FIG. 1—TRANSISTOR-DIODE CURVE TRACER plugged directly into a scope. The output of this tracer can be displayed on any general-purpose scope.

Using a Solid State Curve Tracer

Many important time-saving tests can be made using a scope-curve tracer combination. Here are some tests you will want to try

by MANNIE HOROWITZ

THE TV OR HI-FI SERVICE TECHNICIAN uses a curve tracer to check the quality of semiconductors when they are wired in the circuit or as individual components. The hobbyist uses the instrument to select devices sold in a bulk package that he may have purchased at some "bargain" counter. The engineer uses a curve tracer to note and check characteristics of transistors and diodes when he designs them into equipment. Test and quality control technicians use curve tracers to evaluate the grade and type of device supplied by a vendor.

It is not presumptuous to state that a curve tracer is so versatile, that it serves some function to everyone involved directly in modern electronics. It may be used in a different manner by each individual, but the applications overlap.

Some skeptic might stop here and say, "I can do anything with my transistor tester that can be done with a curve tracer." While it is true that there are excellent transistor testers on the market, they will measure only a limited number of characteristics of some devices, and these only at a specific collector current or voltage level. Using a transistor tester, will in many cases, enable you to separate good devices from bad ones. Yet you can know much more about a device with but one glance at the crt of a curve tracer.

It is easier to perform the tests and measurements on the curve tracer if your scope uses direct coupling (no input or coupling capacitors in the amplifier circuits) in both the vertical and horizontal amplifier chains. A typical arrangement of scope and curve tracer is shown in Fig. 1.

Transistor curves

The collector characteristics of a transistor can be displayed on the screen of a curve tracer. Briefly, the collector current flowing through a bipolar transistor is dependent upon two factors—the collector to emitter voltage and the base current. The traces on the screen of a curve tracer display this information. Much can be learned about the transistor from this display. A typical set of curves for an npn transistor is in Fig. 2. The pnp transistor characteristics are very similar—only the polarity of the voltages and currents are reversed.

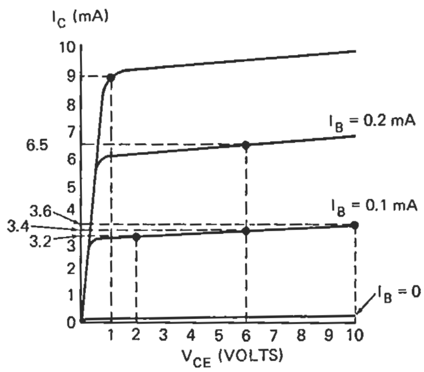

FIG. 2—TYPICAL NPN collector display and construction to determine characteristics of bipolar device.

Each relatively horizontal line describes how the collector current, I_C, varies with the collector-to-emitter voltage, V_{CE}. The different horizontal lines define this relationship for the various values of base current. For example, draw a vertical line from the 6-volt point on the V_{CE} axis up to the $I_B = 0.2$ mA curve, and a horizontal line from the intersection to the I_C axis. It crosses the I_C axis at 6.5 mA. For this particular transistor, when there is 6 volts between the collector and emitter, and 0.2 mA flows into the base, the collector current is 6.5 mA.

The construction may be repeated to determine the collector current at any point on the characteristic curves. You can determine bias requirements from the display on the crt and make the necessary calculations to establish the desired idling current for the particular transistor under test.

Beta can be determined from the curves. Although it is not drawn as such, the curves do not have to be evenly spaced and the horizontal lines are not always parallel to each other. Because of this, beta will vary with I_C and V_{CE}.

Beta is the short-circuit current gain of the transistor. As you recall, two types of beta are encountered—the dc and the ac. Dc beta (B_{dc}) is the ratio of collector current flowing to the base current causing this collector current, at a specific collector-to-emitter voltage. In the figure, at $V_{CE} = 6$ volts, there is 6.5 mA of collector current when the base current is 0.2 mA. B_{dc} is 6.5 mA/o.2mA = 32.5.

