all about curve tracers

This article tells what to look for when purchasing a curve tracer; how to test different solid-state devices, and how to interpret the resulting waveforms

by CHARLES GILMORE*

LAST MONTH WE COVERED THE FUNDAmentals of curve tracers and started discussing the testing of diodes.

This month we will complete testing and look into testing of bipolar and field-effect transistors.

The curve tracer can examine curves of the reverse-biased diode as well as the forward biased diode. When the diode is reverse biased, theoretically no current flows. However, as shown in Fig. 6, there is current flow once the reverse breakdown voltage of the diode is reached. When the unknown diode is being used as a replacement part in a circuit, the reverse breakdown voltage should be measured. Once the diode's reverse breakdown voltage has been determined, the circuit parameters will tell you if it can be used as a replacement part. Some diodes tend to show a fairly large reverse current before they reach reverse breakdown. This leakage current can make the diode an unsuitable replacement. Generally, with small signal diodes the leakage currents are so small that they are unnoticeable on most curve tracers.

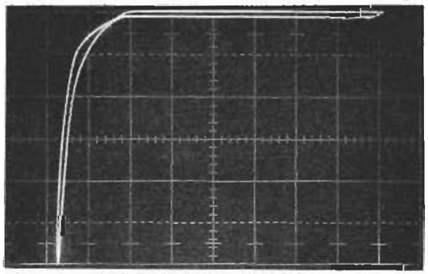

FIG. 6—THE REVERSE CHARACTERISTICS of the 1N4149 silicon small-signal diode. Settings are: cathode series limiting resistance, 10,000 ohms; horizontal sensitivity, 20 volts/cm; vertical sensitivity, 0.5 mA/cm. Note that some looping is caused by internal heating of the diode during sweep and by stray capacitances.

The Zener diode is simply a diode whose reverse breakdown characteristics are known and controlled. Figure 7 shows the characteristics of a 1N750 Zener diode. Poor regulation in a Zener-regulated circuit can be caused by too high dynamic resistance when the Zener is conducting. The dynamic resistance of the Zener diode can be computed in exactly the same manner as the forward dynamic resistance of a diode. By referring to the manufacturer's data on the Zener diode, we can learn at what current the Zener voltage is specified and over what current ranges the dynamic impedance of the Zener is specified. When measurements are made "in circuit," the dynamic resistance of the diode is increased by the resistance of other circuit elements in series with the measurement.

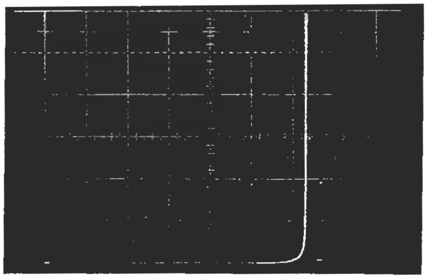

FIG. 7—THE REVERSE CHARACTERISTICS of the 1N709A silicon Zener diode. The diode is rated at 6.2 volts ± 5% at a Zener current of 25 mA. The curve tracer settings are: cathode series limiting resistance, 5000 ohms; horizontal sensitivity, 1 volt/cm; vertical sensitivity, 5 mA/cm. Note that the Zener curve passes through 6.4 volts at the horizontal line representing 25 mA.

The curve tracer is ideal for determining tunnel diode characteristics. As shown in Fig. 8, the characteristics of the tunnel diode are quite unique and you can readily identify the device by them. When using the tunnel diode, the limiting resistor may have to be adjusted to prevent oscillation. Tunnel diodes have a negative resistance region, where the current *decreases* as the voltage *increases*. Given the proper conditions, the negative resistance sustains oscillation.

