

# CURVE TRACER Checks Semiconductor Quality from Breakdown Voltage to Beta

**A** SIMPLE go/no-go tester will tell you if a transistor will operate, but it will not tell you the quality of operation. For this, you need a curve tracer, which is usually an adapter designed to be used with an oscilloscope. The Experimenter's Assistant tracer/tester described here can test virtually any type of discrete semiconductor device, classify it according to type (npn or pnp) and material (silicon or germanium), and check reverse and forward breakdown voltages and leakage. It can also provide a rough indication of a transistor's beta.

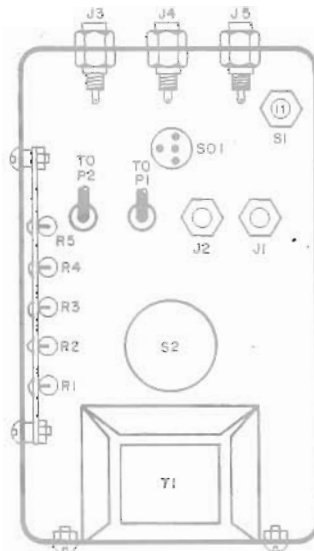
In addition to semiconductor devices, the tester can also check capacitors and inductors. With a little imagination, it can also be used for in-circuit testing. To make testing conditions as safe as possible, the maximum test current is limited to slightly less than 4 mA.

**Circuit Operation.** The tester provides a simple means of depicting the voltage/current behavior characteristic of the component under test, graphically displaying the characteristic on an oscilloscope screen. The basic circuit shown in Fig. 1 consists of transformer  $T1$ , resistors  $R1$  and  $R2$ , switch  $S1$ , and component attachment jacks  $J1$  and  $J2$ . Note the three connections that must be made from the tester to the oscilloscope's horizontal and vertical inputs and ground. The remainder of the circuit is used for actual semiconductor testing and is connected to the basic circuit by plugging  $P1$  into  $J1$  and  $P2$  into  $J2$ .

With  $S1$  open, the 12.6 volts rms at  $T1$ 's secondary provides the sweep for the scope. Because the input impedance of the scope is virtually infinite, relative to the value of  $R1$ , the full transformer swing of  $\pm 17.82$  volts peak-to-peak is applied to the horizontal input of the scope. Since no effective current flows through  $R1$ , no signal appears at the scope's vertical input. The result is a horizontal trace on

the CRT, with the right and left ends of the trace representing  $+17.82$  and  $-17.82$  volts, respectively.

If test leads are connected to  $J1$  and  $J2$  and their test tips are shorted together, the full secondary voltage of  $T1$  will appear across  $R1$ , while no voltage is applied to the scope's hori-



*A typical layout for the curve tracer.*

zontal input. This results in a vertical trace on the CRT, with the top of the trace representing a current of 3.8 mA ( $17.82 \text{ volts}/4800 \text{ ohms} = 3.8 \text{ mA}$ ).

Removing the short between the test leads and depressing  $S1$  places  $R1$  and  $R2$  in the circuit. Now, the scope will display a  $45^\circ$  trace, assuming the horizontal and vertical input channel gains of the scope are properly set. Resistor  $R2$  and switch  $S1$  are used for balancing the channel gains. Once the channel gains have been set to display a  $45^\circ$  trace, any component whose resistance is greater than 4700 ohms will produce a more nearly horizontal trace, while component resistances of less than 4700 ohms will produce a more nearly vertical trace. The actual slope of the trace is directly related to  $R1/R_{\text{TEST}}$ , where  $R1 = 4700$  ohms and  $R_{\text{TEST}}$  is the resistance of the

component connected across the  $J1/J2$  test probes.

**Construction.** You can assemble the tester in any enclosure of a convenient size using a point-to-point wiring technique. Use a terminal strip to mount the five resistors. The best place to mount  $SO1$ ,  $S1$ ,  $S2$ ,  $J1$ , and  $J2$  is on the cover of the enclosure.