When ac signal is applied to the base of a transistor, it forces the base current to vary with the size of the input. In turn, the collector current will vary with the base current. The ac beta, B_{ac}, is the ratio of these two variations at specific collector to emitter voltages. As an example, let us assume that the signal causes the base current to change from 0.1 mA to 0.2 mA and that V_{CE} is 6 volts. The collector current will, in turn, swing from 3.4 mA to 6.5 mA. B_{ac} is (6.5 mA -3.4 mA)/(0.2 mA - 0.1 mA) = 31.

Alpha is the ratio of the collector current to the emitter current. It is used primarily when dealing with common-base circuits. The ac alpha, α_{ac}, and dc alpha, α_{dc}, can both be calculated from the respective betas using the equation

$$\alpha = \frac{\beta}{\beta + 1}$$

Another important characteristic of the transistor is the saturation voltage. At the extreme left of the display in Fig. 2, note the curve at low collector voltages. The relatively vertical curve is inclined at a slight angle. The transistor cannot operate to the left of the vertical line. At the maximum collector current of interest to you, draw a horizontal line from the vertical axis to the highest base current curve. Next draw a vertical line from the point of intersection to the V_{CE} axis. The voltage on the V_{CE} axis is a good approximation to the saturation voltage of the transistor.

From Ohm's law, resistance of any device is a voltage divided by a current. The ac collector resistance, r_d, is the ratio of the peak-to-peak voltage to the peak-to-peak current. The ratio is the slope of a particular display. For the transistor, the ac resistance varies with the base and collector currents. On the I_B = 0.1 mA curve, the collector resistance around the I_C = 3.4 mA point is (10 volts - 2 volts)/(3.6 mA -3.2 mA) = 20,000 ohms. This resistance is valid for the common emitter circuit. For the common base mode of operation, the collector resistance is approximated by beta multiplied by r_d.

The ac collector resistance of the vertical portion of the characteristic is radically different from the rest of the curve. It has been assigned the special name of saturation resistance. Ideally, it should be zero ohms so as not to limit the minimum value of collector voltage. In the figure, it is 1 volt/9 mA, or 111 ohms.

Leakage current and breakdown voltage are important characteristics of the transistor. Although they can be estimated from displays similar to those in Fig. 2, they are diode characteristics and can be determined by testing the transistor as a diode.

FET curves are similar in form to those of the bipolar transistor, except that while the current steps are fed to the base of the latter, voltage steps are impressed between the gate and source of the FET. A typical set of n-channel curves are shown in Fig. 3.

The I_{DSS} is the current flowing when the gate-to-source voltage, V_{GS}, is zero. V_P is the pinch-off voltage and is

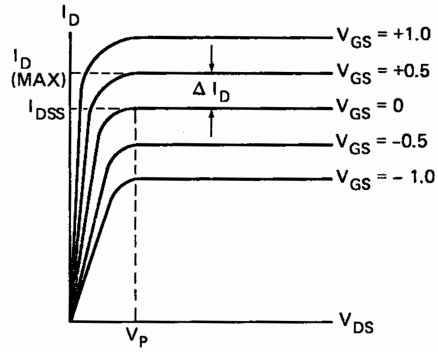

FIG. 3—TYPICAL N-CHANNEL DISPLAY and construction to determine characteristics from the display.

equal to the V_{DS} (drain-to-source voltage) at the point where the V_{GS} = 0 curve becomes horizontal. The zero gate voltage transconductance, g_{mo} is approximately equal to the ratio of the difference in drain current, ΔI_D, to the difference in gate voltage, ΔV_{GS}, causing the change in drain current. In the drawing, the two V_{GS}'s are chosen at 0 and +0.5 volts. To avoid misleading answers, do not choose values of V_{GS} greater than 0.5 volts for the calculation.

For p-channel devices, only the polarity of the voltages and currents are changed. In either case, the transistor is treated as a diode to test for breakdown voltage and leakage current, I_{GSS}.

Diode breakdown curves

As you know, diodes conduct readily when a voltage is applied making the anode positive with respect to the cathode. Should the voltage be applied in the opposite direction, only a small leakage current, I_L, will flow. The current will be large when the reverse voltage is increased beyond the breakdown voltage, V_B, of the diode. A curve showing this is drawn in Fig. 4.