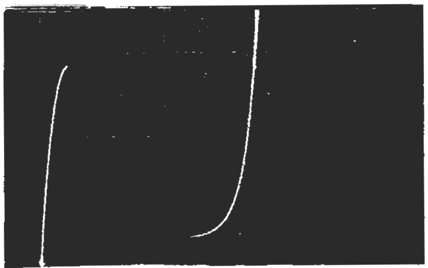

FIG. 8—THE FORWARD CHARACTERISTICS of a GE TD-716 tunnel diode. Settings are: anode series limiting resistance, 5000 ohms; horizontal sensitivity, 0.1 volt/cm; vertical sensitivity, 1 mA/cm. Note the area of trace between the peak current and the valley current is almost impossible to see. If this area of the display contains scrolls, read just the value of series limiting resistance and the sweep voltage to get a trace without scrolling.

When the display has been properly adjusted and there is no oscillation (identified by looping or scrolls on the trace), some of the frequently specified characteristics on a tunnel diode can be readily measured. These are: the peak voltage at the start of the tunneling region (V_p); the valley voltage at the end of the tunneling region (V_v); the peak current at the start of the tunneling region (I_p); and the valley current at the end of the current tunneling region (I_v). Once these parameters are known, the average value of negative resistance can be computed as (V_v - V_p) divided by (I_p - I_v). When tunnel diodes are displayed on the curve tracer, the region between the peak and valley voltages, that is, the region of negative resistance, is frequently quite dim.

The diac or trigger diode, that is frequently used in series with the gate of a Triac or SCR to fire the device, has the characteristic curve shown in

---

*Design Engineer Heath Company, Benton Harbor, Mich.

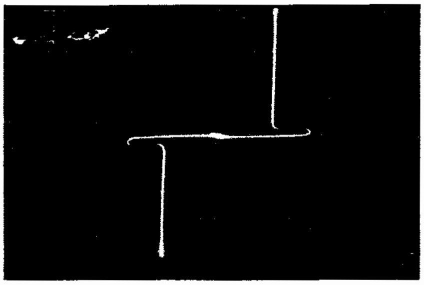

FIG. 9 — THE FORWARD AND REVERSE CHARACTERISTICS of a diac or trigger diode. A double exposure shows both forward and reverse curves in one photograph. Curve tracer settings for reverse measurements are the same as for the forward measurements except the polarity of measurement has been reversed. The curve tracer settings are: series limiting resistance, 5000 ohms; horizontal sensitivity, 20 volts/cm; vertical sensitivity 2.0 mA/cm. Note the match between the forward and reverse breakover voltages.

Fig. 9. Two curves are shown for the diac, a bi-directional device, as the diac has similar characteristics in the forward bias and reverse bias directions. The forward blocking voltage indicated on the display is that voltage where the horizontal line stops and a fine trace swings back to the high current point, showing low forward voltage drop. As the sweep voltage is decreased, the current through the diac is reduced until it finally stops abruptly. This point gives a measurement of the holding current.

2. The bipolar transistor — A large number of characteristics of npn and pnp transistors can be measured with a curve tracer. All measurements applicable to npn devices also apply to pnp devices. The only difference is in the initial set-up. To measure npn devices, the collector or sweep voltage must be positive, and often this is shown on the curve tracer as the npn position. The base or stepping generator must also be in the positive current or npn position. (Note that at this time we use a current generator, as a transistor is a current-operated device). Transistors can be easily damaged if the voltage output of the stepping generator is used.

If an unknown device is found and a curve tracer is used to checkout the characteristics of the device, including pnp or npn, the beam may be initially placed in the center of the curve tracer display. Very moderate levels of sweep voltage and step current are applied first, with a midrange setting of the steps per family control, in the npn direction and then in the pnp direction. One test will yield a family of curves, the other a straight line. The test yielding the family of curves identifies the device. Be sure to keep both the base current and the collector sweep voltage well within the reverse breakdown ratings of the transistor. If incorrect settings are used and the device is forced beyond the breakdown characteristics of its junctions, it could be damaged.

