltage limitation.

Another transistor with lower gain exhibited similar avalanche symptoms. Fig. 16C shows how the avalanche corner extended down to meet the "maximum base current" curve when the collector voltage was increased to 20 volts.

Because many transistors are soldered to the circuit board, in-circuit testing can save valuable time ordinarily spent unsoldering and removing the transistor. Also, the possibility of damaging the transistor is reduced.

The Jud Williams Transistor Curve Tracer Model A is reported to have the capability of finding defective transistors in most circuits. One plug and cable supplied with the tracer has three small clips on the end for connection to out-of-circuit transistors or diodes which do not fit the sockets on top of the tracer, or for in-circuit connection to any transistor where space permits. A three-tip B&K probe (see Fig. 17), with cable and connector, also is supplied. Each of the three sharp tips is free to swivel in a circle, and each is spring loaded to retract partially into the probe when under pressure so that solid electrical contact can be maintained against any copper foil circuit board. Each tip has a color band, to identify the base, emitter and collector connections.

The family of curves produced by in-circuit tests are radically different than those produced with the transistor out of circuit. Mr. Williams advocates that these displays be called "signature patterns", and suggests that they be included by

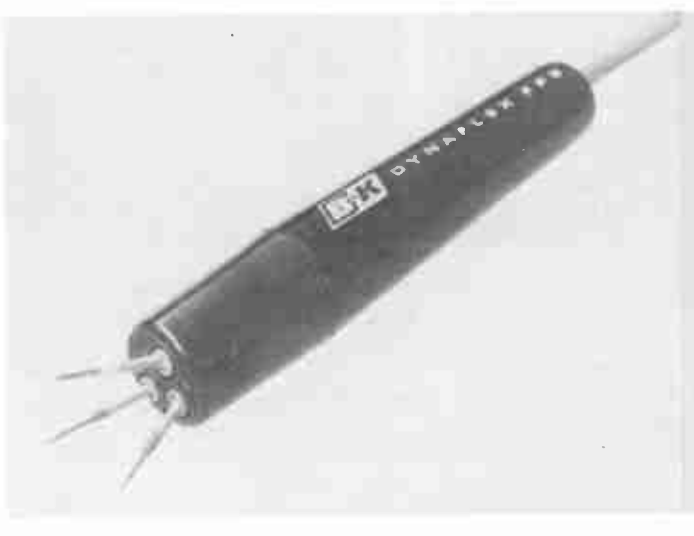


Fig. 17 Probe (for testing transistors on circuit boards) supplied with the Jud Williams Curve Tracer.

the manufacturers in their service data, or added by technicians to their PHOTOFACT schematics after the pattern for each normal in-circuit transistor has been determined.

Capacitances and inductances in the circuit often make loops out of the curves, while resistances cause the curves to tilt as though the transistor were leaky. For example, a .25-mfd capacitor (without any transistor) connected between the base and collector clips of the tracer probe produces an approximately

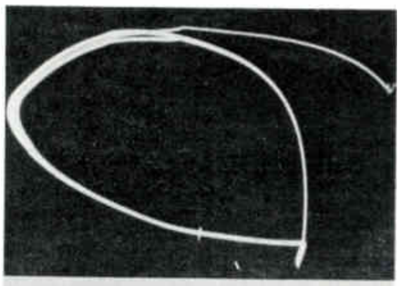


Fig. 18 A near-ellipse is produced by connection of a .25-mfd capacitor between the base and collector clips of the probe.

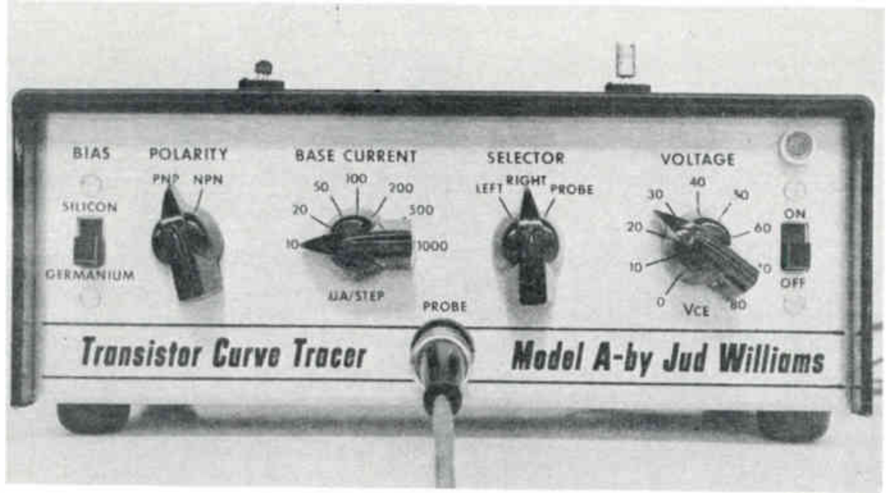
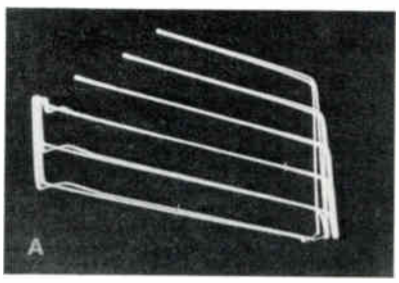
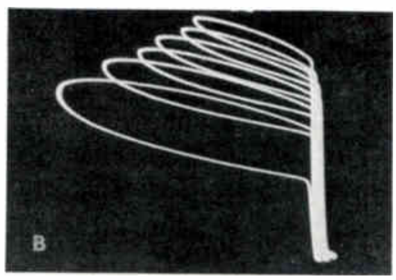


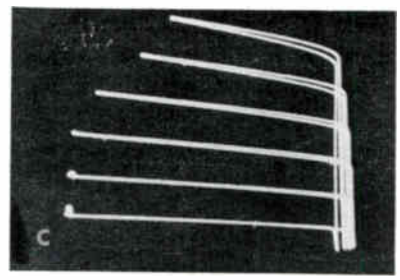
Fig. 19 Front panel controls of the Williams curve tracer.



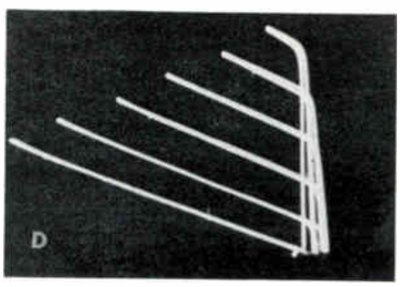
(A) Curves of a 2N408 PNP transistor in a resistance coupled audio amplifier. Base-emitter conduction in the following transistor amplifier stage causes what appears to be an avalanche condition at the end of the zero base current line.



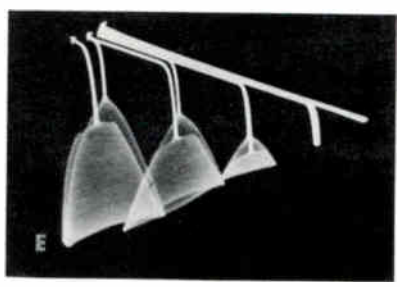
(B) Signature pattern curves of a 2N408 PNP transistor in an output circuit which includes a transformer in the collector circuit, but with the speaker disconnected. BASE CURRENT set for 10 μA.



(C) A PNP audio output transistor with a transformer and speaker connected to the collector circuit produced curves resembling out-of-circuit ones. BASE CURRENT switch set for 20 μA.



(D) Signature pattern curves of a mixer-oscillator PNP transistor in a portable radio resemble those of a leaky out-of-circuit transistor. However, a BASE CURRENT setting of 1000 μA was necessary because of loading by the circuit.



(E) The same transistor and circuit as in (D) gave this set of false curves which include pulses of RF oscillation when the POLARITY switch was changed to the incorrect NPN.

Fig. 20 Examples of in-circuit transistor curves.

oval shape, as shown in Fig. 18

Higher setting of the BASE CURRENT switch (often to the full 1000 μA position) and the VOLTAGE control are required to overcome the loading of some circuits. By comparison, most transistors can be tested out of circuit with only 10 μA of base current. Locations of these controls on the panel of the curve tracer are shown in Fig19.

Distortion of the signature patterns often can be reduced by connecting together the positive and negative voltage supply terminals of the circuit under test (no power is applied to the circuit during in-circuit tests with the tracer).

Several typical signature patterns of good in-circuit transistors and one interesting pattern resulting from the use of wrong polarity are shown in Fig.20.

It is clear that effective in-circuit testing of transistors can be done with this curve tracer, especially if comparisons with known good transistors are used to aid interpretation of borderline cases.

Testing Other Solid-State Components

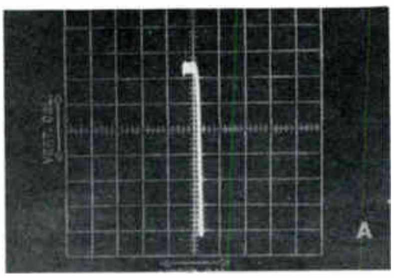
Go/no-go tests of solid-state components, such as diodes, zener diodes, SCR's and FET's, also can be made with the Williams curve tracer, although the instrument was primarily designed for transistor testing. Typical waveforms obtained when these other solid-state devices were tested out-of-circuit are shown in Fig21.

The base-emitter junction of solicon transistors exhibit zener action when tested as a diode. This is a positive way of identifying silicon alloy type transistors, since germanium types do not exhibit zener action.

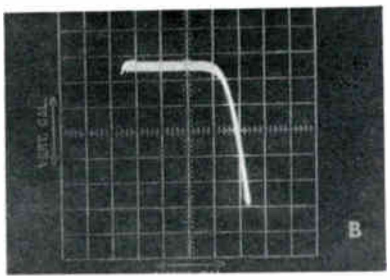
Inside the Jud Williams Transistor Curve Tracer

A simplified schematic of the Williams curve tracer is shown in Fig.22. A pulsating DC staircase waveform is applied to the base of the transistor under test, through fixed resistors selected by the BASE CURRENT switch. During the time each step of the staircase is present at the base, a pulsating DC voltage of parabolic waveshape is applied to the collector. This voltage starts at zero, increases to the maximum determined by the setting of the VOLTAGE control, then decreases

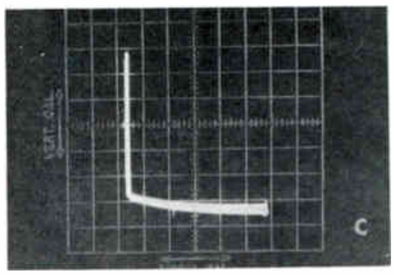
Fig. 21 Out-of-circuit tests of diodes, FET's and SCR's.



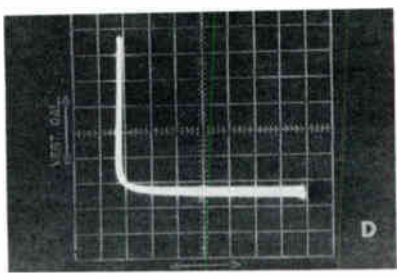
(A) Curve of a power supply diode connected between the emitter and collector clips of the external probe. POLARITY switch is set for NPN. Reverse the polarity and a horizontal line should be obtained, indicating an open circuit.



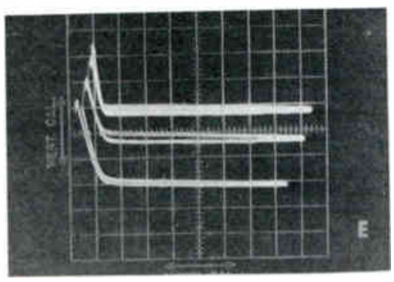
(B) The right angle curve of (A) widened by increasing the horizontal gain of the scope. A good diode should have this horizontal part of the angle, while a shorted diode will produce only a vertical line.



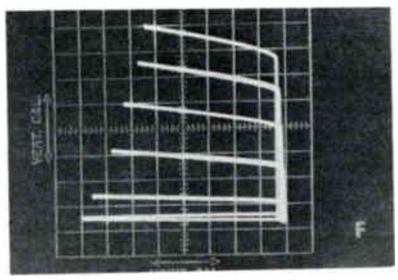
(C) Curve produced by a zener diode connected with its cathode to the emitter clip and its anode to the collector clip. The POLARITY switch should be set for PNP. The base-emitter junction of a silicon transistor shows the same zener curve. Incorrect setting of the POLARITY switch produces the normal diode curve shown in (A).



(D) Leakage and avalanche voltage are best shown with the base disconnected, but emitter and collector connected normally. This 2N410 transistor was not leaky, but showed avalanche at about 28 volts.



(E) A FET of unknown characteristics produced this unusual waveform. It seems advisable to test a known-good FET as a standard before testing a suspected one.



(F) Surprisingly, one SCR produced a set of curves very similar to those of a power transistor.

to zero. Because there is one parabola for each step of the 6 step staircase, and the parabola frequency is 120 Hz, the repetition frequency of the staircase pattern is 20 Hz and some visual flicker is noticed on the pattern.

A dynamic visual display of the emitter current at zero and five increasing base current steps is created on the screen of any scope by: 1) applying the voltage developed across the emitter resistor to the vertical amplifier and 2) by applying the collector voltage to the horizontal sweep amplifier.

Although it is seldom necessary in practical servicing to measure accurately the DC beta (the height of the curves tell the approximate gain), such a reading is possible. Calibrate the gain of the vertical amplifier of the scope so that each vertical division of the graticule is .1 volt. Then with the BASE CURRENT switch set for 10 μA, each division represents a beta of 100, when the space between the two desired curves is measured. Fig.23 shows transistor curves for a beta of 40. Each division represents a beta of 50 when the base current is 20 μA, etc.

Several minor trade-offs in the curve tracer design prevent the curves displayed from being true base current-vs-collector current graphs, such as those found in transistor manuals. Collector-emitter current is measured by the voltage drop across an emitter resistor, and

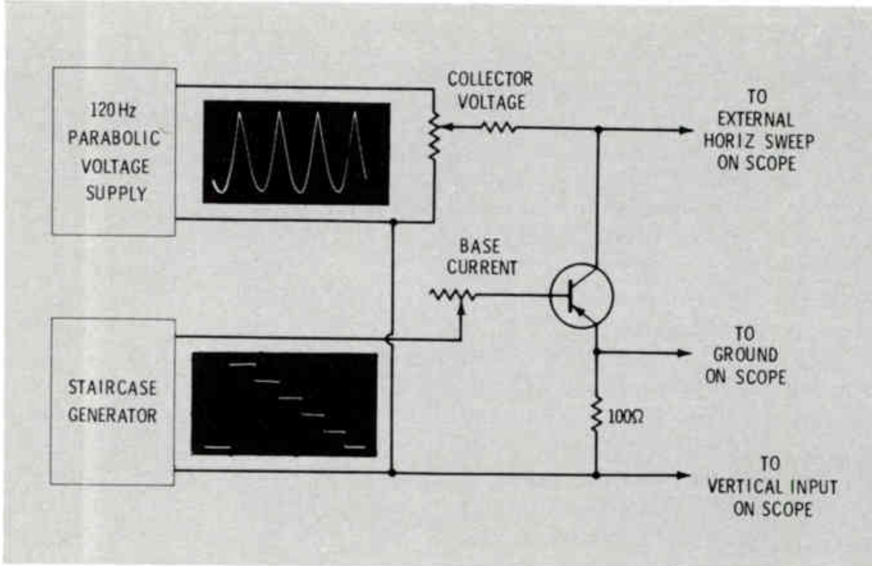


Fig. 22 Simplified schematic of the Williams curve tracer showing the polarity of waveforms required to test a PNP transistor.

the voltage there (see Fig.24) is degeneration, which subtracts from the base signal and makes the display slightly more linear. This was done so you can use your normal service scope and avoid the expense of obtaining a special scope with an ungrounded vertical amplifier. Inversion of the vertical waveform (negative voltages go up, positive go down) is the result of this small compromise.