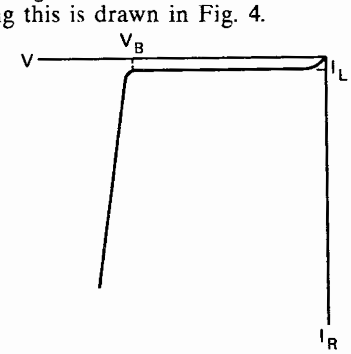

FIG. 4—REVERSE BREAKDOWN CURVE of solid-state rectifier.

Much can be learned from the curve. The diode breakdown voltage is at V_B, the voltage that causes the curve to turn from the horizontal. (This is also the regulating or rated voltage of a zener diode.) The leakage current is I_L, the distance in microamperes from the zero axis to the essentially horizontal portion of the curve at the breakdown voltage.

An extremely important characteristic can only be seen on a curve tracer. Diodes which can best withstand transient voltage pulses (and these pulses can be extremely high), exhibit low resistance in the breakdown region. It is desirable that the vertical portion of the display be as near vertical as possible.

A good diode will be capable of dissipating as much power in the reverse direction as it is permitted to dissipate in the forward direction. As a rule of thumb, $I_R(max) = 0.7I_F/V_B$, where I_F is the forward current rating of the diode. When making tests, limit the curve tracer so that the current through the diode will not exceed the calculated $I_R(max)$. The diode should, however, be capable of conducting this current.

A bad junction can only be seen on a curve tracer. The V_B voltage should be stable and not jump, however minutely, from one value to another. Any jumping indicates a poor diode that should be disposed of.

Leakage current and breakdown voltages of a transistor can be determined using diode measuring techniques.

For the bipolar transistor, I_{CBO} is the reverse current that will flow between the base and collector when the emitter lead is left disconnected. The npn device can be checked by connecting the base to the anode terminal of the diode jacks and the collector to the cathode terminal. The leakage current at any particular voltage is I_{CBO}. If you increase the voltage up to V_B, you can find the BV_{CBO} or collector-to-base breakdown voltage of the transistor.

To determine the I_{CEO} of the npn transistor, the base rather than the emitter is left open. The collector remains connected to the terminal where you would ordinarily connect the cathode of a diode, and the emitter is connected to the anode terminal. Leakage and breakdown voltage, BV_{CEO}, are measured as before.

In each case, the pnp transistor is measured by reversing the connections indicated for the npn device, on the curve tracer.

The I_{GSS} or leakage of an n-channel JFET is measured by connecting the gate to the anode terminal on the instrument and the remaining two leads to the cathode terminal. The leakage and gate-to-source breakdown voltage are measured in the same manner as the equivalent factors of the bipolar devices. The drain-to-source breakdown voltage can be checked on the curve tracer by connecting the drain to the cathode terminal and gate and source to the anode terminal. Increase the voltage until V_B is reached. Of course, the connections must be reversed should a p-channel JFET be tested

Diode breakdown measurements also apply to the SCR. Just connect the

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gate on the device to the cathode on the device thorugh a 1000-ohm resistor. Then check the anode-to-cathode breakdown voltage in both directions by simply reversing the connections of the SCR to the curve tracer.

Forward diode characteristic

All diodes have a distinct relationship between the applied forward voltage and the forward current. These curves tell much about the particular rectifier or diode. A typical curve is shown in Fig. 5.

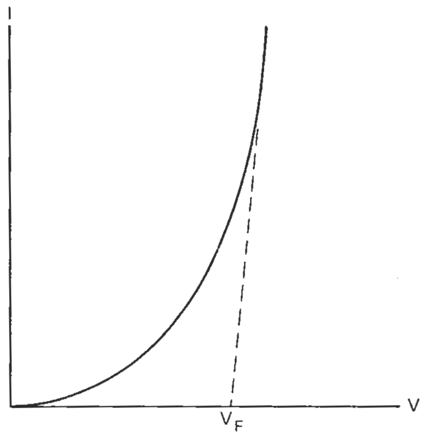

FIG. 5—FORWARD CHARACTERISTIC curve of solid state diode.

