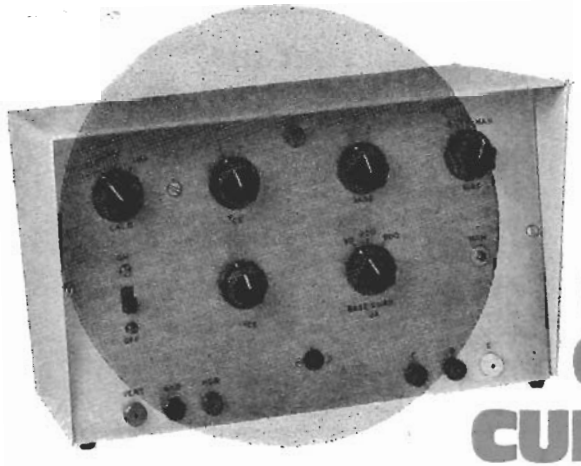


BUILD A VERSATILE SEMI-CONDUCTOR CURVE TRACER

CREATES CHARACTERISTIC CURVES FOR MOST SEMICONDUCTORS

BY JOHN KEITH

SEMICONDUCTOR characteristic curve tracers have been used very little by experimenters and hobbyists because many people are just not familiar with their operation. Then too, commercial units are expensive. However, a curve tracer is almost indispensable when you need to know the characteristics of the semiconductors you have on hand, especially when you are looking for a pair of matched devices for a particular application.

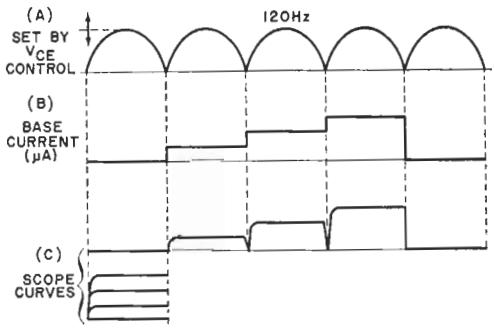
A curve tracer automatically displays the voltage-current parameters of a semiconductor device by varying one parameter while measuring another. Although this can be done manually, it is a slow, tedious job requiring many individual plots. An automatic tracer, used in conjunction with an oscilloscope, can display a family of curves in a matter of seconds. For example, the collector current curves of a transistor are created by applying the selected collector-to-emitter voltage through a load resistor and varying the base current. A voltmeter connected across the collector resistor will show a variation in indicated voltage as the base bias is varied. Obviously, a selection of different values of applied base bias currents will be needed to plot a "family" of curves such as those seen in transistor manuals.

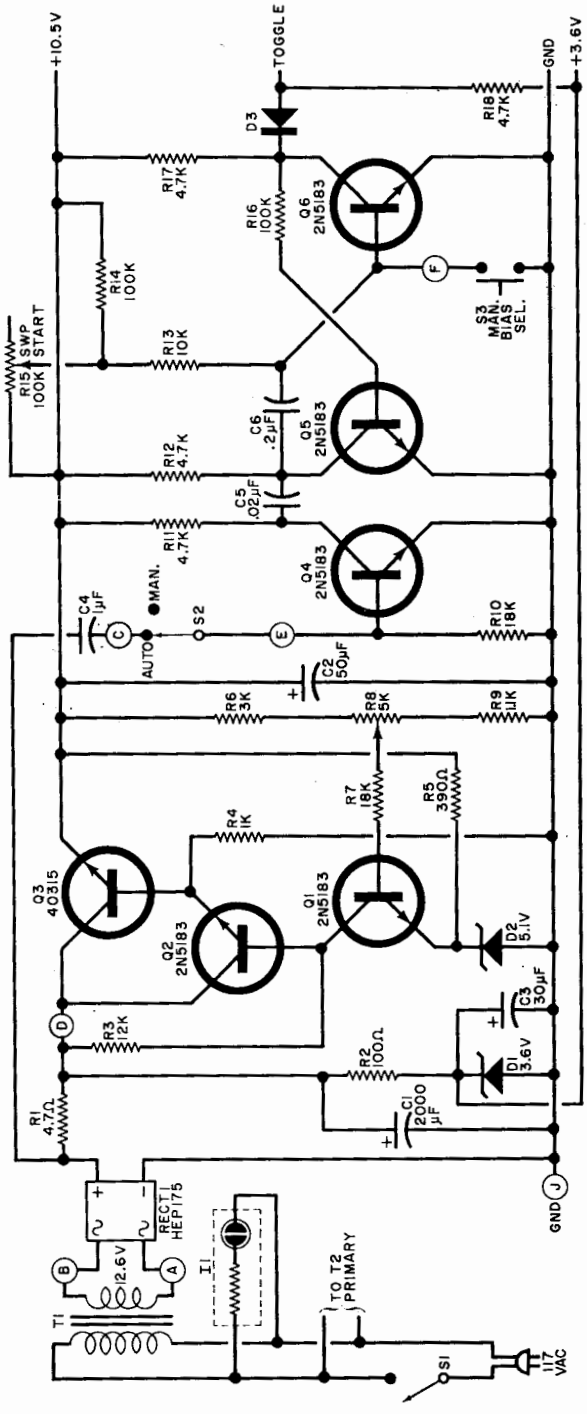
The low-cost automatic curve tracer described here is straightforward in design, easy to use, and makes an excellent addition to any workbench.