Horizontal sweep for the scope is taken from the parabolic voltage at the collector of the transistor under test. Therefore, changing the setting of the VOLTAGE control also changes the width of the waveshape on the scope; width can be restored by use of the horizontal gain control. This apparently was done so that a shorted transistor will cause a vertical line, and so a right angle will result from diode and zener diode tests.

The effect on the family of curves when the horizontal sweep for the scope is taken from the parabolic supply **before** the VOLTAGE control is shown in Fig.25. The reason for the slanted zero-collector voltage side is that before collector current can flow, the collector voltage must exceed the base voltage (both voltages relative to the emitter). As the base voltage is increased at

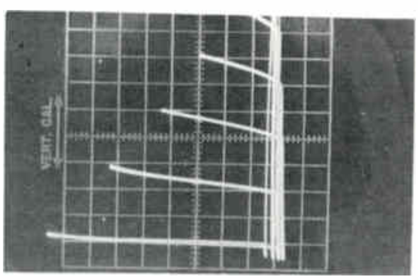


Fig. 23 Curves of a transistor measuring a beta of 40. Calibrate the scope for .1 volt per vertical division on the graticule, then with the BASE CURRENT switch set for 10 μA, each division between the curves represents a beta of 100; at 20 μA each division represents a beta of 50. In this example, the BASE CURRENT switch was set for 50μA, therefore each division represents a beta of 20.

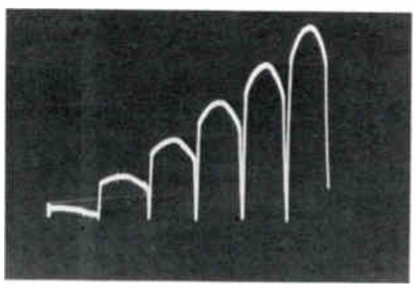


Fig. 24 Waveform across the emitter resistor when the sawtooth horizontal sweep in the scope is used instead of the parabolic horizontal sweep supplied by the curve tracer.

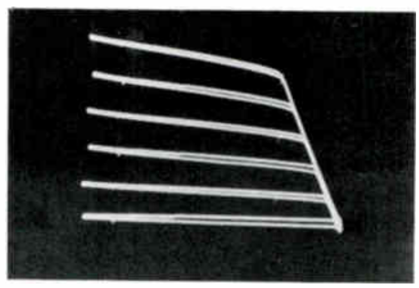


Fig. 25 A sloping zero-collector-voltage side of the curves is the result of experimentally taking the horizontal deflection voltage for the scope from the parabolic supply before the VOLTAGE control.

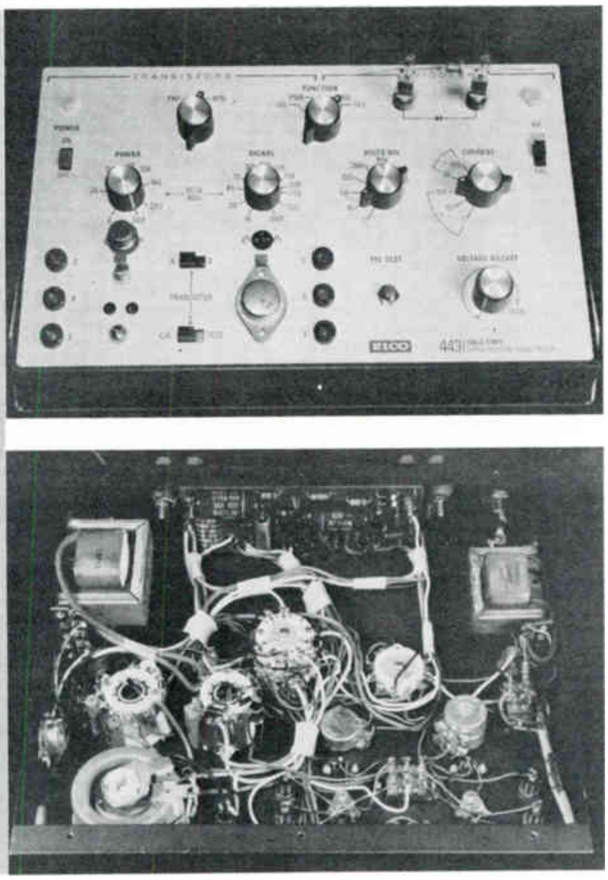


Fig. 26 Front panel layout and the internal wiring of the Eico 443 Semiconductor Curve Tracer.

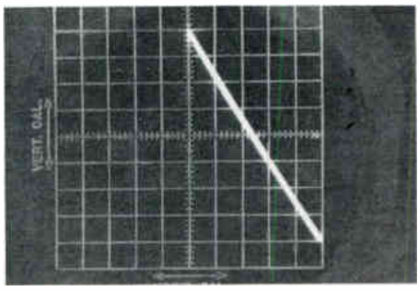


Fig. 27 Calibrate the scope for transistor beta tests with the Eico 443 by adjusting the horizontal gain, vertical gain and the centering controls on the scope for a 5-by-8 division diagonal line.

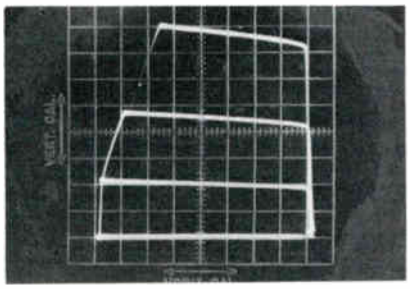


Fig. 28 Typical of curves obtained using the Eico 443 are these curves of a non-defective PNP transistor which measures a beta of 60. Adjust the beta knob until the total height of the waveform is 8 divisions, then read the beta from the dial calibration.

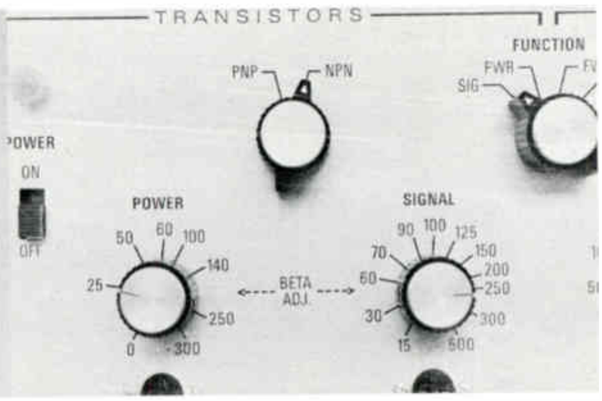


Fig. 29 Power and signal beta calibrations on the transistor-testing side of the curve tracer.

each step of the staircase, more collector voltage must be applied before current can flow. This actually produces a more accurate set of curves.

These explanations of the minor trade-offs are not intended as criticism, but are given for anyone who really wants to understand completely the electronic principles involved in this curve tracer.

Using The Eico 443 Transistor-Diode Curve Tracer

Another solid-state curve tracer suitable for use in electronic servicing shops is the Eico 443; both the front panel and the internal wiring are shown in Fig. 26. The design of this tracer seems to be somewhat different than that of the Jud Williams tracer previously described, and, consequently, so is the resultant pattern.

One strong feature of the Eico 443 is the accurate series of tests for diodes, including reverse leakage, maximum PIV and voltage drop in the forward direction.

Four combination binding post/banana plug jacks are provided on the rear of the cabinet, for connection to a scope. It appears, from the function and spacing of the posts, that the tracer can be plugged directly into the binding posts of the Eico 465 DC scope by the use of four male-to-male banana plug adapters. A 10-by-10 division graticule for use on any scope is included.

The Eico 443 is available in either kit or wired form. We built our sample from the kit and encountered no problem; the tracer worked on the first try.

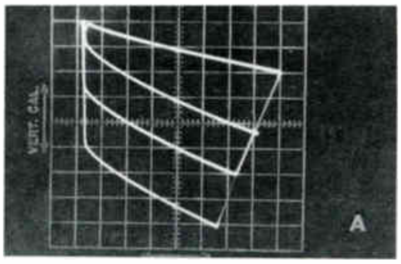
Testing Transistors With The Eico 443

A zero base current line and three steps of base current are supplied by the Eico unit; thus, four curves are displayed. All small, or "signal", transistors are tested with 10 volts applied to their collectors and a maximum current of 12 milliamps. Power transistors are tested separately, using another beta-calibrated scale at 10 volts of collector voltage and a maximum of 1 ampere.

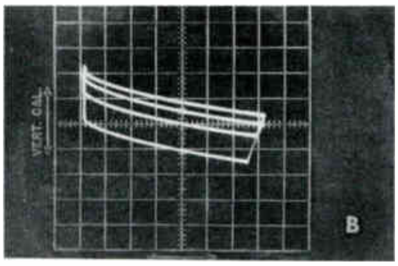
Pre-setting of the vertical and horizontal gain controls of the scope by means of standard voltages from the curve tracer is necessary if calibrated readings are to be obtained. Use these steps for maximum accuracy of readings:

- Connect leads (not supplied with the unit) from the binding posts on the tracer to the matching vertical and horizontal inputs on the scope.
- Slide the POWER switch to OFF and plug in the power cable of the tracer.
- Slide the diode TEST-CAL switch to TEST and the transistor TEST-CAL switch to CAL; then turn the FUNCTION switch to SIG for small transistors or PWR for power transistors.
- Slide the POWER switch to ON.
- Select the DC function of the scope, if the scope is thus equipped. Calibrate the scope by using the vertical and horizontal gain controls and the centering controls to produce a diagonal line 5 divisions wide and 8 divisions high, as shown in Fig. 27.
- Change the transistor TEST-CAL switch to TEST, and the polarity switch to either PNP or NPN, according to the type of transistor you wish to test. If the transistor polarity is not known, try both positions after a transistor is connected; use the one that produces a family of curves.
- Connect the transistor to be tested either by using test leads (not supplied with the unit) or by plugging it into one of the two different sockets. Position the A-B transistor selector switch correctly.
- Measure the DC beta by turning either the POWER or SIGNAL beta knob (according to which type was selected by the FUNCTION switch) until the total height of the pattern (meaning all curves) is 8 divisions, as shown in Fig. 28. Use centering controls as needed. Read the beta from the dial calibration, as shown in Fig. 29.

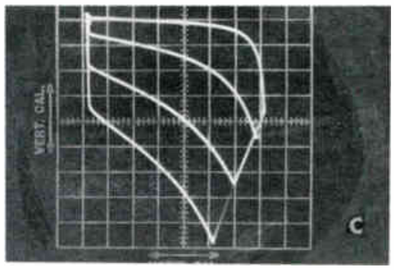
Several typical curves of abnormal transistors are shown in Fig. 30. Leakage, if any, is shown by the tilt of the zero base current line.



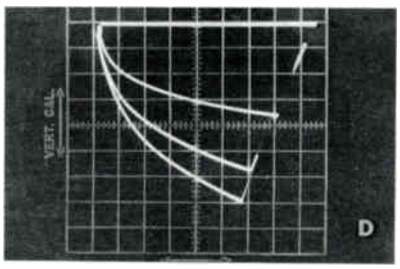
(A) A NPN silicon transistor with excessive leakage that causes the curves to be tilted.



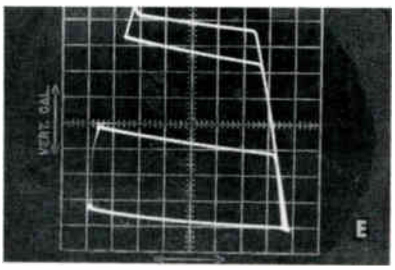
(B) These curves of a NPN small-signal transistor show excessive leakage, and a beta below 15 (because the curves cannot be adjusted to 8 divisions high).



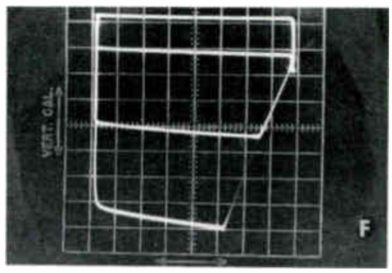
(C) Another NPN small-signal trantor with a beta measuring over 500, but with avalanche at a low collector voltage and excessive leakage.



(D) The forward resistance of the base-emitter junction measured on an ohmmeter a normal 110 ohms, but the base-collector resistance was an abnormal 1.2K ohms. Notice the sloping zero-collector-voltage side of the curves. Beta measured less than 15 on the Eico curve tracer. This is the same transistor tested in the February '71 issue of ELECTRONIC SERVICING in Fig. 12 on page 43. A meter-type tester gave a beta reading of 170 for this defective transistor.



(E) Excessive leakage is indicated in these tilted curves of a PNP power transistor, and the beta tested only 25.



(F) A high beta of over 500 was measured on this NPN silicon small-signal transistor. However, the avalanche at only 10 volts would prevent satisfactory operation in many circuits.

Fig. 30 Typical curves obtained from defective transistors.

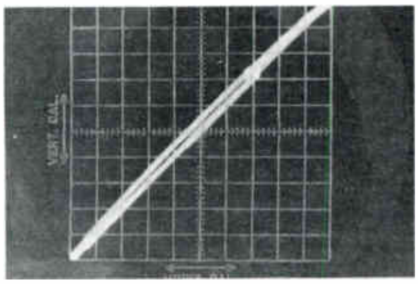


Fig. 31 Scope calibration for diode measurements requires the vertical gain, horizontal gain and the centering controls on the scope to be adjusted for a 10-by-10 division diagonal line.

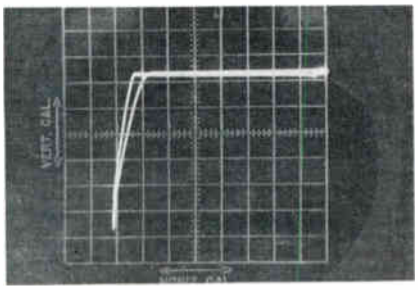


Fig. 32 The diode true PIV rating shown here is 700 volts, because the horizontal line is 7 divisions wide before avalanche occurs and the VOLTS-DIV PIV switch was set to 100.

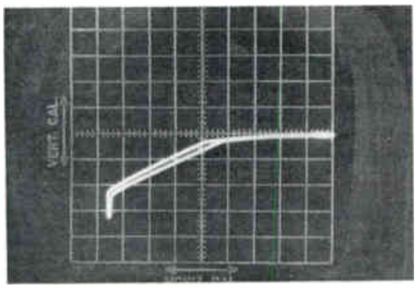


Fig. 33 This zener diode should be rated at 8.5 volts, because the VOLTS-DIV PIV switch was set to 1.