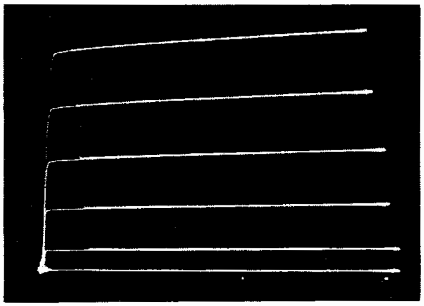

FIG. 10—A FAMILY OF SIX CURVES generated by a 2N3393 silicon npn general-purpose small-signal transistor. Settings are: step generator, 0.01 mA/step; collector series limiting resistance, 100 ohms; horizontal sensitivity, 2 volts/cm; vertical sensitivity, 1 mA/cm. At a collector voltage of 8 volts, the current change indicated by curves three and four is 1.3 mA. As this was caused by a step of 0.01 mA of base current, the beta of this device at this particular operatinig point is 1.3/0.01 = 130.

One transistor parameter we frequently measure is dc gain or beta, abbreviated h_{fe}. To a reasonable approximation, the beta of the transistor is the ratio of the collector current to the base current.

Each curve that the curve-tracer gives us represents the collector characteristics for a different base current. DC beta can be readily determined at various collector current and voltage levels. The curves in Fig. 10 show that the spacing between curves caused by the various base steps is not uniform, indicating the beta of the transistor is not uniform for large variations in collector current or voltage. Therefore, beta should be measured as the change in collector current from one step to another, caused by the change in base current from one step to another. Beta measured in this manner is often referred to as the ac beta or the h_{fe} of the device. This is a better way to check a transistor because the test is made near the operating current and voltage for the device. However, this is not the high-frequency beta of the device, and does not represent the beta of the device at a few kilohertz or higher.

Once we know that a replacement transistor has enough beta, we must find out if its voltage breakdown characteristics allow it to operate successfully in the circuit. The characteristics in question are the collector to emitter voltage breakdown, V_{CE}, and the collector to base voltage breakdown, V_{CB}. The curves in Fig. 11 show the area of collector breakdown, defined as the area where the collector current becomes independent of the base current and begins to rise very sharply.

Voltage breakdown measurements must be made as rapidly as possible or excessive power dissipation in the transistor caused by the high collector currents and voltages used in the procedure may damage the device being tested.

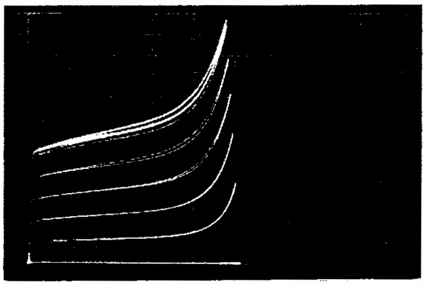

FIG. 11—A FAMILY OF CURVES for the 2N3393 showing collector breakdown. Collector current becomes independent of the base current as the collector voltage exceeds the 30 to 40-volt region. Settings are: step generator, 0.01 mA/step; collector series limiting resistance, 200 ohms; horizontal sensitivity, 10 volts/cm; vertical sensitivity, 5 mA/cm.

To detect collector-to-base and base-to-emitter breakdowns, connect the base-collector or base-emitter terminals of the transistor to the curve tracer as though you were checking an ordinary two-terminal diode for reverse-breakdown characteristics. Do not connect the unused lead of the transistor.

When a transistor is used in relatively high-impedance circuits, the amount of leakage current may be important. This leakage current is often specified in two different forms: I_{CEO}, the collector-emitter current with the base open; and I_{CES}, the collector-emitter current with the base shorted.