The broken line is an extension of the relatively straight portion of the diode characteristic to the voltage axis. It crosses the axis at V_F. V_F is between 0.3 and 0.5 volts for junction germanium diodes and between 0.6 and 0.8 volts for silicon devices.

The resistance of a germanium junction diode is lower than that of a point contact signal device. You can then separate the two devices by noting that the slope of a junction diode is more nearly vertical than that of a point contact diode.

The relative size of a rectifier chip determines its current carrying capacity. The capacity may be estimated from the type of curve shown in Fig. 5. At any one current level, large devices will have lower voltage drops than will power rectifiers constructed with smaller chips.

The EICO model 443 curve tracer

The EICO 443 curve tracer is shown in Fig. 6. It can produce the curves shown in Figs. 2, 3, 4 and 5, and then some, when measuring semiconductor devices. The functional panel layout allows the operator to readily use the instrument. The technician just calibrates his scope using the calibration voltages from the 443, and starts making measurements using a few of the simple controls on the panel. A circuit designer will undoubtedly use his ingenuity to accumulate a great deal more information about a device under test than is readily available at a glance.

Using the FUNCTION switch, you can select the required one of the four groups of displays that can be generated by this instrument. Let's select and discuss one function at a time.

Transistors—signal types

Four current steps produced in this instrument feed the base of the transistor under test. The steps are synchronized to the 60 Hz power supply frequency. Thus four steps are generated during each cycle. Half-cycle pulses are fed to the horizontal input of the scope sweeping the trace four times each cycle—once on the rise and once on the decay of each half cycle. These half cycles serve two other functions as well. First they are applied across the transistor to serve as the collector supply voltages. Second, they are fed to the step generator so that the steps fed to the base of the transistor under test, will be in time with the swept quarter cycles.

The emitter current of the transistor being tested flows through a resistor. In bipolar devices, the emitter current is just about equal to the collector current. This current, a product of the base current and beta, flows each time one of the four different steps is supplied to the base. The voltage across the resistor in
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FIG. 6—EICO MODEL 443 is a typical solid-state semiconductor curve tracer.