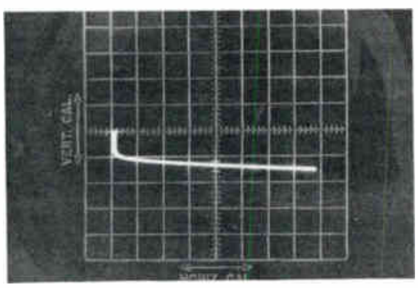


Fig. 34 A forward voltage drop of .75 volt at 800 milliamps is measured by this diode curve.

Testing Diodes With The Eico 443

A different scope calibration is needed for diode tests:

- Slide the diode TEST-CAL switch to CAL position.
- Rotate the VOLTAGE ADJUST control to minimum (CCW).
- Turn the FUNCTION switch to REV position.
- Adjust the vertical and horizontal gain controls of the scope for a diagonal line across 10 divisions, as shown in Fig. 31.
- Slide the diode TEST-CAL switch to TEST. The HV neon bulb above the switch should flash on and off.
- Turn the CURRENT switch to 10 μa, and the VOLTS/DIV PIV switch to an appropriate scale, such as 10 for a detector diode or 100 for a power supply rectifier.
- Connect the diode to be tested. (Observe polarity markings.)
- Press the PIV TEST button and advance the VOLTAGE ADJUST control. The horizontal line should move to the left until, at a definite voltage reading, a vertical line is formed on the left terminus of the horizontal line; the height of the vertical line will increase with CW movement of the VOLTAGE ADJUST control, as shown in Fig. 32. Use the centering control of the scope to position the extreme right end of the horizontal line on the right border line of the graticule.
- Read the maximum PIV by the number of divisions from the right end of the trace to the vertical angle line. Multiply the number of divisions by the setting of the VOLTS/DIV PIV switch. Don't be surprised if the PIV of many diodes measures better than the manufacturers' ratings.

A horizontal line indicates an open diode, and a vertical line a shorted one. A horizontal line also can indicate that the VOLT/DIV PIV switch is set too low.

Zener diodes are measured the same way, except the VOLTS/DIV PIV switch is set to a lower scale in anticipation of what the zener voltage should be. See Fig. 33 for the curve produced by one zener diode.

Forward tests of diodes use the same scope calibration as for PIV tests. Use this procedure:

- Turn the VOLTAGE ADJUST control completely down (CCW).
- Change FUNCTION switch to FWD position.
- Set the CURRENT switch for 10 or 100 mA/DIV, according to the expected rating of the diode.
- Slide the diode TEST-CAL switch to TEST position.
- Connect, or insert into the test clips, the diode to be tested.
- Increase the VOLTAGE ADJUST control (do NOT press the PIV test button) to produce a horizontal waveform similar to that in Fig. 34. Position the vertical portion of the trace on the left borderline of the scope graticule, with the trace initially starting on the zero voltage (horizontal) line. The vertical divisions are .5 volts each (many silicon rectifiers will measure about .7 or .8, as shown). A vertical line indicates no current (an open diode).

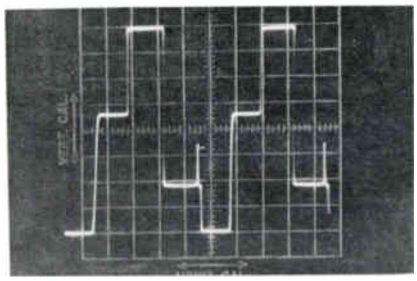


Fig. 35 Base-to-emitter voltage (without a transistor) in the Eico 443 curve tracer shows zero and three steps of base voltage.

How The Eico 443 Works

The voltage applied between base and emitter during beta tests is shown in Fig. 35. There are zero and three different steps of voltage, but they are not in sequence. This accounts for the faint lines across the ends of the curves.

Conclusion

A 2N410 PNP transistor was measured for beta by both curve tracers and a good commercial meter-type beta tester. The meter measured a beta of 42 at 10 milliamps and 38 at 1 milliamp. The Eico 443 indicated a beta of 60, and the Jud Williams tracer showed a beta reading of 40. Since all three instruments applied different voltages to the transistor under test conditions, we believe the degree of difference is satisfactory. After all, the DC beta of a transistor varies according to the conditions under which the transistor is operated, and an **exact** beta is not essential in service work. ▲

Chapter 11

Transistor substitution—important characteristics

Type To Be Replaced	RCA Replacement Type	Type To Be Replaced	RCA Replacement Type	Type To Be Replaced	RCA Replacement Type	Type To Be Replaced	RCA Replacement Type
2N564	SK3004	2N639	SK3009	2N990	SK3006	2N1130	SK3004
2N565	SK3004	2N639A	SK3009	2N991	SK3006	2N1136	SK3009
2N566	SK3004	2N639B	SK3009	2N992	SK3006	2N1136A	SK3009
2N567	SK3004	2N640	SK3008	2N993	SK3005	2N1136B	SK3009
2N568	SK3004	2N641	SK3008	2N994	SK3008	2N1137	SK3009
2N569	SK3003	2N642	SK3007	2N1000	SK3011	2N1137A	SK3009
2N570	SK3003	2N643	SK3007	2N1007	SK3009	2N1137B	SK3009
2N571	SK3003	2N644	SK3007	2N1009	SK3003	2N1138	SK3009
2N572	SK3003	2N645	SK3007	2N1010	SK3011	2N1138A	SK3009
2N573	SK3004	2N647	SK3010	2N1011	SK3009	2N1138B	SK3009
2N574	SK3004	2N648	SK3010	2N1012	SK3011	2N1144	SK3003
2N574A	SK3004	2N649	SK3010	2N1014	SK3009	2N1145	SK3003
2N576	SK3011	2N650	SK3004	2N1017	SK3011	2N1146	SK3009
2N576A	SK3011	2N650A	SK3004	2N1018	SK3011	2N1146A	SK3009
2N578	SK3005	2N651	SK3004	2N1020	SK3009	2N1146B	SK3009
2N579	SK3005	2N651A	SK3004	2N1021A	SK3009	2N1146C	SK3009
2N580	SK3005	2N652	SK3004	2N1022	SK3009	2N1147	SK3009
2N581	SK3005	2N652A	SK3004	2N1022A	SK3009	2N1147A	SK3009
2N582	SK3003	2N653	SK3004	2N1023	SK3006	2N1147B	SK3009
2N583	SK3005	2N654	SK3004	2N1029	SK3009	2N1147C	SK3009
2N584	SK3003	2N655	SK3004	2N1029A	SK3009	2N1149	SK3020
2N585	SK3011	2N657	SK3005	2N1029B	SK3009	2N1150	SK3020
2N586	SK3005	2N659	SK3005	2N1029C	SK3009	2N1151	SK3020
2N587	SK3011	2N660	SK3005	2N1030	SK3009	2N1152	SK3020
2N588	SK3006	2N661	SK3005	2N1030A	SK3009	2N1153	SK3020
2N588A	SK3006	2N662	SK3005	2N1030B	SK3009	2N1157	SK3012
2N589	SK3009	2N663	SK3009	2N1030C	SK3009	2N1157A	SK3012
2N591	SK3004	2N665	SK3009	2N1031	SK3009	2N1159	SK3009
2N592	SK3005	2N669	SK3009	2N1031A	SK3009	2N1160	SK3009
2N593	SK3005	2N677	SK3009	2N1031B	SK3009	2N1162	SK3009
2N594	SK3011	2N677A	SK3009	2N1031C	SK3009	2N1162A	SK3009
2N595	SK3011	2N677B	SK3009	2N1032	SK3009	2N1163	SK3009
2N596	SK3011	2N677C	SK3009	2N1032A	SK3009	2N1163A	SK3009
2N597	SK3005	2N678	SK3009	2N1032B	SK3009	2N1164	SK3009
2N598	SK3005	2N678A	SK3009	2N1032C	SK3009	2N1164A	SK3009

UNIVERSAL REPLACEMENT TRANSISTORS

JEOEC TYPE OR PART NO.	GE REPLACEMENT	JEOEC TYPE OR PART NO.	GE REPLACEMENT	JEOEC TYPE OR PART NO.	GE REPLACEMENT	JEOEC TYPE OR PART NO.	GE REPLACEMENT
2N2187	GE-21	2N2354	GE-8	2N2672	GE-9	2N3083	GE-17
2N2188	GE-9	2N2357	GE-3	2N2673	GE-17	2N3115	GE-17
2N2189	GE-9	2N2358	GE-3	2N2674	GE-17	2N3116	GE-17
2N2190	GE-9	2N2360	GE-9	2N2675	GE-17	2N3128	GE-17
2N2191	GE-9	2N2361	GE-9	2N2695	GE-21	2N3129	GE-17
2N2192	GE-17	2N2362	GE-9	2N2696	GE-21	2N3132	GE-16
2N2192A	GE-17	2N2363	GE-9	2N2706	GE-1	2N3133	GE-21
2N2193	GE-17	2N2370	GE-21	2N2708	GE-17	2N3134	GE-21
2N2193A	GE-17	2N2371	GE-21	2N2711	GE-17	2N3135	GE-21
2N2193B	GE-17	2N2372	GE-21	2N2712	GE-20	2N3136	GE-21
2N2194	GE-20	2N2373	GE-21	2N2713	GE-20	2N3137	GE-21
2N2194A	GE-20	2N2375	GE-1	2N2714	GE-17	2N3148	GE-25
2N2194B	GE-20	2N2377	GE-21	2N2715	GE-17	2N3209	GE-21
2N2195	GE-17	2N2378	GE-21	2N2716	GE-20	2N3213	GE-16
2N2195A	GE-17	2N2387	GE-20	2N2717	GE-9	2N3214	GE-16
2N2196	GE-17	2N2388	GE-20	2N2728	GE-4	2N3215	GE-16
2N2197	GE-17	2N2389	GE-20	2N2729	GE-17	2N3217	GE-21
2N2198	GE-20	2N2390	GE-20	2N2730	GE-4	2N3218	GE-21
2N2199	GE-9	2N2393	GE-21	2N2731	GE-4	2N3219	GE-21
2N2204	GE-12	2N2394	GE-21	2N2732	GE-4	2N3226	GE-19
2N2205	GE-20	2N2395	GE-21	2N2784	GE-17	2N3232	GE-14
2N2206	GE-17	2N2396	GE-20	2N2793	GE-4	2N3235	GE-14
2N2207	GE-9	2N2397	GE-20	2N2801	GE-21	2N3241	GE-20
2N2209	GE-9	2N2398	GE-9	2N2802	GE-21	2N3241A	GE-20
2N2210	GE-4	2N2399	GE-9	2N2803	GE-21	2N3242	GE-20
2N2212	GE-3	2N2400	GE-1	2N2804	GE-21	2N3245	GE-21
2N2225	GE-1	2N2401	GE-1	2N2805	GE-21	2N3250	GE-21
2N2234	GE-20	2N2402	GE-9	2N2806	GE-21	2N3251	GE-21
2N2235	GE-20	2N2411	GE-21	2N2807	GE-21	2N3267	GE-20
2N2236	GE-20	2N2412	GE-21	2N2831	GE-17	2N3289	GE-17
2N2237	GE-20	2N2413	GE-17	2N2836	GE-3	2N3290	GE-17
2N2240	GE-20	2N2423	GE-16	2N2837	GE-21	2N3291	GE-17
2N2241	GE-20	2N2424	GE-21	2N2838	GE-21	2N3292	GE-17
2N2242	GE-17	2N2425	GE-21	2N2857	GE-17	2N3293	GE-17
2N2244	GE-17	2N2427	GE-21	2N2861	GE-21	2N3294	GE-17
2N2245	GE-17	2N2428	GE-2	2N2863	GE-21	2N3297	GE-19
2N2246	GE-17	2N2429	GE-2	2N2865	GE-17	2N3304	GE-21
2N2247	GE-17	2N2430	GE-8	2N2869	GE-3	2N3305	GE-21
2N2248	GE-17	2N2431	GE-2	2N2869/2N301	GE-3	2N3306	GE-21
2N2249	GE-17	2N2447	GE-2	2N2870/2N301A	GE-3	2N3307	GE-21

Fig. 1 Shown here are portions of two cross-reference charts published by manufacturers (RCA and GE).

The number of transistor types now in use makes it virtually impossible to stock all the original type numbers. Even stocking a portion of them ties up considerable capital in transistors that might or might not be needed.

Not too long ago, when germaniums were the only kind of transistors used, several manufacturers marketed eight to ten replacement units that would fill 90 percent of the replacement needs. Today, with silicons added to the replacement lists, 30 general replacement types are needed to fill the majority of requirements. Whether you use the suggested replacements cross-referenced by several manufacturers, or whether you categorize your own replacement types, the information in this article should make selection of transistor replacements less of a guessing game.

PNP or NPN

How can you be sure you are selecting the right replacement? The simple and most practical way is to check manufacturers' cross-reference charts, like the ones shown in Fig. 1. Find the original transistor type number and then check for the replacement recommended.

If the replacement guide is not available, or if you cannot tell what the original part number was, then you will need to find out as much as you can about the characteristics of the original. First, is it an NPN or PNP? If you have the schematic, you can determine this by the direction of the emitter arrow; as shown in Fig. 2, if the arrow is pointing "out", it is an NPN, and if pointing "in", a PNP. (Some technicians remember this by using this little saying: PNP for "Pointing 'N Proper" and NPN for "Not Pointing 'N".)

A second method of checking the type (it's possible for the draftsman to draw the arrow wrong, or you might not have a schematic) is to determine the polarity of the collector-to-emitter voltage. If the collector is negative relative to the emitter (not necessarily to ground), the transistor is a PNP. If the collector is positive to the emitter, the transistor is an NPN (Fig. 3). You can remember which polarity is which by recalling that the **middle** letter of the type designation indicates the collector to emitter polarity—negative for PNP and positive for NPN.

Is It Germanium or Silicon?

If the type number is lost, or you have no cross-reference information, the best way to determine whether a transistor is a silicon or germanium is by the amount of base-to-emitter bias. The bias for a germanium type will be 0.2 volt or less, while the silicon will have a bias of 0.4 volt or more. (This will not hold true always, because certain circuits, such as sync clippers or oscillators, can have little or no DC bias, or they might even have reverse bias when operating normally.)

The above information should be obtained from the schematic (as in Fig. 4), because you won't be able to take an accurate bias reading if the transistor is defective. Usually, though, you can expect all transistors in a particular design to be either germanium or silicon, especially if they are in the same type case. In this event, you can measure the bias on other transistors to determine how much bias to expect on the defective one. But even here there are pitfalls, because in a DC-coupled circuit, the bias on all transistors will be changed when one transistor fails.

Another way to determine whether the transistor is germanium or silicon is the design of the circuit itself. (Again, this is not absolute, but at least it is a good clue.) For example, which one of the circuits in Fig. 5 almost surely uses a silicon transistor? The answer is B, because there is no emitter resistor. Only a silicon, with its excellent stability, can be operated safely without a protective emitter resistor. Also note that there is only one base bias resistor. This, too, is permissible in silicon transistor circuits, because of the low internal leakage of silicons, and because they have minimal change in leakage within a reasonable change in ambient temperature.

The circuit in Fig. 5A **could** be using a silicon transistor, but is more apt to be using a germanium. Some designers continue to use the conservative design of the germanium circuit for silicons, but these are gradually disappearing.

Selecting a Replacement

There are several manufacturers who cater to the replacement transistor market, and it seems foolhardy not to take advantage of their experience by buying the transistors which they have selected as ideal replacements, and by using their cross-reference charts.