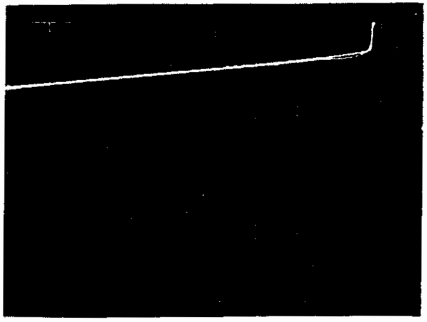

FIG. 12—A MEASUREMENT OF I_{CEO} on a 2N398A germanium pnp transistor. Curve tracer settings are: collector series limiting resistance, 1000 ohms; horizontal sensitivity, 2 volts/cm; vertical sensitivity, 0.5 mA/cm. The step generator is not used, as the base lead is open. Germanium transistors generally have higher leakage currents than silicon. Leakage on this particular device is 800 mA with a collector-emitter voltage of 18 volts.

To measure I_{CEO}, connect the collector and emitter leads to the curve tracer terminals and leave the base lead open. Then increase the sweep voltage far as possible, without exceeding breakdown, and measure the leakage current as shown in Fig. 12. If the leakage current is quite small, you may have to use the magnifier on the curve tracer to see this current. Frequently, it will not be measureable at all. If I_{CES} is to be determined, short the base lead to the emitter lead and make the measurement in the same way as for I_{CEO}.

Transistors that are used in digital circuits have a few additional special characteristics, as they specify that the device may be used as a switch. When a transistor is used as a switch, the collector-to-emitter voltage when the transistor is saturated (that is, drawing its maximum collector current) is very important. For instance, if we wanted to use a transistor in a common-emitter circuit to drive the input of a series 7400 TTL gate, we would need a logic zero of at least 0.4 volt. This means that the collector-emitter voltage of less than 0.4 of a volt when sinking a maximum current of 1.6 mA from the input of the gate plus its own collector current.

To determine whether this transistor will properly drive its gates, use a curve tracer to measure V_{CE} (sat) or the collector-emitter saturation voltage. Figure 13-a shows the curves of an npn 2N2369 that is often used in such applications. Note that the saturation voltage increases as the collector current increases. Figure 13-b shows the same transistor, but here the base current is 100 times larger.

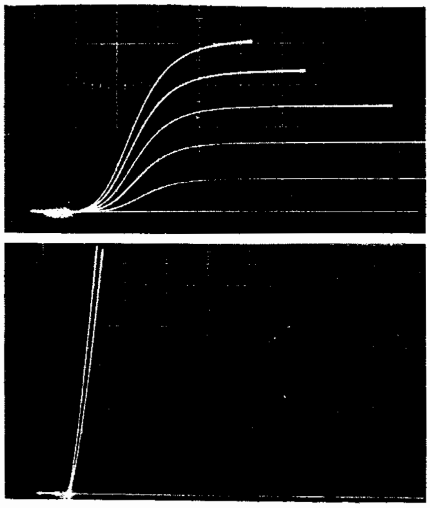

FIG. 13 — SATURATION VOLTAGE ON A 2N2369 switching transistor. a). The transistor is operated at moderate levels of base drive. Settings are: step generator, 0.02 mA/step; collector series limiting resistance, 50 ohms; horizontal sensitivity, 0.1 volts/cm; vertical sensitivity, 2 mA/cm. b). The transistor operates at high levels of the base drive, as might be found in a switching circuit. Settings are: step generator, 2 mA/step; collector series limiting resistance, 50 ohms. Horizontal sensitivity, 0.1 volt/cm; vertical sensitivity, 2 mA/cm.

In some critical applications, temperature has a great effect on transistor characteristics. One way to determine if a transistor will or will not cause problems in a circuit is to operate the transistor in a curve tracer, using collector voltages and currents that represent those of the anticipated application. Once a family of curves has been established, heat the transistor (a soldering iron, or even finger heat may be sufficient) and note any variations in these curves. With "looping", shown in Fig. 14, the characteristics of the transistor have actually changed between the time the sweep makes the deflection from the left hand to the right hand side of the screen and its return.