Details of Circuit Design. Timing in the curve tracer circuit is set by the frequency of the ac power input. After it is rectified, the input is a 120-Hz half sine wave with a maximum value of about 20 volts as shown in Fig. 1A. This voltage is used as the collector-emitter supply (V_{CE}) for the transistor being tested, with the upper limit determined by a potentiometer. The V_{CE} supply is also used for the horizontal sweep on the external scope while the collector-emitter voltage drop (across a resistor) is applied to the scope's vertical sweep.

During the time of one 120-Hz sweep, the base bias current to the transistor under test is held at a selected constant value by a built-in "staircase" generator that changes

Fig. 1. Waveform at (A) is basic timing voltage. Transistor base current is at (B); while (C) shows how family of characteristic curves is generated.





PARTS LIST

C1—2000-μF, 15-volt electrolytic capacitor
C2—50-μF, 15-volt electrolytic capacitor
C3—30-μF, 15-volt electrolytic capacitor
C4—1-μF, 15-volt disc capacitor
C5—0.02-μF, 15-volt disc capacitor
C6—0.2-μF, 15-volt disc capacitor
D1—3.6-volt, 1-watt zener diode (HEP102 or similar)
D2—5.1-volt, 300mW zener diode (HEPZ0211 or similar)
D3,D5-D13—Any silicon diode
D4—10-volt zener diode (HEPZ0220 or similar)
D14-D17—Rectifier (1N4002, HEP156 or similar)
F1—¾-ampere fuse and holder
I1—117-volt neon lamp assembly (with internal resistor)
IC1—Integrated circuit (MC790P or HEP572)
J1-J6—Five-way binding post
Q1,Q2,Q4-Q10—Transistor (2N5183 or HEPS3001)
Q3—Transistor with heat sink (RCA40315 or HEP53)
R1—4.7-ohm, ½-watt resistor
R2—100-ohm, 2-watt resistor
R3—12,000-ohm, ¼-watt resistor
R4—1000-ohm, ¼-watt resistor
R5—390-ohm, ¼-watt resistor
R6—3000-ohm, ¼-watt resistor
R7,R10,R19,R20,R21—18,000-ohm, ¼-watt resistor
R8—5000-ohm trimmer potentiometer (CTS type U-201 or similar)
R9—1100-ohm, ¼-watt resistor
R11,R12,R17,R18,R27—4700-ohm, ¼-watt resistor
R13—10,000-ohm, ¼-watt resistor
R14,R16—100,000-ohm, ¼-watt resistor
R15—100,000-ohm trimmer potentiometer (CTS type U-201 or similar)
R22—2700-ohm, ¼-watt resistor
R23—500-ohm trimmer potentiometer (CTS type U-201 or similar)
R24—680-ohm, ¼-watt resistor
R25—250-ohm trimmer potentiometer (CTS type U-201 or similar)
R26—1500-ohm, ¼-watt resistor
R28—470-ohm, ¼-watt resistor
R29—10,000-ohm, 5%, ¼-watt resistor
R30—30,000-ohm, 5%, ¼-watt resistor
R31—100,000-ohm, 5%, ¼-watt resistor
R32—100-ohm, 5%, 2-watt resistor
R33—250-ohm, 5W, wirewound potentiometer
R34—10,000-ohm, 5%, ¼-watt resistor
S1,S2—Spst switch
S3—Normally open pushbutton switch
S4,S7—Single-pole, 3-position rotary switch
S5,S6—Dpdt switch
T1—Transformer: 12.6V, 1A
T2—Transformer: 24V, 1A
Misc.—Suitable chassis, knobs (6) terminal strips, line cord and grommet, rubber feet (4), spacers, mounting hardware, etc.