You will find, once in a while, that a designated replacement will not take the place of the original in some particular circuit. It is almost impossible for a manufacturer to design a complete line of transistors that will replace every transistor in any type circuit with perfect results in all cases. You must recognize that there are a few exceptions to each of the rules that apply to replacements.

The main rules that you should always obey are:

- the replacement transistor you select should be of the same general type as the original
- it should be designed to operate in the same general kind of circuit
- the collector-to-emitter voltage rating should be high enough.

For example, you should not try to replace a germanium with a silicon, nor the other way round, nor should you try to replace an NPN with a PNP. You should not replace an FM RF amplifier with an AM Mixer type, nor an IF amplifier with an AF type. (Though, in the latter case, it often is permissible to substitute in the opposite direction; that is, replace a transistor of a "lower" type with one of a "higher" type. For example, an audio amplifier transistor can be replaced with an IF amplifier type, or a low-frequency transistor can be replaced with one meant for higher frequencies.)

What About Gain?

So many factors enter into the

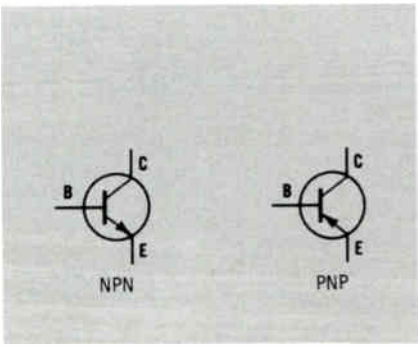


Fig. 2 The direction of the emitter arrow indicates whether the transistor is an NPN or PNP. Other checks will verify this, as pointed out in the text.

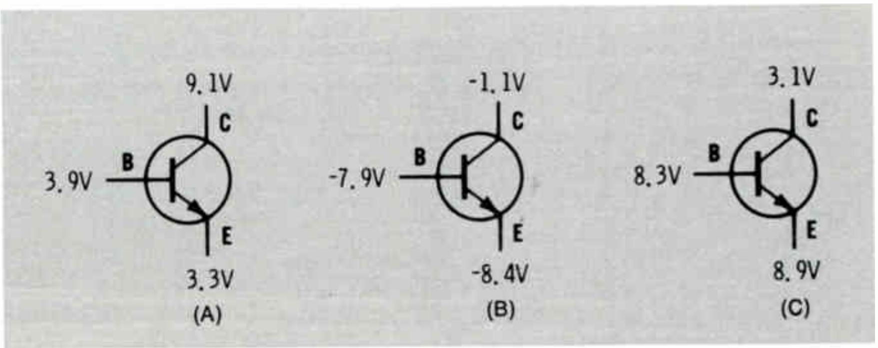


Fig. 3 Which of the above transistor symbols is incorrect, assuming that the voltage readings are correct? The answer is C. Note that the collector is actually more negative than the emitter; this wound indicate that the transistor symbol should be a PNP, with the arrow pointing in.

calculation of stage gain that the actual DC gain, as read on a tester, can be meaningless. The voltage gain is important in a voltage amplifier, yet that same transistor is not a good choice for a transformer-coupled audio driver, in which current, or power, gain is desired.

The beta (gain) of different RF amplifier transistors might vary considerably, but in some cases the one with the lower beta might actually function a little better in-circuit. For this reason, replacement transistor gain is usually not considered critical. Current gains will range around 70, but might drop to as low as 40 or so for power amplifiers, or up to 140 or 150 for some mixers, RF and IF amplifiers, especially silicon types.

The gain of a particular transistor seldom will change during its lifetime; consequently, as long as a transistor has gain, it usually can be assumed that the indicated gain is normal. This is particularly true of silicon transistors, which seldom develop troublesome leakage. Germanium transistors sometimes develop an apparent change in gain due to a change in leakage resistance.

What About Leakage?

The maximum permissible leakage in a transistor circuit depends a great deal on the impedance of the input circuit. For example, if the DC resistance of the input circuit is 5K ohms or less, more transistor leakage can be tolerated than if the DC resistance is one megohm.

Germanium transistors, even of the same type number, have different amounts of leakage, which always increases as the temperature increases. On the other hand, silicon transistors normally have almost no leakage, and remain stable over a wide temperature range. As a matter of fact, silicons seldom have, or develop, any significant leakage, unless they go **completely** bad, in which case they become shorted, or nearly so.

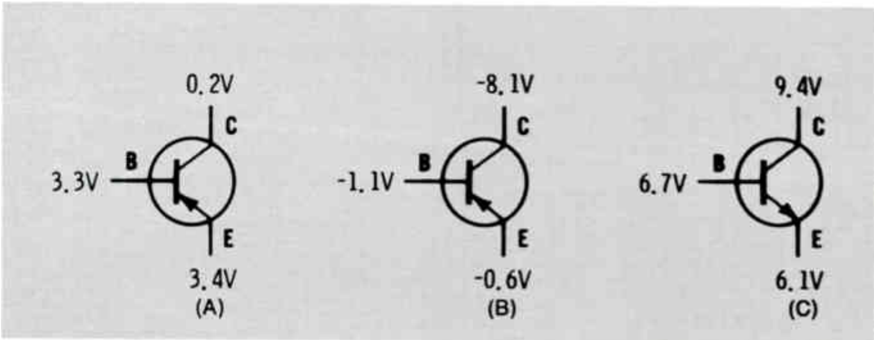


Fig. 4 Which of the above transistors are silicons? The Answer: B and C., because both have more than 0.4 volt base-to-emitter bias.

Other Considerations

Four-lead transistors often are found in older high-frequency equipment, such as FM tuners or radios. The fourth lead usually is connected from the metal case of the transistor to common, or ground, in the circuit. In most instances, a four-lead transistor can be replaced with a three-lead one, as long as it is the same general type. Connect the replacement leads to the emitter, base and collector terminals, and disregard the fourth wire connection.

Today, most new solid-state circuits use silicon transistors, and you can expect good uniformity and, thus, interchangeability among units

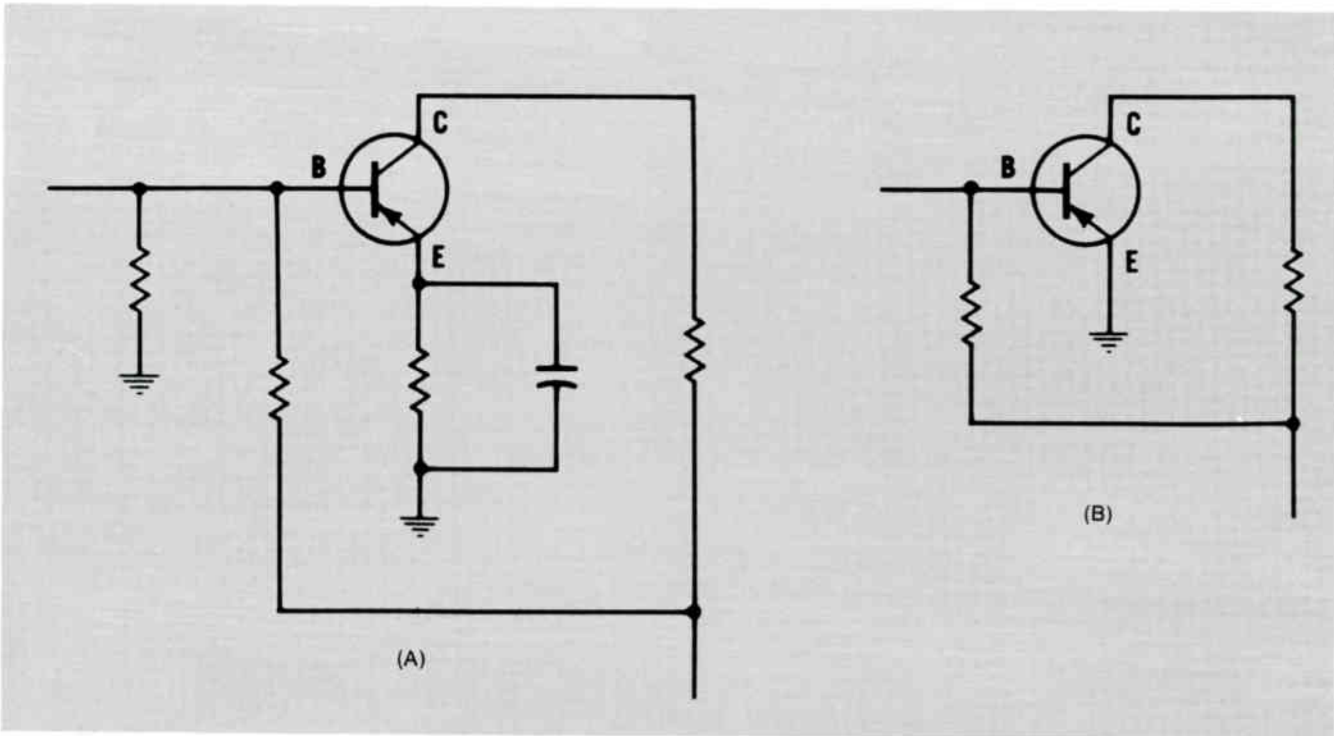


Fig. 5 Which of these circuits most likely uses a silicon transistor? The answer is B. See text for complete explanation.

of the same general type; for example, an NPN FM amplifier used as the replacement in one make of radio would replace, in just about every case, an NPN FM amplifier in another make radio. Consequently, if you have some exact replacements in stock, you can use them in the same stages in other makes of equipment, to help relieve stocking problems.

Take special care when replacing transistors in DC-coupled, or "stacked", circuits, such as those used in the audio amplifier stages of auto radios. Tack in the replacement temporarily, and take collector-to-emitter voltage reading of each stage to see if they correspond closely to the original readings. If they do, and the gain and fidelity is good, the replacement then can be installed permanently.

Be sure that the voltage rating (Vceo) of a replacement transistor is at least a little above the supply voltage used for that particular stage. Be particularly careful about transient voltages, such as can occur when connecting or disconnecting a transistor while the power is turned on. Transients are one of the biggest causes of transistor failure.

Don't overload a transistor—even a temporary short can permanently damage it. Keep the current below the rated limits, or the transistor might be ruined instantly.

When installing transistors on a heat sink, be sure to install properly the necessary mica- or oxide-coated washers, and insulators. Also, always add a thin coating of a special oxide-filled silicone compound between the transistor case, the insulator and the heat sink on the chassis to improve the transfer of heat from the transistor to the heat sink. The correct type of silicon compound is available at nearly all electronic parts distributors.

Compare the lead arrangement of the replacement with the original transistor—it could be different. If it is, bend the lead wires on the requirement so that they will correctly fit the holes in the printed board without touching the other leads.

You should always recheck the alignment of any RF circuit in which you install a new transistor, even with an "exact" replacement transistor. Usually, if the replacement is suitable, you will not need to make any drastic change, but a check and touch-up is recommended to insure peak performance.

If you are not sure about a particular replacement, it's a good plan to "tack" it in before making the installation permanent. It usually is easier to tack in the replacement on the print side of the board, but be sure you have removed the original transistor. If the circuit functions as required after a check-out, install the transistor permanently on the component side of the board.

To prevent callbacks, always allow a circuit to perform normally for at least 30 minutes before returning it to the customer.

Soldering Precautions

When soldering leads on a replacement, it's always a good idea not to apply heat for any longer than absolutely necessary, especially if the leads are short. This is because the short leads will conduct the heat into the transistor itself, and possibly damage it. If possible, you should grasp the transistor leads with a pair of long nose pliers, which will act as a heat sink to reduce the amount of heat reaching the transistor. Unfortunately, it often is impossible to use any type of heat sink because of the crowded location of the transistor. The following tips can prevent possible trouble in any case:

- Don't let the soldering iron touch the transistor leads for more than 8 to 10 seconds, especially if the leads are a half-inch or shorter.
- Leave the leads as long as feasible when soldering in the replacement. However, pay particular attention to correct lead length in UHF circuitry.
- Use a small soldering iron with a small tip.
- If possible, grip the transistor lead with a pair of long-nose pliers between the body of the transistor and the point being soldered. ▲

Chapter 12

Servicing solid-state TV

Almost every technician is now, or soon will be, confronted with the problems of solid-state TV servicing. Troubleshooting transistor-TV circuitry involves some new approaches, compared with localizing and repairing tube-type TV circuit defects. The chief reasons for these differences are as follows:

1. DC operating voltages are usually much lower in transistor circuits, than their tube-type counterparts. On the other hand, DC currents may be considerably greater.
2. AC pulse voltages in sweep circuits are generally very low in transistor circuits, compared with tube-type sweep circuits. However, the AC pulse currents are often very large, by comparison.
3. The base of a transistor draws DC current continuously, except in a few specialized cases. By way of contrast, the control grid of a tube seldom draws DC current, except in a few specialized cases. These facts are implied by the statement that a transistor usually has a very low input impedance, whereas a tube usually has a very high input impedance.
4. Because of nonlinear junction characteristics, resistance

measurements are not nearly as useful in analyzing transistor-circuit defects as they are in localizing tube-circuit defects.

5. Transistors are commonly tested in-circuit because they are rarely plugged into sockets, as are tubes.
6. There is considerably more danger of damage to transistors than to tubes in case of accidental short-circuits. The same observation applies to surges resulting from quick-tests, such as bridging a suspected electrolytic capacitor by a new capacitor.
7. Test-equipment requirements are different in some cases; for example, a DC voltmeter should have a first range of 1 volt full scale, or less. A capacitor tester must not apply excessive test voltage to electrolytic capacitors. Generators must have blocking capacitors in their output leads.

Comparison of DC Voltage Values

The DC voltage values in transistor RF tuners are very different from those in tube-type tuners. Figs. 1 and 2 show the electrode voltages for a 6FH5 tube in an RF tuner, compared with the electrode voltages for a 2SA290 transistor. Note that the plate voltage of the tube is about 80 times as high as the collector voltage of the transistor.

Next, compare the DC voltages at the electrodes of the tube and transistor in the IF stages in Fig. 3. The plate of the 6BZ6 operates at about 8 times the voltage applied to the collector of the 2SA70. Also, the cathode of the tube operates at about ⅓ of the voltage applied to the emitter of the transistor.

Observe the comparative voltage values shown in Fig. 4. The emitter-follower stage in Fig. 4B operates with a collector voltage of 10.2 volts, compared with a plate voltage of 115 volts for the video-amplifier tube in Fig. 4A. The difference in operating voltages is less in the transistor video-output stage; that is, the collector operates at 90 volts, which is relatively close to the 115 volts on the plate of a video-output tube.

Also note that the picture tubes used in transistor TV receivers generally operate at lower electrode voltages, except that the second-anode voltage is necessarily the same for a given screen size.

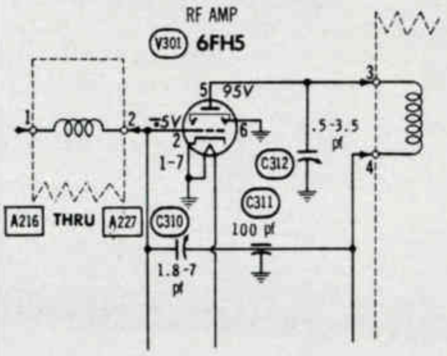


Fig. 1 Electrode voltages in typical tube-television RF amplifier stage.