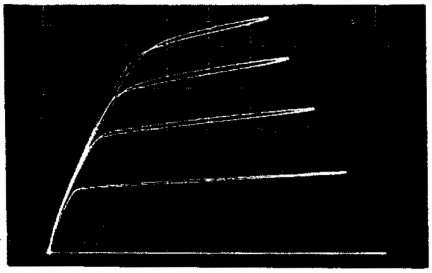

FIG. 14—THERMAL LOOPING CAUSED BY INTERNAL HEATING of the transistor. Transistor is a 2N3393, that has 200 mW dissipation. The curve tracer settings are: step generator, 0.1 mA/step; collector series limiting resistance, 100 ohms; horizontal sensitivity, 5 volts/cm; vertical sensitivity, 20 mA/cm. At the center of the display, the point where there is distinct thermal looping, represents a collector-emitter voltage of 20 volts at a current of 60 mA. This yields a power of 1.2 watts.

In Fig. 15, we can see that with increasing collector voltages this effect can be carried to the limit, and the curves shown in Fig. 15 represent thermal runaway. At this stage, the transistor parameters are no longer under the control of the base current, but have completely succumbed to device heating. A transistor subjected to this test may be damaged quite rapidly, so work quickly.

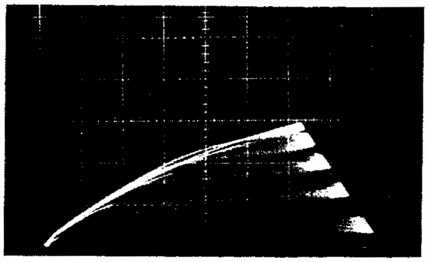

FIG. 15—THERMAL RUNAWAY CAUSED BY EXCESSIVE internal heating of the transistor. The entire characteristics of this transistor were changing as this photograph was being taken (one second exposure). The transistor was destroyed a short time later. Settings are: step generator, 0.1 mA/step; collector series limiting resistance, 50 ohms; horizontal sensitivity, 5 volts/cm; vertical sensitivity, 50 mA/cm.

When testing transistors on a curve tracer, setups should be made carefully, always starting with low initial voltages and currents, as semiconductor devices can be easily damaged. Curve tracers can produce large voltages and large currents, especially when compared to the limit parameters on small signal semiconductors. You can destroy a transistor within the first few sweeps of an improperly set-up curve tracer.

Certain hazardous conditions exist when making measurements. Transistors can get very hot when their parameters are exceeded and severe burns can result from touching the cases of both power transistors *and small-signal* transistors that have been used beyond their limits.

Curve tracers can produce exceptionally high voltages to insure breakdown of most junctions; they also have fairly large current capabilities. The net result is power supplies that are potentially lethal. It is altogether too easy for a person to come in contact with leads on devices that are under test, especially those which have metal cans. *Be sure to reduce the sweep voltage to zero before connecting or disconnecting the device from its test socket or leads.*

When intermittent tests for transistor breakdown are desired, the A-B switch is an excellent way to rapidly control the curve tracer. To compare devices, a "standard" transistor can be left in one socket and the second socket used to interchange transistors that are being compared or sorted.

The user must remember when making in-circuit tests, that parameters may not be exactly as expected, due to other components in the circuit such as resistors and large capacitors. To make exact parameter measurements on a transistor, remove it from the circuit.

3. Field-effect transistors—Like the bipolar transistor, the field-effect transistor has two major categories of different polarity devices. Unlike the bipolar device, field-effect transistors are voltage operated devices. Initial set ups for measuring field-effect devices include changing the step generator from the current mode to the voltage mode. Today there are six major categories of field-effect devices. Their set ups are shown in the setup table (see May 75 issue). A special note should be made of enhancement-mode field-effect devices, as some curve tracers can not provide the combination of sweep polarity and step generator voltage polarity to properly display their characteristics. One method to overcome this, for example with the n-channel enhancement type, would be to use a positive collector sweep voltage and a negative step voltage. This step voltage must be offset by some positive voltage so the most negative step produces a zero gate to source voltage. One way to do this is to place a battery or an adjustable power supply in series with the gate (the base terminal) of the curve tracer.

(to be continued)