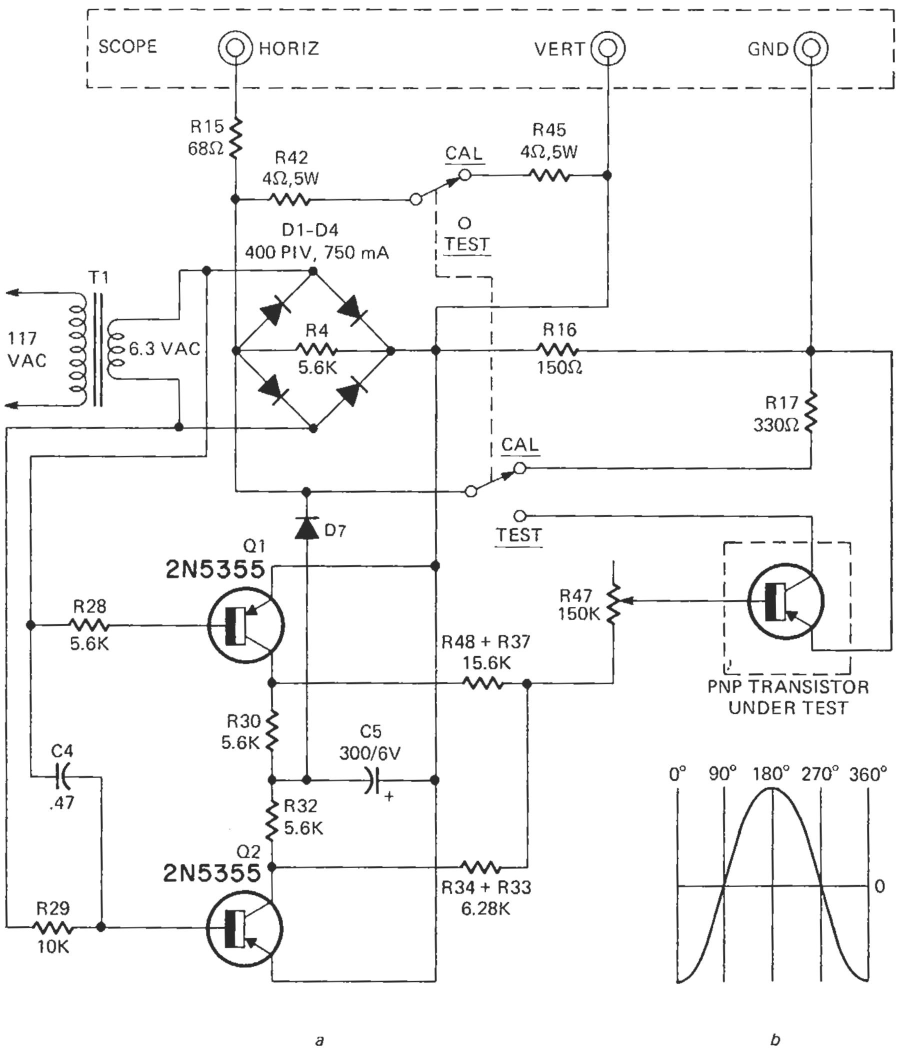

FIG. 7—CIRCUIT TO TEST SIGNAL TRANSISTORS is in (a). The negative cosine wave in (b) is used to explain the formation of the four steps fed to the base of the transistor under test.

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the emitter circuit is proportional to the current flowing through it. This voltage is applied between the vertical input of the scope and ground. Hence the vertical deflection is proportional to the collector (and emitter) current.

On the 443, different circuits are used to accommodate pnp and npn transistors. The circuit in Fig. 7-a is used for a pnp device. Q1 and Q2, along with the associated circuitry, establish the steps for the base circuit in an interesting manner. Assuming the negative cosine wave of Fig. 7-b appears across the secondary of power transformer T1, the base of Q1 is negative with respect to the emitter for the first quarter cycle up to 90°. The transistor conducts and is in saturation. The collector of Q1 approaches the emitter voltage of the transistor. Meanwhile, the base of Q2 is negative with respect to its emitter, so that it does not conduct and its collector remains at the supply voltage potential. Resistors R48+R37 and R34+R33, connected to the collectors of Q1 and Q2 respectively are the components of a voltage divider. The voltage resulting from the divider action and from the relative voltages at the collectors of the

FIG. 8—CIRCUIT USED TO TEST POWER TRANSISTORS. The base current steps of Fig. 7 are amplified by transistors Q3 and Q4.

transistors, forms one step at the SIGNAL beta control. R47.

In passing, it should be noted that some JFET and IGFET characteristics can be tested on the 443. Once you know the current in milliamperes per step fed to the base, you can change the input steps into volts per step by merely adding a 1000-ohm resistor from the base to emitter terminal. The steps fed to the transistor are normal for the enhancement mode of operation and is quite satisfactory for most IGFET's. For JFET's, the bias should be in the reverse direction. However, it may be used in the direction supplied on the 443 for gate to source values up to 0.5 volts, if there is to be no conduction between the gate and source. The I_{DSS} will, of course, be the lowest step established when $V_{GS} = 0$. V_P can be determined from this curve. The ratio of the difference in drain current between the I_{DSS} step and the next step, to the difference in gate voltages establishing these steps, is the g_{mo}.

Extended use and imaginative applications are not limited to the engineers. Technicians can use any ac transistor tester to check transistors in