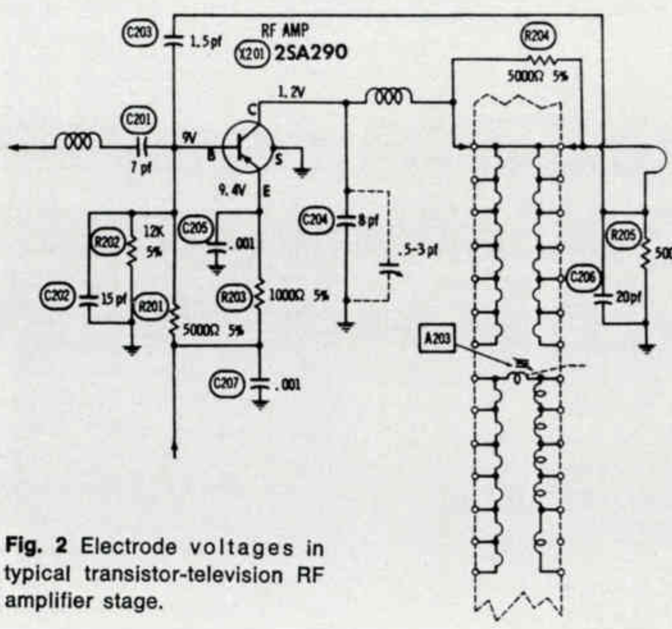
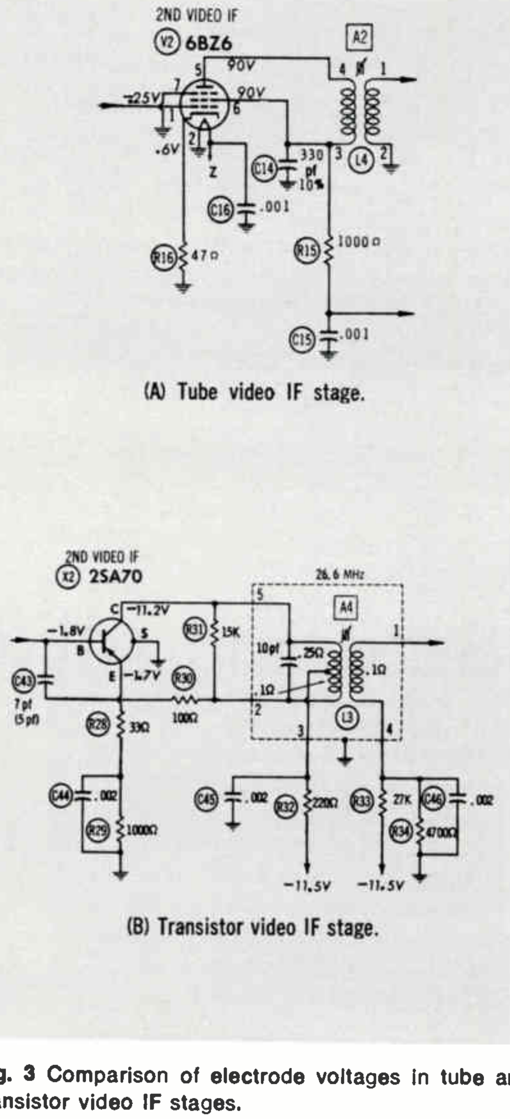


Fig. 2 Electrode voltages in typical transistor-television RF amplifier stage.



(A) Tube video IF stage.

(B) Transistor video IF stage.

Fig. 3 Comparison of electrode voltages in tube and transistor video IF stages.

It can be seen in Fig. 5 that the DC voltages for a transistor keyed-AGC stage are quite different from the voltages in its tube counterpart. Similar differences could be cited for AGC amplifier circuits, horizontal and vertical sync sections, horizontal and vertical oscillator stages, horizontal and vertical sweep systems, and intercarrier sound and audio configurations.

To summarize briefly, comparatively low DC voltage values throughout transistor-TV receiver systems is the main concern. Also, in some cases a low-range DC voltmeter must be used; for example, the normal base-emitter voltage in Fig. 3B is 0.1 volt.

Comparison of DC Current Values

As might be expected, a transistor circuit may draw more DC current than a comparable tube circuit. Power is equal to voltage multiplied by current, and if the operating voltage is low, then the operating current must be high in order to produce a given amount of power.

In Fig. 6A, a 6DQ6B tube is used to scan a larger raster, and the cathode current is approximately 130 ma. On the other hand, a transistor is used in Fig. 6B to scan a small raster, but the emitter current is approximately 240 ma.

Another striking example is found in a comparison of transistor and tube-type vertical-output arrangements: The transistor draws 1 ampere of emitter current, whereas a tube in a comparable configuration draws 47 milliamps of cathode current.

Comparison of AC Pulse Voltages

Considering the foregoing examples, it is not surprising to find that AC pulse voltages in transistor stages are usually much smaller than those in their tube counterparts. For example, in Fig. 6B, the transistor driving pulse has a normal amplitude of 6 volts p-p, whereas the tube driving waveform in Fig. 6A has an amplitude of 115 volts p-p.

Even a greater disparity is found in pulse voltages for keyed-AGC circuits. For example, a transistor is typically keyed by an 8.5-volt p-p pulse, whereas a tube uses a typical keying voltage of 440 volts p-p.

In other cases, AC pulse voltages are about the same in both transistor and tube configurations. For example, the sync-pulse volt-

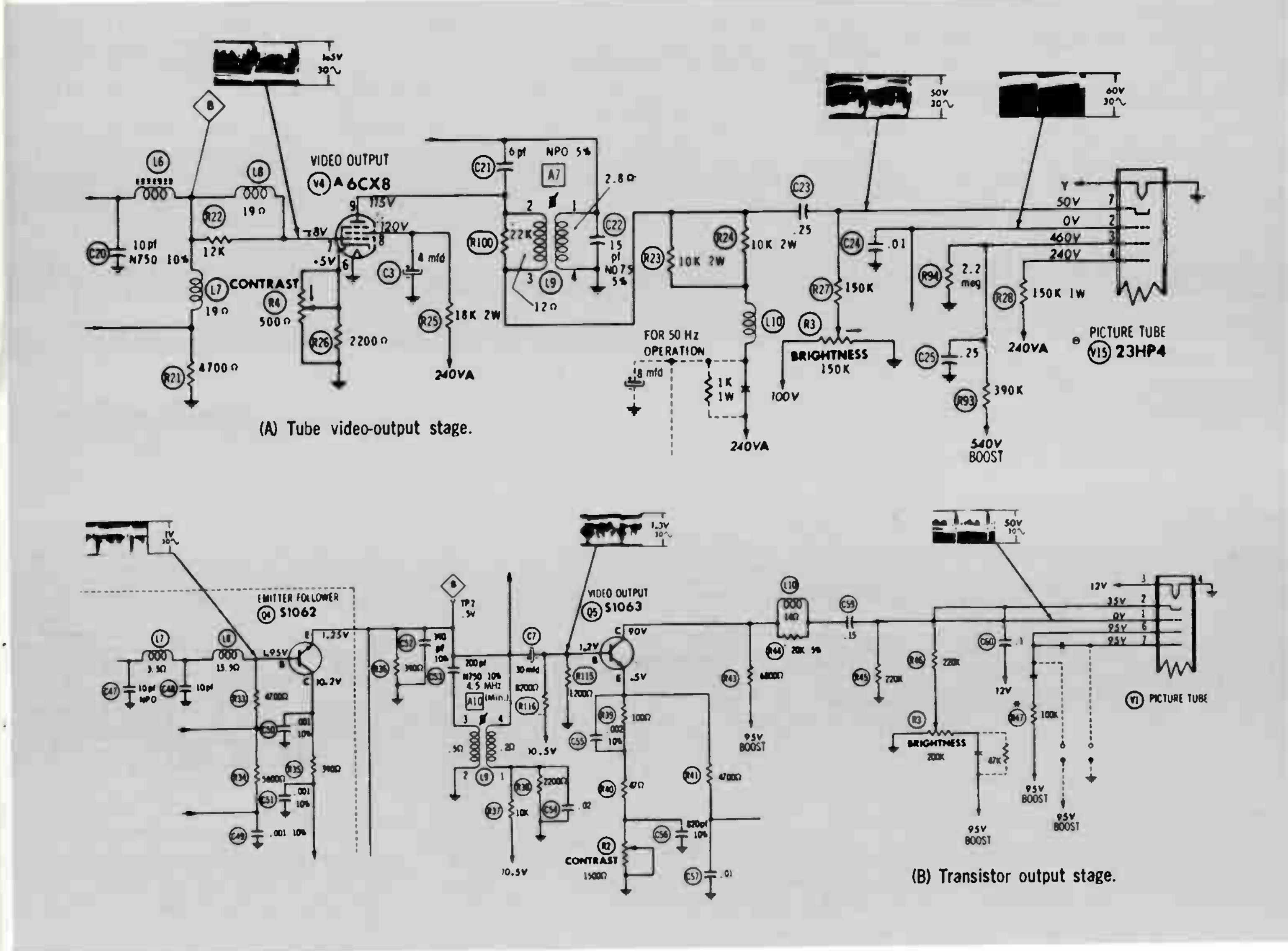


Fig. 4 Comparison of electrode voltages in tube and transistor video-output stages.

ages are approximately the same in Fig. 4. On the other hand, do not suppose that these two video-amplifier circuits operate in the same way. The operating differences can be summarized as follows:

1. Although the control grid of the tube draws practically no pulse current, the base of the transistor draws substantial pulse current.
2. Since impedance is equal to the ratio of AC voltage to AC current, it is evident that the input impedance of the transistor is much lower than the input impedance of the tube.
3. The low input impedance of Q5 in Fig. 4B requires the use of a driver stage that can supply appreciable signal current. Therefore, Q4 is employed as an emitter-follower (analogous to a cathode follower).
4. In most cases, the output impedance of a transistor is lower than the output impedance of a tube. This is due to the low ratio of collector AC voltage to collector AC current, and also to the comparatively high value of collector junction capacitance.
5. Because transistor junctions have appreciable capacitance, peaking-coil inductances are much smaller in transistor video amplifiers than in comparable tube-type circuits.

Resistance Measurement Difficulties

A tube does not draw current unless sufficient current flows through its heater. On the other hand, a transistor has no heater, and the transistor will draw current whenever a forward voltage is applied across a junction. Because of this characteristic, and because an ohmmeter applies voltage to the circuit or device under test, trouble analysis by resistance measurements in transistor circuits is not often practical.

A transistor junction is nonlinear, as depicted in Fig. 7. Because of this, an ohmmeter reading of junction resistance is very unpredictable—we usually do not know exactly how much voltage is being applied by the ohmmeter, nor the exact amount of current that will be drawn.

Troubleshooting would be simpli-

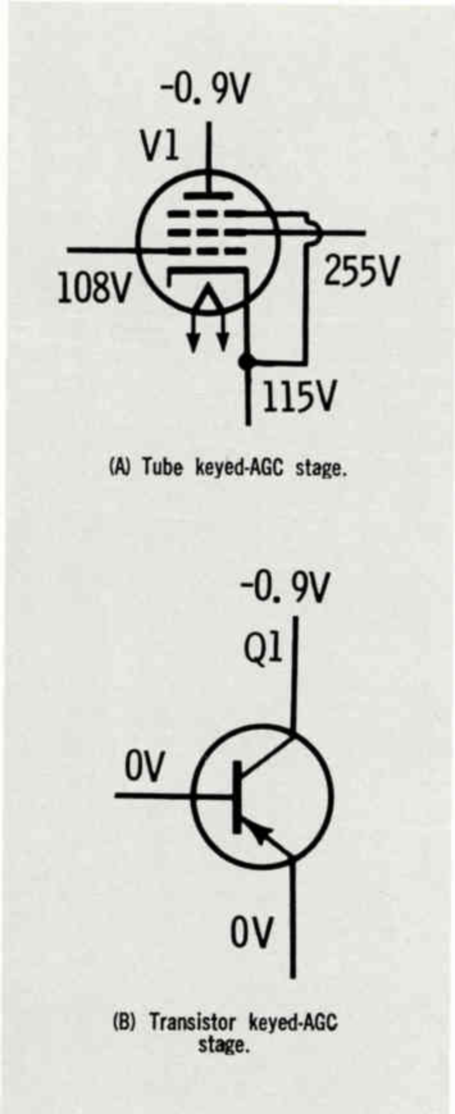


Fig. 5 Comparison of electrode voltages in tube and transistor keyed-AGC stages.

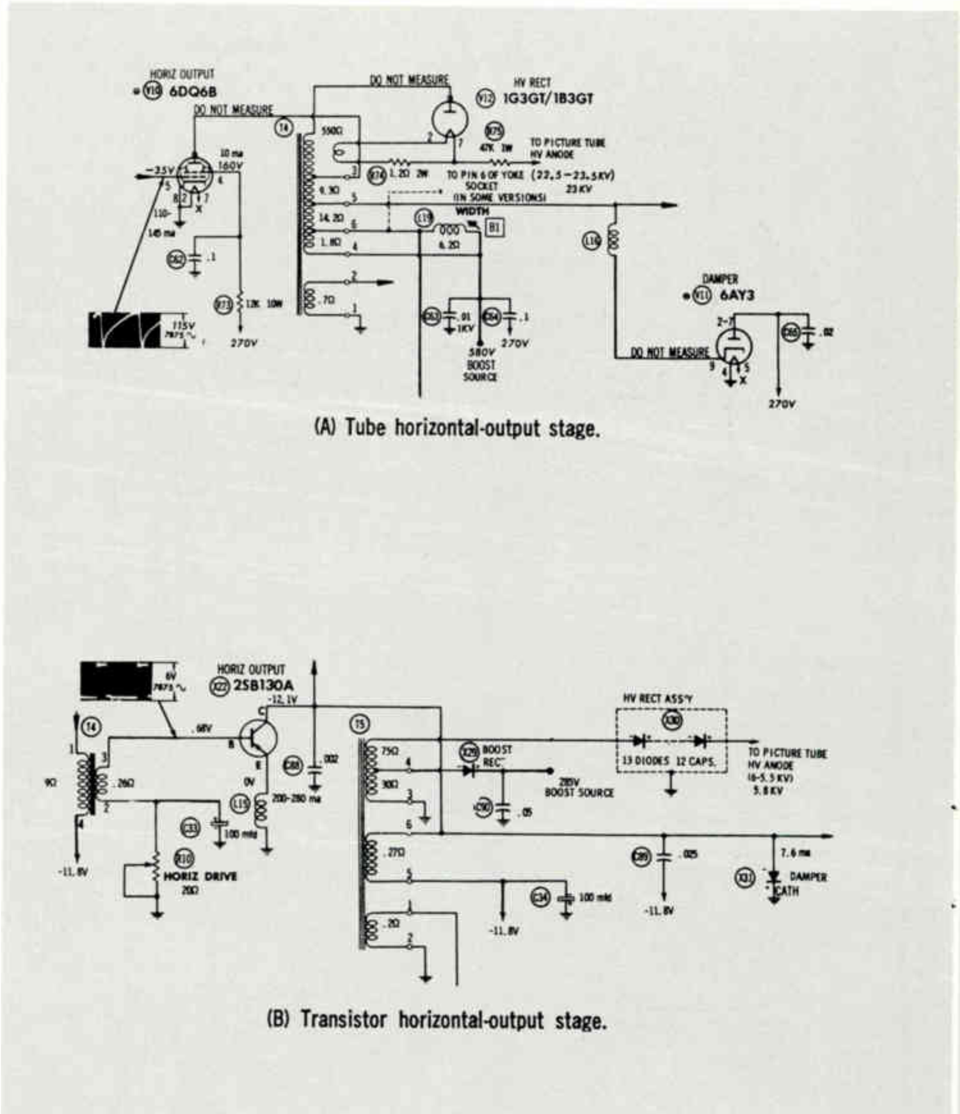


Fig. 6 Transistor draws more current than tube in these horizontal-output stages.

fied if transistors could be unplugged from sockets, as tubes are unplugged. However with few exceptions, it is customary to solder transistors into their circuits, with the result that appropriate test procedures must be employed by the technician to contend with nonlinear junction resistances.