Fig. 2. Power supply and delay circuit of tracer. Regulated supply insures stable operation. The sweep start control is adjusted to remove any curve instability.

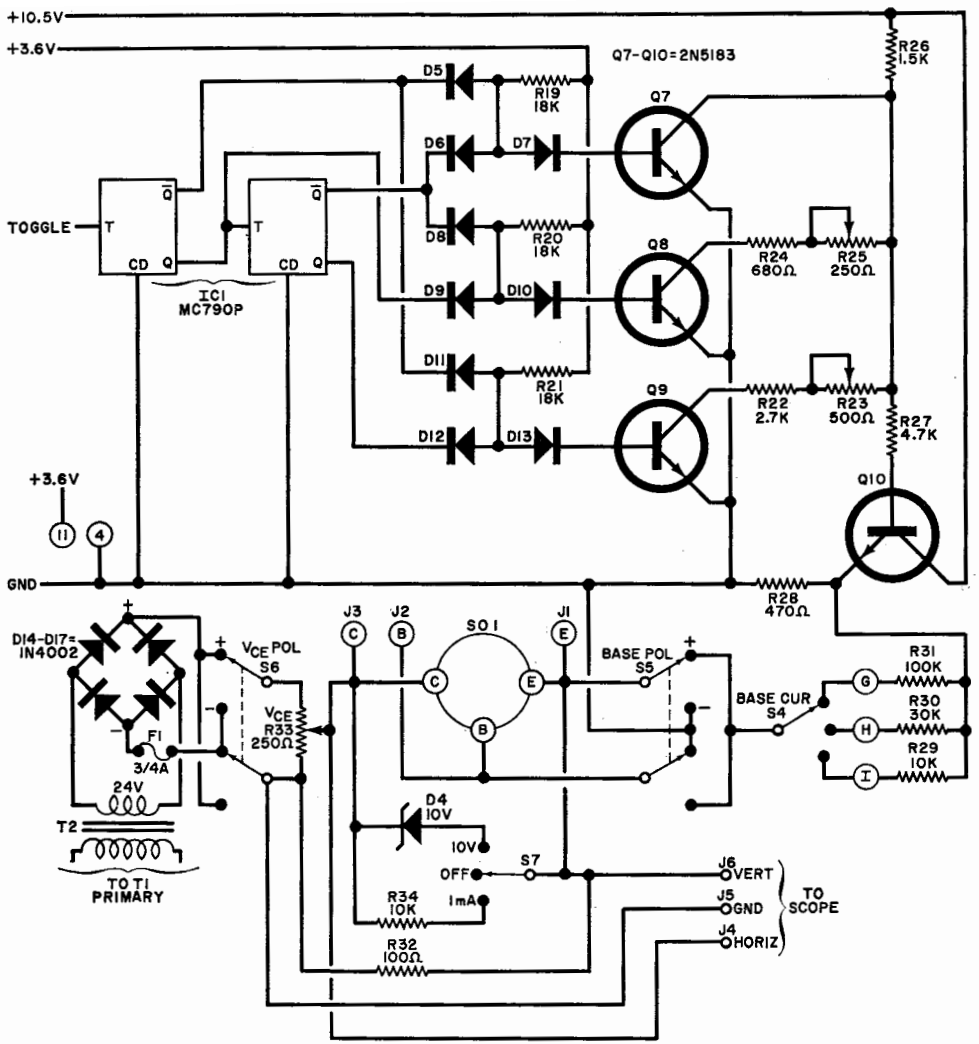


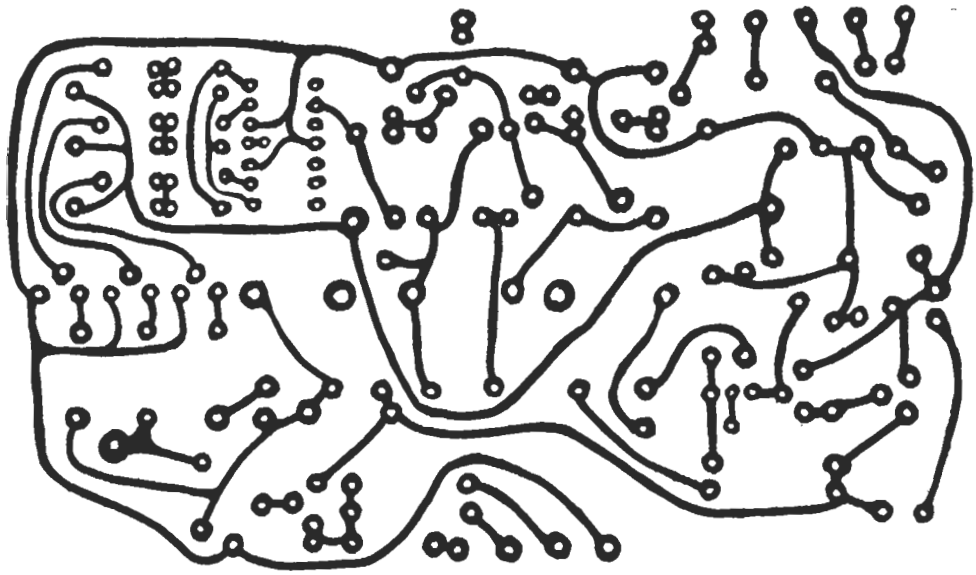
Fig. 3. Staircase generator uses divide-by-four logic circuit in association with diode gating to produce the four bias levels needed to create family of curves.

the bias current during each sweep interval to display a family of four curves. The staircase generator is synchronized to the power line frequency as shown in Fig. 1B. Figure 1C shows the scope curves for each value of base bias, and the final composite family of curves.

As shown in Figs. 2 and 3, a delay circuit consisting of *Q4*, *Q5* and *Q6* provides a variable delay to insure that the staircase switches at exactly the same time as the V_{CE} trace starts. This prevents "clutter" in the display.

Integrated circuit *IC1* provides a binary four count which is applied to *Q7*, *Q8*, and *Q9* through a diode gating network to produce the staircase bias levels. These are summed in *Q10* whose emitter is always at one of four voltage states: 0, 3, 6, or 9 volts. These voltages are determined by the divider made up of *R22* through *R26*; and they are preset by *R8*, *R23*, and *R25*.

The voltage staircase is coupled through one of three series bias resistors—*R29*, *R30*, or *R31*, selected by *S4*. This provides bias current values of 30, 60, and 90 microam-



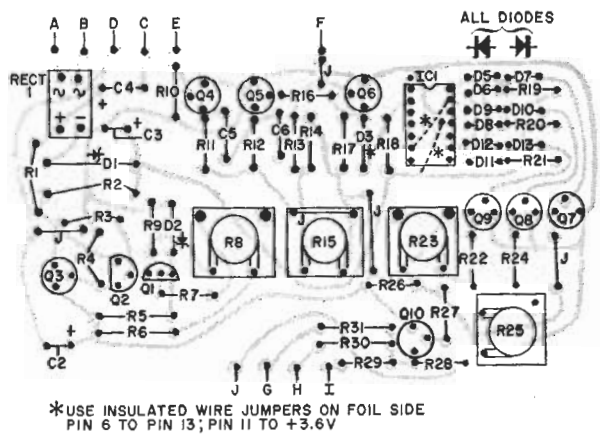