Connect one end of a 12" (30.5-cm) length of flexible test lead to the C lug on  $SO1$ , tie a knot in it to serve as a strain relief, pass the free end through a rubber-grommet-lined hole in the top of the case, and terminate the cable with a banana or tip jack (to mate with  $J1$ ). Repeat this procedure with a cable connected to the E lug on  $SO1$ . These two cables, when plugged into  $J1$  and  $J2$ , allow transistors plugged into  $SO1$  to be tested. For in-circuit tests of transistors and diodes that do not fit into  $SO1$ , separate test cables must be plugged into  $J1$  and  $J2$ . Prepare these with appropriate plugs at one end and standard test probes at the other end.

Mount  $J3$ ,  $J4$ , and  $J5$  on the rear wall of the case. Prepare three 36" (about 1-meter) test cables with plugs ( $P3$ ,  $P4$ , and  $P5$ ) to match these jacks on one end and plugs to match the input connectors on your scope at the other end. These last jacks and cables are for interconnecting the tester with a scope. Alternatively, you can connect the cables directly to the appropriate points in the tester circuit and have them exit the case through grommet-lined holes and eliminate  $J3$ ,  $J4$ ,  $J5$ ,  $P3$ ,  $P4$ , and  $P5$ .

After wiring the circuit and assembling the case, label the jacks, plugs, switches, and test socket.

**Using the Tester.** If an "ideal" diode is connected between  $J1$  and  $J2$ , it will act as a short circuit for one-half of the ac cycle when forward biased. During the other half-cycle, it will be

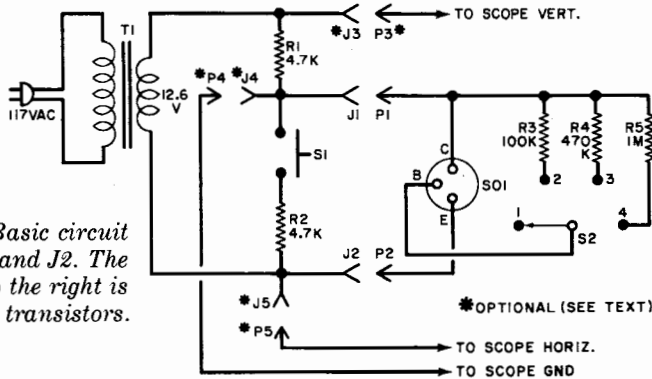


Fig. 1. Basic circuit ends at J1 and J2. The circuit to the right is used to test transistors.

### PARTS LIST

- J1 to J5—Banana or tip jack (J3, J4, J5 optional—see text)
- P1 to P5—Banana or tip plug to match jacks (P3, P4, P5—optional—see text)
- R1, R2—4700-ohm, ½-watt, 1% resistor
- R3—100,000-ohm, ½-watt, 1% resistor
- R4—470,000-ohm, ½-watt, 1% resistor
- R5—1-megohm, ½-watt, 1% resistor

- S1—Normally-open pushbutton switch
- S2—4-position, nonshorting rotary switch
- SO1—Transistor socket: (chassis mount)
- T1—12.6-volt filament transformer
- Misc.—Line cord with plug; flexible test-lead cable; control knob; test probes (2); jacks for scope input (3); case (such as Radio Shack No. 270B098—6¼" × 3¾" × 2"); lettering kit; machine hardware; rubber grommets; hookup wire; solder; etc.

trace will be displayed as shown in Fig. 2D.

For most transistors,  $\beta$  can be determined by rotating S2 until the trace is close to 45°. For the component values shown in Fig. 1, and a trace slope of 45°, the  $\beta$  is approximately 21 in position 2 of S2, approximately 100 in position 3, and approximately 213 in position 4.

**Other Uses.** If you connect a good capacitor across the test leads connected to J1 and J2, an elliptical trace will be displayed. This trace will result because of the phase shift at 60 Hz between the vertical and horizontal inputs of the scope due to the RC network. A trace shape approaching a circle is obtained when the capacitive value under test is approximately 0.5  $\mu$ F. Inductors will produce similar

reverse biased and will seem to be an open circuit. Hence, the trace observed on the scope's CRT will form a right angle with one leg horizontal and the other vertical. The intersection of the two legs will be centered on the screen.