Suitable test methods include:
1. DC voltage measurements,
2. Control-action tests,
3. Signal-tracing procedures,
4. Signal-injection procedures.

DC Voltage Measurements

After picture and sound analysis have localized the cause of a trouble symptom to a particular section of the receiver, DC voltage measurements are the most useful guide in analysis of circuit action and in the pinpointing of defective components.

For example, suppose that sound reproduction is normal, but picture reproduction is poor, with low contrast and a normal raster. With reference to Fig. 4B, these symptoms throw suspicion on the video-output stage. If the emitter, base, and collector DC voltages of Q5 do not measure close to 0.5, 1.2, and 90 volts, respectively, the trouble probably would be found in this stage. The receiver service data or Sams PHOTOFACT is the best guide in this respect.

Incorrect voltages at the transistor electrodes do not necessarily mean that the transistor is defective; it is also possible that a capacitor is leaky or shorted. Although resistors do not change their values often, this also can happen. Therefore, we must evaluate the abnormal DC voltage distribution in an attempt to narrow the number of suspects. Since seemingly logical conclusions are not always absolute, check your reasoning by testing individual components, such as capacitors. In most cases, one end of a capacitor must be disconnected for accurate testing.

DC Voltage Distribution

It is helpful to understand the basic principles of DC voltage distribution in transistor circuits.

For example, Fig. 8 shows an NPN transistor in a typical IF stage configuration. For a better understanding of DC voltage distribution, consider the simplified circuit shown in Fig. 8B. Tabulate the DC voltage distribution in this example:

Emitter-Ground ...	—4.5 volts
Base-Ground	—4.3 volts
Collector-Ground ..	0 volts
Emitter-Base	—0.2 volt
Collector-Base	—4.3 volts

One of the most common transistor defects is leakage from collector to base (leakage through the collector junction). In the first analysis, this leakage affects the DC voltage distribution as if a resistor were connected between collector and base, as shown in Fig. 8C. The junction leakage resistance draws current from the voltage divider that biases the base of the transistor, and the base voltage decreases. This decrease of base-voltage also affects the emitter voltage in the following manner:

1. A decrease in base voltage increases the emitter-base bias voltage;
2. An increase in emitter-base bias voltage causes the collector current to increase;
3. Since the increased collector current flows through the emitter resistor, the voltage drop across the emitter resistor increases;
4. An increased voltage drop across the emitter resistor causes the emitter voltage to decrease.

In the example of Fig. 8C, the 100K leakage resistance between collector and base causes both the emitter voltage and the base voltage to decrease by 0.15 volt. Therefore, the emitter-base bias voltage remains unchanged, although the transistor is drawing more current. If the leakage current becomes excessive, the collector junction will overheat. The transistor then becomes open or shorted, and the stage is dead. Moderate amounts of junction leakage generally cause gain reduction in a stage.

Open and Shorted Collector Junctions

Consider the effects on the DC voltage distribution in Fig. 8B if the collector junction becomes short-circuited. The base voltage will be zero. Since the emitter-base

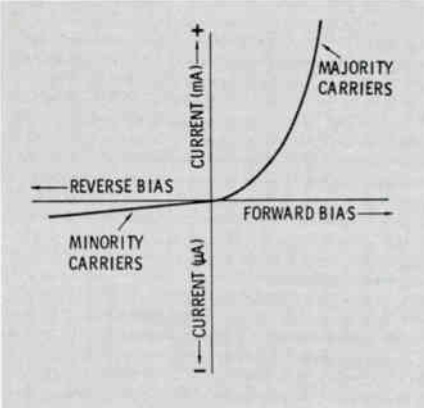
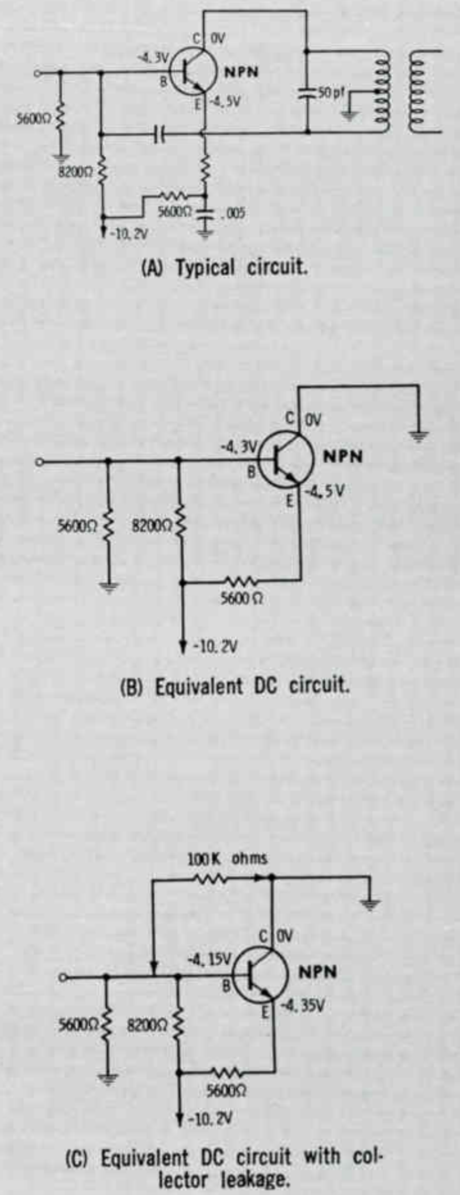


Fig. 7 Plot of current through and voltage across a PN junction.



(A) Typical circuit.

(B) Equivalent DC circuit.

(C) Equivalent DC circuit with collector leakage.

Fig. 8 Transistor IF circuit.

junction has a very low forward resistance, the emitter current is nearly equal to the supply voltage divided by the emitter resistance, or 1.8 ma (in accordance with Ohm's law). The emitter-base bias voltage will rise somewhat above its normal value of 0.2 volt, but the emitter-base junction will not be damaged.

Next, let us suppose that the collector-base junction in Fig. 8B opens up. In this case, the collector current will not load the bias circuit, and the emitter voltage will rise to —6.5 volts. Accordingly, the emitter-base bias will remain normal, and the emitter-base junction will not be damaged.

To summarize briefly, collector leakage or open or shorted collector junctions cause abnormal DC voltage on other electrodes of the transistor. A collector-junction defect causes the emitter and base voltages to be either too high or too low.

Control-Action Test

Control-action tests, also called "turn-on" and "turn-off" tests, are often practical, and are very informative when the normal operating voltages of a transistor are unknown. They also can be useful supplementary tests, even when normal operating voltages are known.

"Turn-off" Test

A cutoff, or "turn-off", test is performed simply by cutting off the base current and checking the voltage drop across the collector resistor, or from collector to ground. For example, to perform a cutoff test of the transistor in Fig. 9, apply a short-circuit between base and emitter. This makes the base and emitter assume the same potential. This normally cuts off the transistor, causing the collector voltage to rise to the supply voltage, or Ecc, as indicated by the voltmeter.

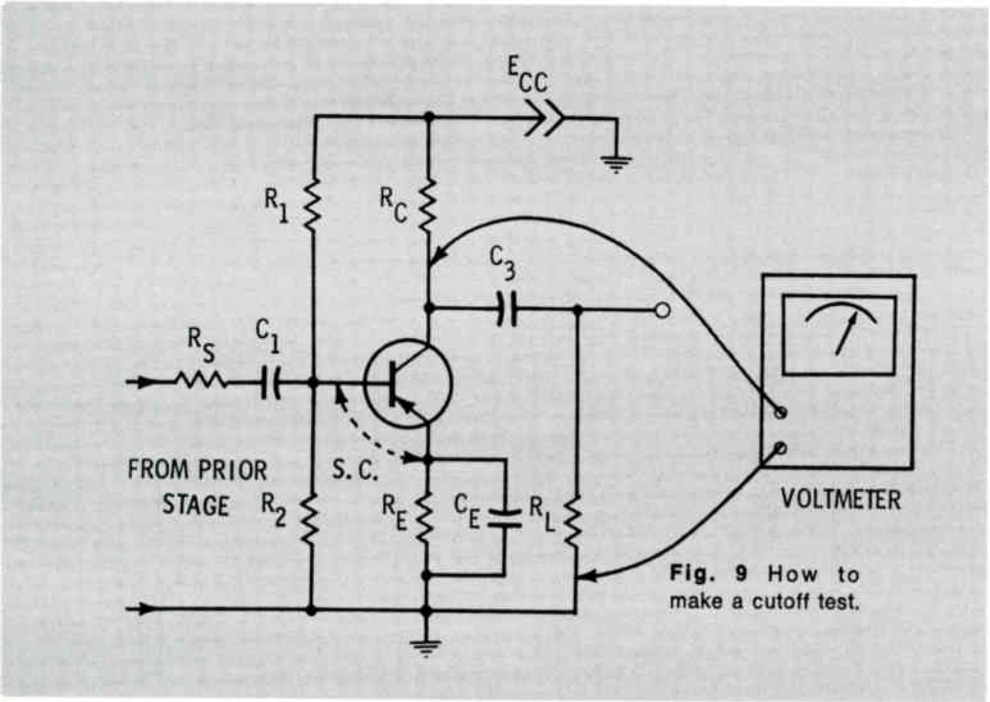


Fig. 9 How to make a cutoff test.

If the voltmeter does not indicate Ecc in the cutoff test, assume that the collector junction is leaky. Of course, C3 could be leaky, and this possibility must be checked before replacing the transistor.

Next, apply the same basic cutoff test to the configuration in Fig. 8A. However, since the circuit does not employ a collector-load resistor, as is obvious from the equivalent DC circuit shown in Fig. 8B, a slightly modified test procedure is employed.

Referring to Fig. 10, short-circuit the 8200-ohm resistor, and check the voltage across the 5600-ohm resistor. Since the collector current is normally cut off in this test, zero voltage normally would be measured across the 5600-ohm resistor. However, if collector-junction leakage is present, a small voltage drop across the 5600-ohm resistor would be measured. The reason for this is seen in the equivalent T circuit for a transistor as in Fig. 11.

If the collector junction leakage is essentially an open circuit (normal condition), no current will flow from the collector into the base-spreading resistance and the emitter-bulk resistance. However, if collector junction leakage is measurable, the current flows into the base and emitter branches, and 0.02 volt will be read, instead of zero volts in the test of Fig. 10.

Since it is occasionally necessary to read very small values of DC voltage, a voltmeter with a first range of 0.25 volt full scale will provide maximum utility for the technician.

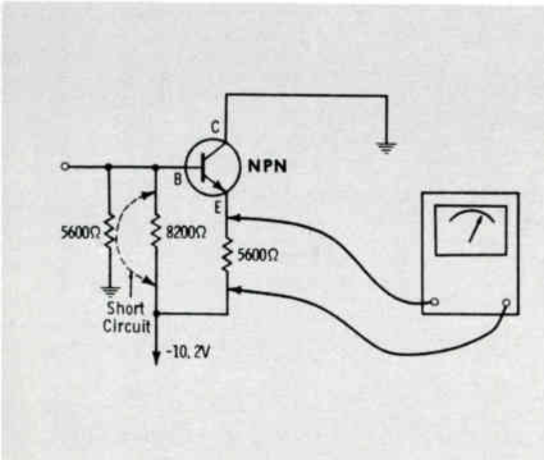


Fig. 10 Cutoff test setup.

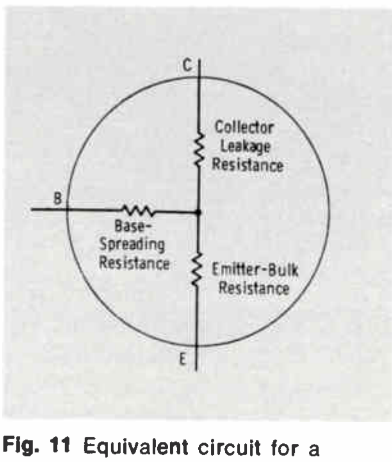


Fig. 11 Equivalent circuit for a transistor with collector-junction leakage.

"Turn-On" Test

A "turn-on" test is another type of control-action test. It is less informative than a cutoff (turn-off) test, because it does not provide an all-or-nothing indication. A turn-on test is a helpful supplement to other tests, as it can confirm prior conclusions.

To understand the turn-on test, refer to Fig. 8B. If a DC voltmeter is connected across the 5600-ohm resistor, the voltage drop, due to collector and base-current flow, will be measured. This is 5.7 volts. Next, if a 100K resistor is connected temporarily from collector to base, as shown in Fig. 8C, the collector will normally draw more current, and the drop across the 5600-ohm resistor will increase. This is an increase from 5.7 to 5.85 volts, or a difference of 0.15 volt.

Accidental Short-Circuits

Avoid random short-circuit tests, because transistors are easily damaged. For example, if a clip lead is used in the Fig. 8C test, the transistor would immediately be burned out. Again, if the high voltage is arced in the flyback circuit, it is very likely that the horizonal-output transistor will be ruined. Any short-circuit that causes excessive base-emitter current to flow will burn out the collector junction. Therefore, avoid surges, which are often caused by shunting a decoupling capacitor or a filter capacitor with a new electroyltic capacitor.

Test-Equipment Requirements

Generators used for signal-injection tests or alignment must have blocking capacitors in their output leads. This precaution avoids disturbance of base-emitter bias voltages because of DC drain-off.

Scopes used in signal-tracing tests should be provided with low-capacitance probes, to minimize circuit detuning.

Capacitor testers must not apply excessive test voltage to the low-rated capacitors employed in transistor circuitry.

In-circuit capacitor testers designed for transistor circuits have some degree of usefulness as well as in-circuit transistor testers, particularly when unusual configurations make control-action tests impractical or impossible.

Flyback checkers used in tube circuits cannot be employed in transistor circuits, because the component values and impedances are widely different. However, the same pattern generators and color-bar generators used to test tube-type receivers are used to test transistor receivers. Some modern tube testers also provide transistor-testing functions. However, if your tube tester is conventional, you will need to supplement an in-circuit transistor tester with an out-of-circuit tester. A high-voltage DC probe is an essential accessory for your VOM or VTVM.

Conclusion

We have reviewed the differences between the servicing procedures used for solid-state and tube-type TV receivers. These differences are reflected in some of our test-equipment requirements. Transistors cannot be easily replaced, and greater reliance must be placed on DC voltage measurements.

Control-action tests are very useful. Since transistors are more easily damaged than tubes, random short-circuits and high-voltage arcing are off-limits. Resistance measurements are less useful in transistor circuits than in tube circuits, due to non-linear junction resistances.