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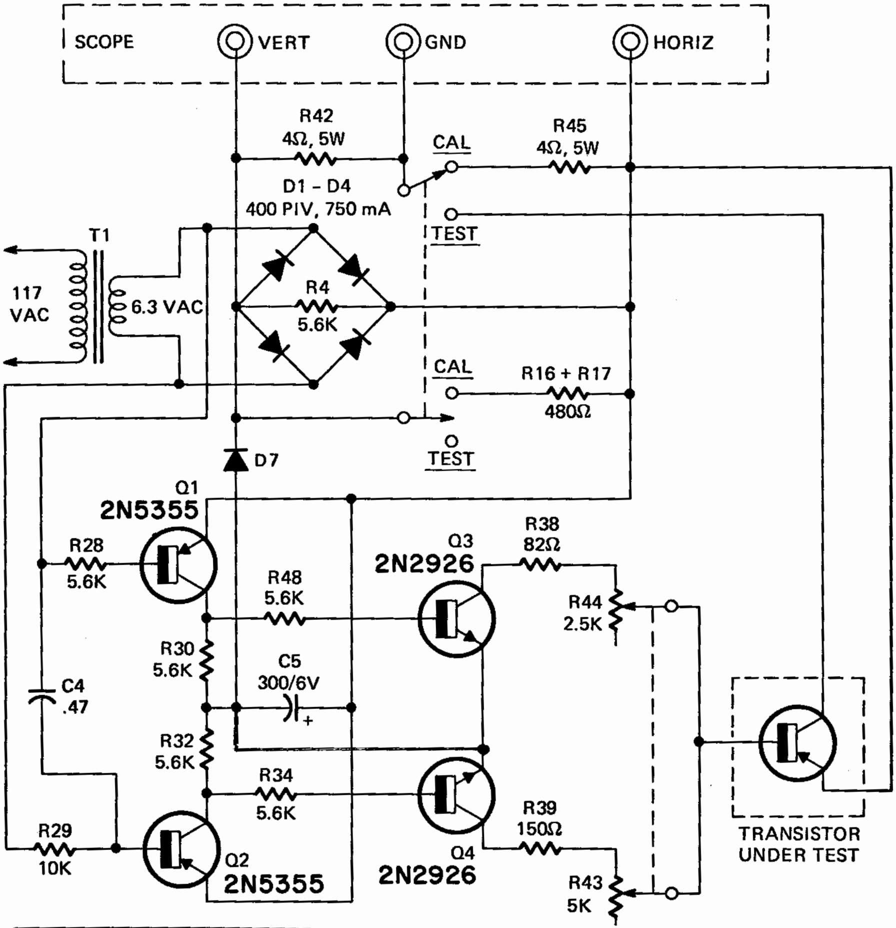

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circuit. The curve tracer is an ac transistor tester. To be sure, the curves will not be as logical nor as valuable as when the transistor is tested out of circuit, but, in some distorted manner, these tests will show four steps and indicate that there is gain if the transistor is not defective. A shorted transistor will appear as a single vertical line on the 'scope while an open transistor will appear as a single horizontal line.

The circuit in Fig. 7-a does not supply enough base drive to accommodate a power transistor. A position on the FUNCTION switch is provided for this type of device. In the 443, two transistors are added to the collector circuits or Q1 and Q2. They increase the current at the collectors enough to drive the base of a power transistor. The circuit is shown in Fig. 8. The performance is exactly as discussed above for the signal device, except that now, the POWER dial must be used for beta measurements. It is accurately calibrated in beta when the maximum collector current step is at 1 ampere. All suggestions listed for diverse tests in the signal transistor discussion can be applied here as well. I am certain you will find a few more!

Only a curve tracer will provide reverse characteristic information about a diode economically. The 443 will test the breakdown of rectifiers up to 2000 volts and show leakage current down to 1 mA per division. A protection switch and flashing warning light are provided on the front panel to alert the user that high voltages are present.

The forward and reverse breakdown voltages of SCR's can likewise be tested. Connect a 1000-ohm resistor from the gate to the cathode and connect the cathode and anode to the tester as you would an ordinary diode. Advance the VOLTAGE ADJUST control and note the reverse breakdown voltage of the SCR. The forward breakdown voltage can be measured by simply reversing the connections of the SCR to the tester. The holding current can likewise be observed in this test.

The 443 must be connected to a scope to observe the various displays. Inexpensive scopes using ac amplifiers are perfectly satisfactory. However, due to capacitive coupling, you will find it necessary to reset the vertical and horizontal controls for many of the measurements. In addition there will not be a true dc level so that you will be unable to note leakage current on the set of collector curves. You will, however, be able to measure it quite accurately using the reverse diode test position.

The best solution is obvious. Use a scope with horizontal and vertical dc amplifiers. **R-E**