Few things in nature are perfect, the diode is no exception. A silicon diode requires about 0.6 volt forward bias before it begins to conduct, germanium about 0.2 volt. Illustrated in Fig. 2A are the differences in forward conduction voltage as "offsets" in expanded horizontal traces. Hence, the tester can identify a diode under test as either silicon or germanium.

If you connect a 5-volt zener diode between the test probes connected to J1 and J2, the resultant waveform will appear as shown in Fig. 2B. Note that the zener's impedance and breakdown voltage can be obtained from an expanded horizontal trace. The zener impedance is equal to the change in voltage divided by the change in current within the linear breakdown region of the trace. Snap-recovery and tunnel diodes also produce their own characteristic traces.

In testing transistors, it is useful to visualize them as variable resistors whose emitter-to-collector resistances are controlled by a minute base current. Within a transistor's operating range, the collector current will approximately double if base current is doubled. The "resistance" of the transistor, as "seen" by its associated circuit components, will decrease by a factor of approximately two.

To use the tester as a transistor checker, the SO1 portion of the circuit

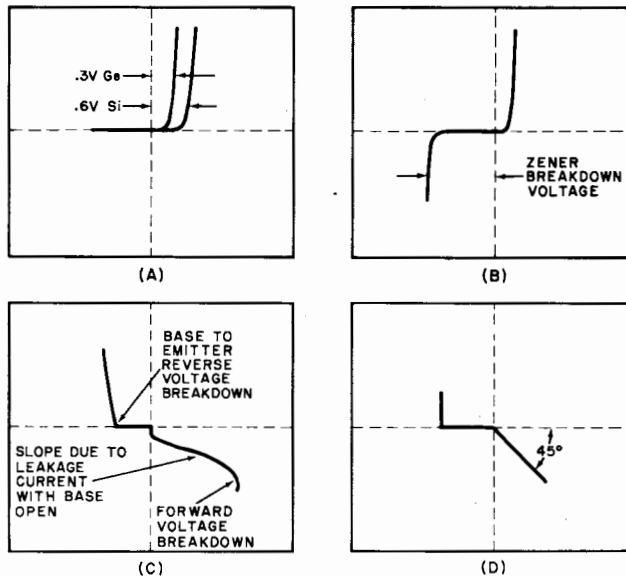


Fig. 2. Typical scope traces: (A) identification of silicon or germanium junction; (B) zener diode curve; (C) transistor with leakage, forward reverse voltage breakdown; (D) transistor with a gain of 100.

in Fig. 1 must be plugged into J1 and J2 or the separate test leads must be plugged into the jacks. Assuming the former, if a transistor is plugged into SO1 and S2 is set to position 1, the trace observed should be a continuous horizontal line. (With no base current, the transistor should have an infinite emitter-to-collector resistance.) The trace will be off the horizontal only if there is leakage current within the transistor or the transistor's breakdown voltage is exceeded. These traces are depicted in Fig. 2C.

To perform a beta ( $\beta$ ) measurement of a transistor, start with no transistor plugged into SO1. Depress S1 and adjust the scope's controls for a 45° slope to the trace. Insert the transistor in the test socket, observing the proper lead basing, and set S2 to position 3. If the transistor's  $\beta$  is 100, a 45°

traces, and the tester can also be used to match inductances of home-made toroidal transformer coils.

Since the current through the probes is limited to less than 4 mA, the tester can be used to check most in-circuit components. Connect the test leads across an in-circuit semiconductor, and the resultant trace shape and slope will be determined by the various resistances and reactances associated with the semiconductor. Although the waveform displayed can be greatly distorted, you can check junction operation by looking for the telltale junction discontinuity that is typical at the zero axis. Not only can you check semiconductor junctions, you can also check the qualities of other components such as resistors, capacitors, and inductors that are common to the transistor stage. ♦