The transistor-TV technician needs to have a good working knowledge of Ohm's law, and he can save time if he is familiar with DC voltage distribution in resistive networks.

A VOM is quite practical for nearly all transistor-circuit troubleshooting, because circuit impedances are comparatively low, with very few exceptions. ▲

Chapter 13

Servicing solid-state audio circuits

Methods of Biasing

One of the most important aspects of servicing solid-state audio is an understanding of the methods used to achieve proper biasing of the transistors.

Common methods

By now, most of us are familiar with the more-or-less standard transistor biasing arrangements. A few of these are shown and explained in Fig. 1. These circuits, or variations of them, are used in most types of solid-state audio equipment.

Dual-Supply Method

A biasing circuit that is not so universally recognized but is being used more is the dual-supply design shown in Fig. 2. It can be identified by the fact that the ground (or common, if you prefer) is not returned to the positive or the negative side of the power supply. (The circuit in Fig. 2B is a power supply that typically is used with the dual-supply type of amplifier.). Instead, in most applications, the ground, which is usually the chassis, "floats" at the electrical mid-point of the two supplies. (However, it sometimes is designed "closer" to one side than the other, although it usually isn't in audio equipment, because this limits the swing of the output voltage waveform).

Increased output voltage swing is one of the advantages of the dual-supply circuit. Another advantage seems to be improved thermal stability. This can mean a lot in an amplifier that has marginal heat-sinking or that is used inside a closed cabinet. A third advantage is that these circuits tend to be less sensitive to hum pick-up caused by power-supply ripple.

Darlington pair

Another type of circuit that is being used more often in solid-state audio equipment is the Darlington amplifier, also called the Darlington pair. An example of this configura-

Fig. 1 Common methods of biasing transistors.

A) **Fixed-Base-Current Bias**—This is the simplest of all bias arrangements, and the most impractical. Bias is established by current flow from the emitter-base junction of the transistor through R1 to the supply voltage. The amount of bias is dependent on the value of R1 and the supply voltage. The primary disadvantage of this bias arrangement is that it provides no means of automatically limiting collector current (stabilization).

B) **Collector-Feedback**—A simple form of self-bias. Because R1 is connected to the transistor side of load resistor R2, any change in collector current will cause a proportional but opposite change in transistor bias. For example, if collector current increases because of a temperature increase, the voltage at the collector decreases (becomes less positive), which, in turn, reduces the current through the circuit comprised of the emitter-base junction and R1. Although this bias system does provide a degree of stabilization, it also introduces degeneration, caused by feedback of any AC signal voltage developed across the load resistor.

C) **Collector-Feedback With AC Bypassing**—This is the same bias system described in (B) except an electrolytic capacitor has been added to filter out, or bypass, AC variations.

D) **Combination Fixed and Self-Bias**—This configuration provides both good stabilization and minimum degeneration. The fixed emitter-base bias is developed by the voltage divider consisting of R1 and R3. Usually, the valve of R3 is substantially less than that of R1. Resistor R4 performs the function of stabilizing the transistor. For example, if emitter-to-collector current increases because of an increase of temperature, the voltage drop across R4 also increases, placing a more positive voltage on the emitter, which reduces the forward bias on this NPN transistor. The capacitor bypasses AC variations around the emitter resistor, to prevent degeneration. The value of R4 usually is five to ten times less than that of R3.

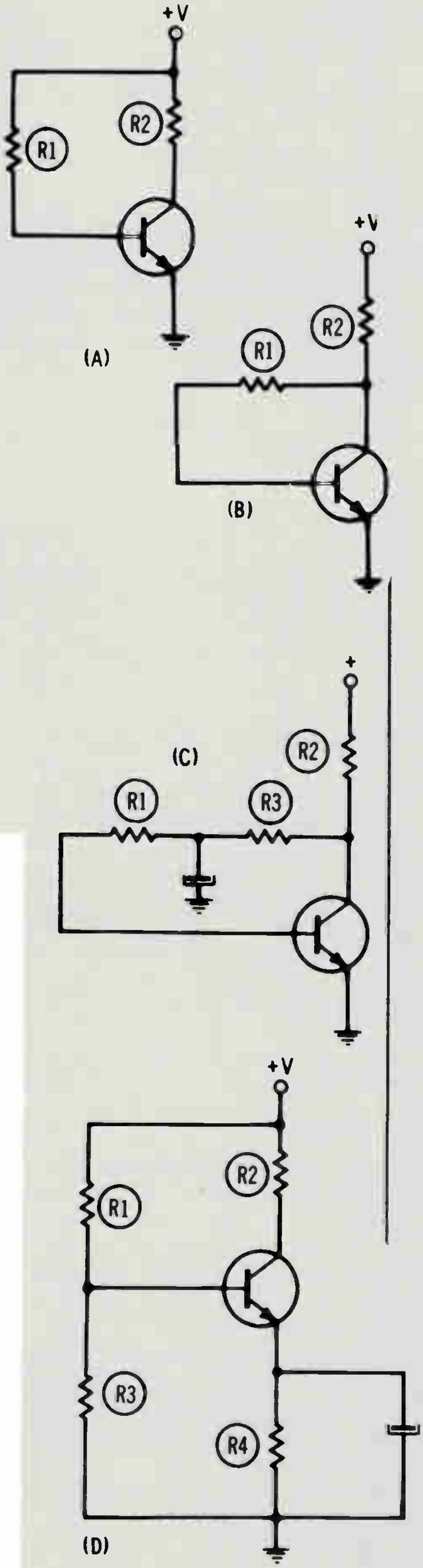
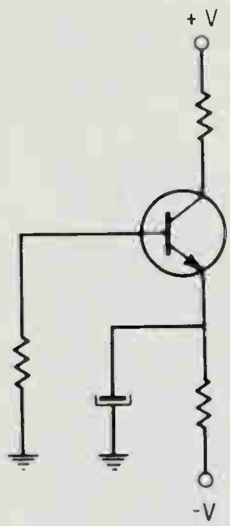
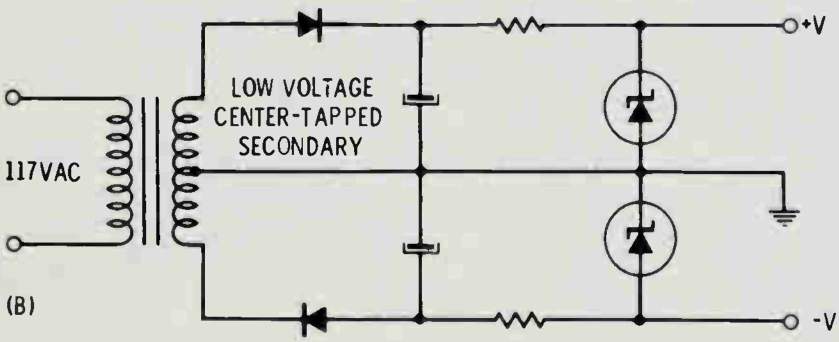


Fig. 2 A) Dual-supply method of biasing a transistor. This method provides a substantially larger PP voltage swing without significant distortion, and also offers improved thermal stability. B) Dual type of power supply used with biasing arrangement shown in (A).



(A)



(B)

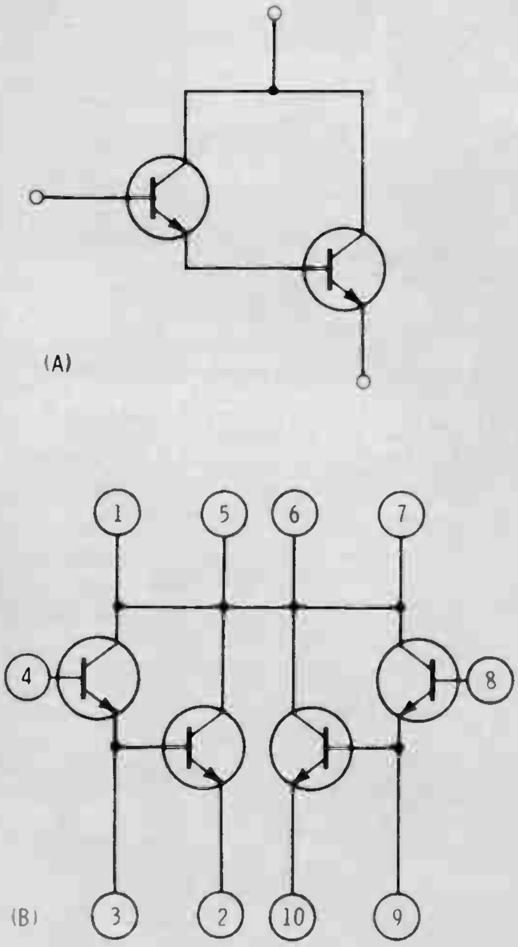


Fig. 3 Darlington amplifiers. A) Conventional Darlington pair. B) Two Darlington pairs tied together in an RCA integrated-circuit.

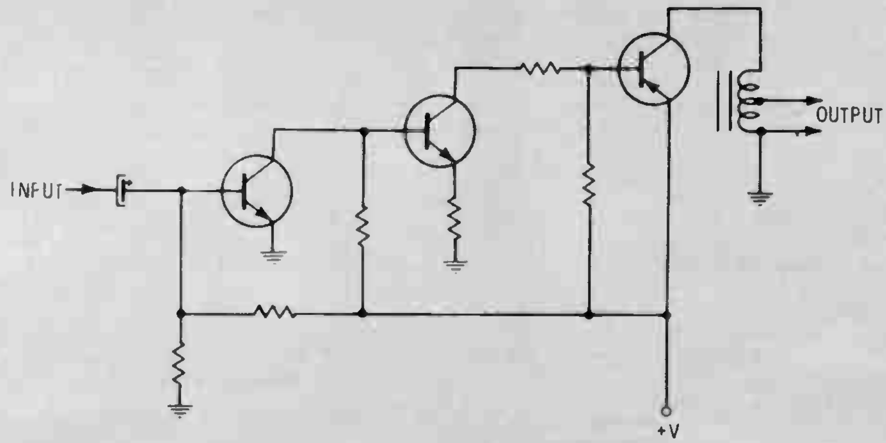


Fig. 4 Single-ended, autotransformer-coupled power amplifier stage without feedback. Distortion is primary disadvantage of this type of power amplifier.

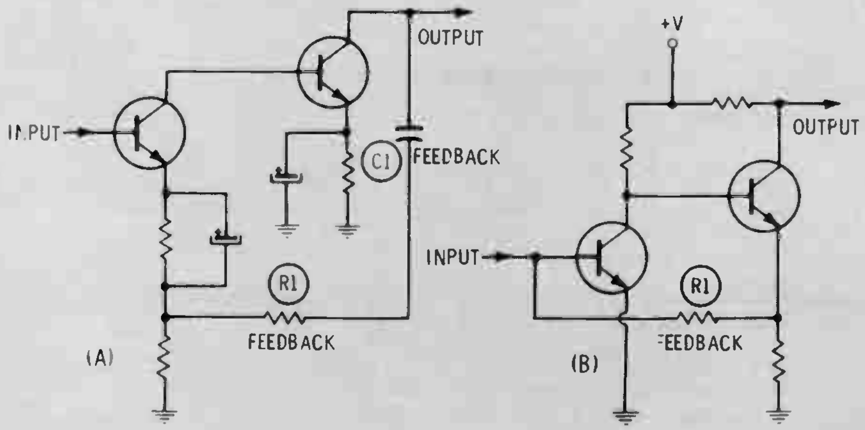


Fig. 5 Two basic types of feedback circuits used in solid-state audio systems. A Second collector-to-first emitter system. B) Second emitter-to-first base system. Feedback reduces or eliminates distortion.

tion is shown in Fig. 3A. Notice that the collectors of the two transistors are tied together. Also note that the emitter of the input transistor is tied directly to the base of the output transistor. This produces higher current gain and a much higher range of input impedances than are normally possible with bipolar transistors.

Although any two properly selected transistors can be used to make a Darlington pair, it has been the practice of several semiconductor producers to make such pairs available in one package. Both integrated-circuit types and dual-transistor types are available. RCA's type CA3036 integrated circuit consists of two Darlington pairs that have all of their collectors tied together. The internal schematic of the CA3036 is shown in Fig. 3B.

Power Amplifier Designs

Single-ended, transformer-coupled

One of the oldest designs of solid-state power amplifiers is the single-ended, choke- or auto-former-coupled type, which, even today, is used in car radios. An example of such a circuit is shown in Fig. 4. By itself, this amplifier can offer little in the way of decent fidelity. Add feedback, however, and the situation changes.

Feedback

There are two basic kinds of feedback circuits normally used in consumer products. One, shown in Fig. 5A, is called the "second collector-to-first emitter" system. With correct values of components, this circuit can make a relatively mediocre amplifier sound like a more expensive one. An open or shorted capacitor or a change in the value of a resistor in this network will create problems that range from mildly irritating distortion to a runaway condition which can destroy the output transistors. A step-by-step check of feedback components should be performed whenever a "strange" set of trouble symptoms is encountered.

Fig. 5B shows the second widely used feedback system. This one has been dubbed the "second emitter-to-first base" system. This circuit often employs only one resistor to supply feedback voltage.

Push-Pull

The push-pull circuit is widely preferred over other types, for both power-handling ability and overall fidelity. Fig. 6 shows the standard push-pull circuit which has been used in almost every audio application, from 5-dollar portable transistor radios to relatively high-priced auto radios and stereo tape players. It is, however, far from efficient when compared to circuits of more recent design.

The circuit in Fig. 7 is a more recent addition to the family of push-pull amplifiers. It often is called the "split-secondary, totem-pole" circuit, and is used in many domestic and imported radios, phonographs and tape players. The particular circuit shown in Fig. 7 is from a Motorola console stereo, Chassis HS-2338. The series connection of the output transistors and the split-secondary interstage transformer are the two main identifying features of this circuit.

One thing that all push-pull amplifiers have in common is the necessity of phase-splitting the input signal to provide two signals 180 degrees out of phase to drive the two halves of the push-pull circuit. In older designs, this was accomplished by either a center-tapped or split-secondary interstage transformer. In many modern designs, the interstage transformer is left out. Although this reduces cost, it does little for fidelity, unless some other means of phase splitting is used.

The transistor phase inverter is one possible replacement for the transformer. These circuits are very similar to their tube counterparts. They have one driving signal taken from the collector circuit and another, of opposite polarity, taken from the emitter, as shown in Fig. 8.

Another method of providing drive signal of opposite polarity is to use an integrated-circuit preamplifier which has both inverted and non-inverted outputs. Such units provide push-pull, wide-band outputs from a common input signal. An example of such a circuit is shown in Fig. 9.

Designers have another method of accomplishing phase inversion that often is more economical than either of the methods mentioned above. It is a circuit called the "complementary symmetry" amplifier. This design, shown in simplified form in Fig. 10, takes advantage of the fact that PNP and NPN transistors require signals of opposite polarity to perform the same function. Notice that the bases of the two output transistors are fed in parallel and that the speaker, minus the output transformer, is connected to the midpoint of the two series transistors. Versions of this circuit which use a single asymmetrical power supply usually employ a capacitor to block DC from the speaker circuit. Dual-supply amplifiers might or might not use such a capacitor.

Complementary symmetry circuits do have a disadvantage: It is difficult to locate matched PNP and NPN transistors. Manufacturers "spec" sheets reveal that there are only a few types that can be paired up for complementary service. As the amplifier's power level requirements increase, the number of types from which the designer can choose decreases drastically. The problem becomes even more acute when selecting replacements for such transistors.

It is relatively easy to find matched pairs for low- and medium-power complementary circuits. Such circuits are used widely in phonographs, stereo tape players, auto radios and low-power stereo amplifiers. It is even relatively easy to find matched pairs in universal replacement lines, if the power requirement is only a few watts.

This has led to an interesting modification of the complementary symmetry circuit. The circuit shown in Fig. 11 employs what is known as the quasi-complementary configuration. In this circuit, the outputs are "totem pole" and the drivers are complementary. For the designer, this means a larger selection of possible power transistors. For the servicer, it means use of a lower-priced line of replacements (less matching necessary).

Fig. 6 Conventional push-pull power amplifier. The two input signals of opposite phase required by push-pull design are provided this circuit by transformer action.

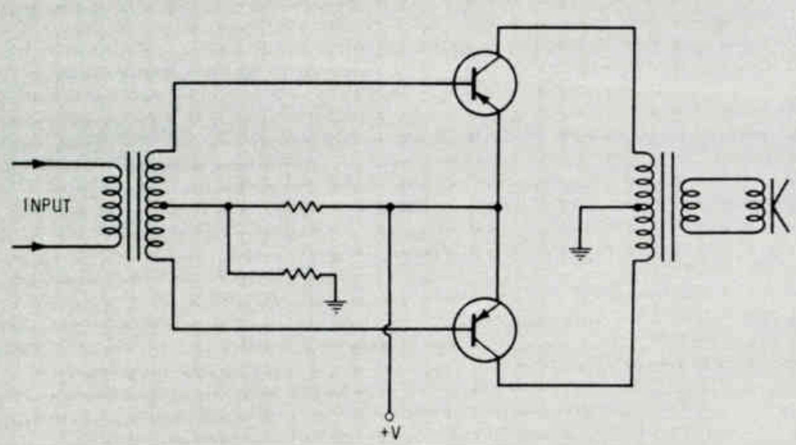
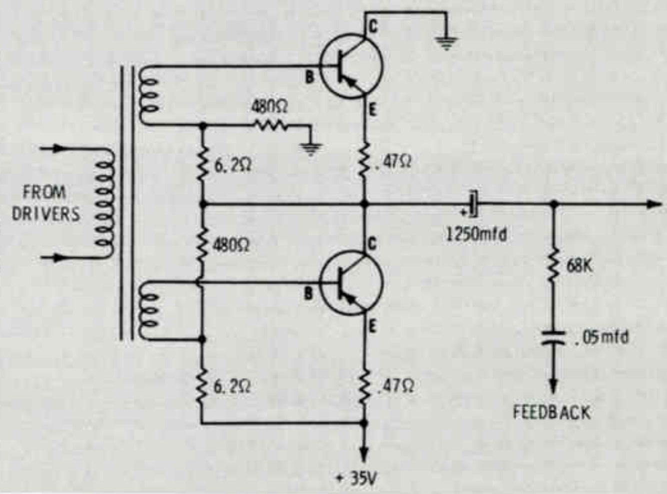


Fig. 7 More recent design of push-pull amplifier used in Motorola HS-2338 stereo chassis.



Complementary and quasi-complementary circuits can provide the technician with a new bundle of headaches, if certain precautions are not followed. For example, these amplifiers have some characteristics similar to those of RF amplifiers. One common characteristic is the wide frequency response required of the transistors used for amplification. Because all of these amplifiers are fed very low levels of input signal, extremely high gain is required.

High-frequency transistors in high-gain circuits are quite capable of oscillating at an RF range that extends from supersonic audio to VHF. The result can be a high level of distortion, "lisping", etc. A square-wave test of the amplifier usually will reveal whether ringing or other types of oscillation are present. The visual indication on the oscilloscope screen will be either ringing or a blurring of the trace. Such oscillations can be caused by open capacitors, incorrect replacement transistors or improper lead dress.

General Troubleshooting Techniques

Most technicians agree that the newer circuits are more difficult to service than some of the older designs.

One reason is that many of the newer circuits are direct-coupled. Another reason is complexity of design.

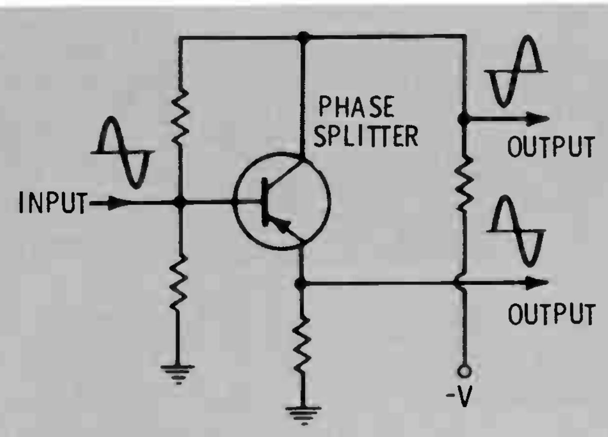


Fig. 8 Phase inverter, which provides two signals of equal amplitude but opposite phase, replaces interstage transformer between driver and push-pull output stages in some audio amplifiers.

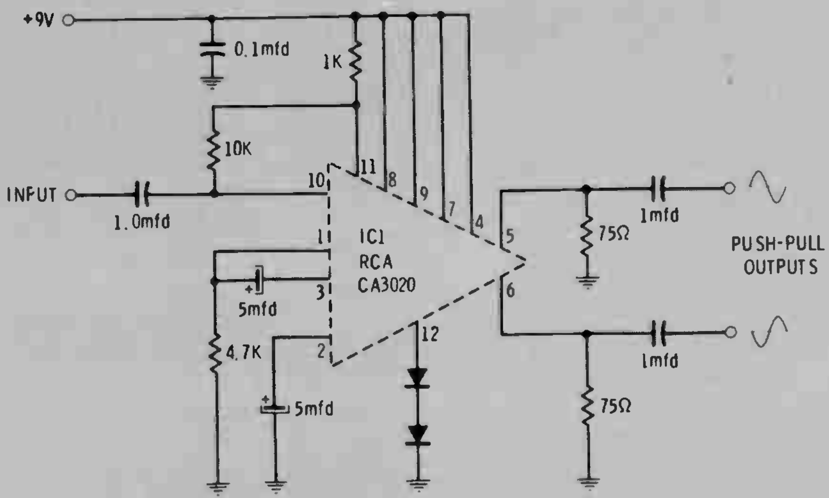
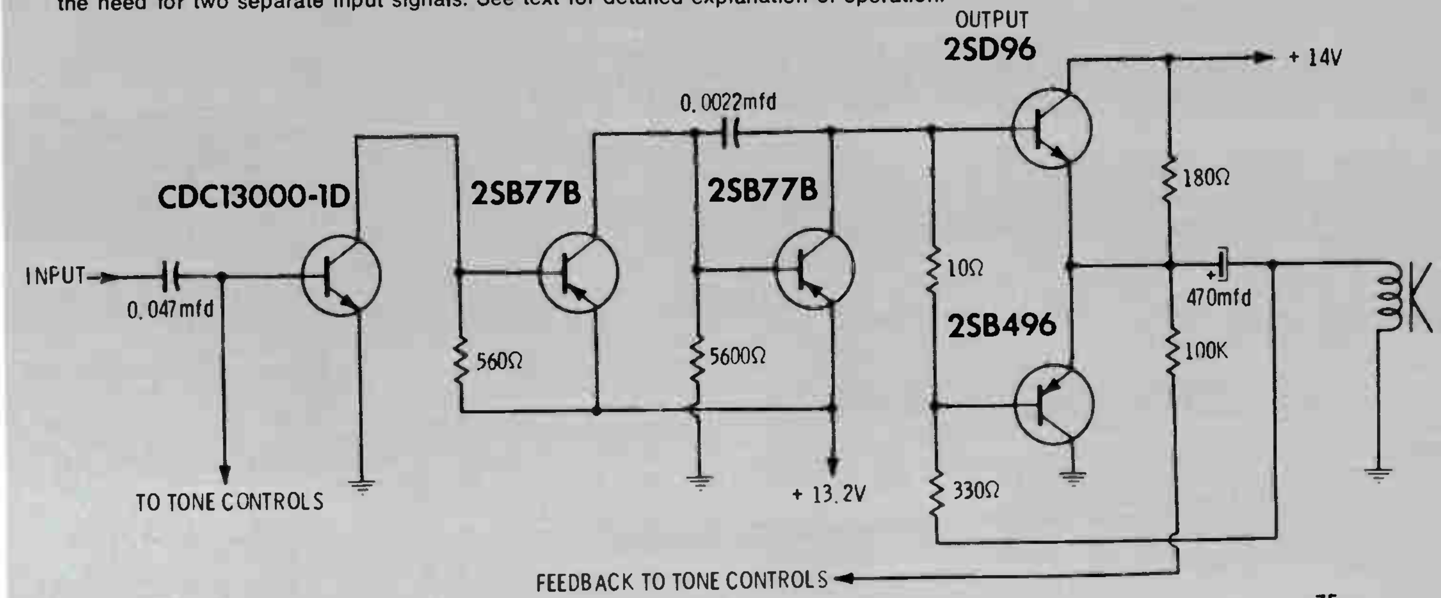


Fig. 9 Equal but opposite drive signals required by push-pull circuit also can be obtained from an integrated-circuit preamplifier which provides inverted and non-inverted outputs.

Fig. 10 Complementary symmetry amplifier is a push-pull design which eliminates the need for two separate input signals. See text for detailed explanation of operation.



Most troubles, however, can be located within a reasonable time if the technician establishes a routine, logical system of diagnosis.

The first step is a preliminary inspection using sight, sound, smell and touch. Notice, for example, whether any fuses are open or if any fuse resistors show signs of overheating. On many sets, the leads to the emitters of the output transistors serve as fusistors. Notice whether their insulations are charred or melted. Also note whether the printing on any of the output transistors has been erased by heat. This could indicate which of several transistors is shorted. A transistor that heats up before shorting can often be detected by touch. I occassionally touch several transistors in a single affected section to determine if any of them are heating quicker than the others.

Shorted and leaky transistors cause a large percentage of the difficulties encountered in solid-state power amplifiers. One way to locate defective transistors is to measure bias and supply voltages with a VTVM. Generally speaking, though, such tests will confirm only what visual evidence already indicates (burned fuse resistors, etc.).

Locating a suitable replacement transistor might take more time than the actual diagnosis. A good rule of thumb is to replace a transistor with an identical type, if the only substitute is from a so-called "universal" line. This advice, in many cases, also applies to using a direct replacement from a manufacturer other than the original.

Always be over-cautious about substitutes. After wading through several large stacks of transistor substitution guides, I have concluded that, in many instances, the people who compile the guides do not even look at the cases of the transistors, much less actually test them. In one incident, I was supplied with a transistor in a small TO-5 case which, according to the substitution guide, was supposed to replace one in the much larger TO-3 diamond case. Because of the inherent mounting difficulties, there would have been heat dissipation problems. Another time, I was sent a drift-field PNP oscillator/RF amplifier transistor to replace an NPN audio unit. All of these examples involved transistors selected from the replacement guide published by a leading transistor supplier. Because of these difficulties, I always carefully read the catalogue description of the recommended replacement. If it doesn't meet the most critical characteristics of the original transistor, I do not order it.

Remember, it is no longer true that a mere handful of universal numbers will replace virtually every transistor you will encounter.

Improper heat sinking of the replacement transistor is one of the most persistent causes of premature failure. This causes profit-robbing callbacks, which don't do anyone any good. Careful tightening of the mounting screws and the use of an approved silicone heat-sinking grease will eliminate most heat-sink problems. The mounting screws are especially important on epoxy case power transistors, which recently have become popular in auto radios, phonos and table-model radios. Many technicians do not make these screws tight enough because they fear cracking the case.

Defective output transistors often cause distortion accompanied by low volume. One way to spot this defect is to measure the DC voltage at the junction where the two output transistors and the output capacitor are connected together. Compare this voltage to the overall supply voltage feeding that series chain. In most circuits, it should be close to half the total supply voltage. If it is significantly higher or lower, suspect one or both of the transistors.

Unfortunately, many types of distortion are not so simple to locate. In many instances, a small transistor defect in a pre-driver stage will cause massive bias changes on the output transistors. The complication of DC feedback compounds the difficulty of diagnosing such a defect. A harmonic distortion analyzer can be useful in such situations.

The power ratings on some modern amplifiers are confusing because the meaning of "watts" seems to vary from manufacturer to manufacturer. The load impedance of late-model audio amplifiers is often listed along with the power rating. You might encounter a specification of "fifty watts into four ohms". Such stipulations are necessary because the load (speaker) impedance is more dependent on the overall operating parameters than was formerly the case.

Short circuiting the output, or, in some cases, open circuit conditions, sometimes can damage the output transistors. Consequently, be certain that the correct speaker or dummy load is used. ▲

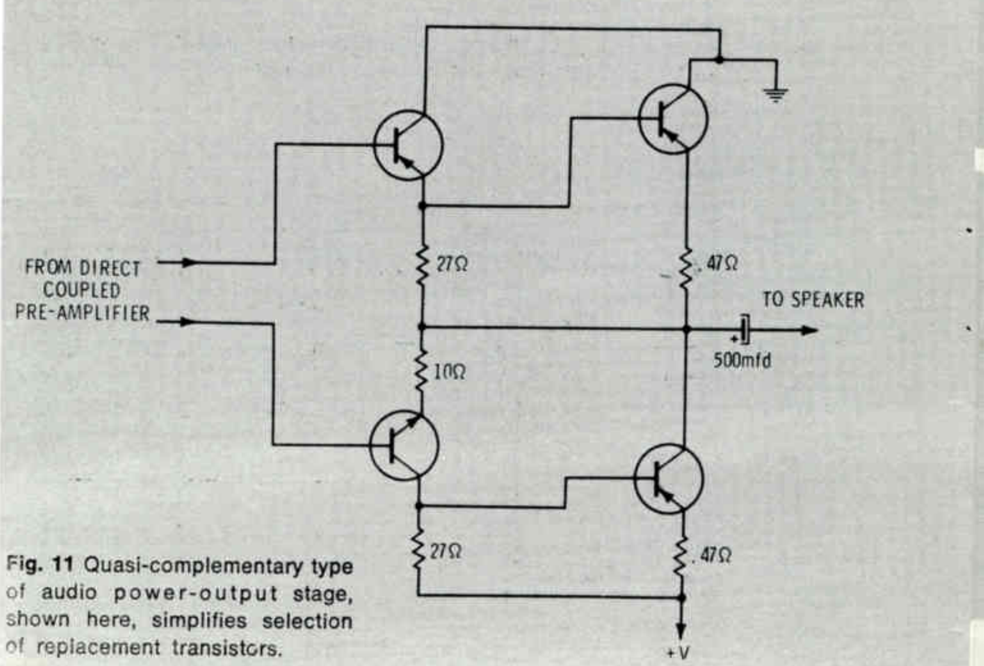


Fig. 11 Quasi-complementary type of audio power-output stage, shown here, simplifies selection of replacement transistors.