Fig. 4. Actual size foil pattern for circuit board is shown above with component layout at left. Circuit can be assembled on a standard perf board if preferred.

peres; 100, 200, and 300 microamperes; and 300, 600, and 900 microamperes. Each has an automatic zero voltage preceding it.

To add versatility, the polarities of V_{CE} and the base bias are independently selected by *S6* and *S5*, respectively. This permits the analysis of both junction and insulated gate FET's, as well as conventional npn and pnp transistors.

Construction. The curve tracer can be built on a perf board or a printed circuit board (Fig. 4). The board and other components can be mounted as shown in the photograph of the prototype. There is nothing critical about the layout, except that the horizontal and vertical scope termination wires should be kept away from other leads.

Calibration. With the circuit complete and power turned on, check that pin 11 of *IC1* is at 3.6 volts dc. Connect the dc voltmeter to the emitter of *Q3* (ground to minus side of *RECT1*), and adjust trimmer *R8* for 10.5 volts.

To check the staircase generator, connect an oscilloscope to the emitter of *Q10*, making sure that *S2* is in the AUTO position. When the existence of the staircase wave has been confirmed, remove the scope and place *S2* in the MANUAL position. Reconnect the dc voltmeter (10-volt scale) to the emitter of *Q10*. Operate pushbutton *S3* until the voltmeter indicates approximately 9 volts. (There should be four discrete voltage levels indicated as *S3* is operated.) With the voltmeter indicating approximately 9 volts,

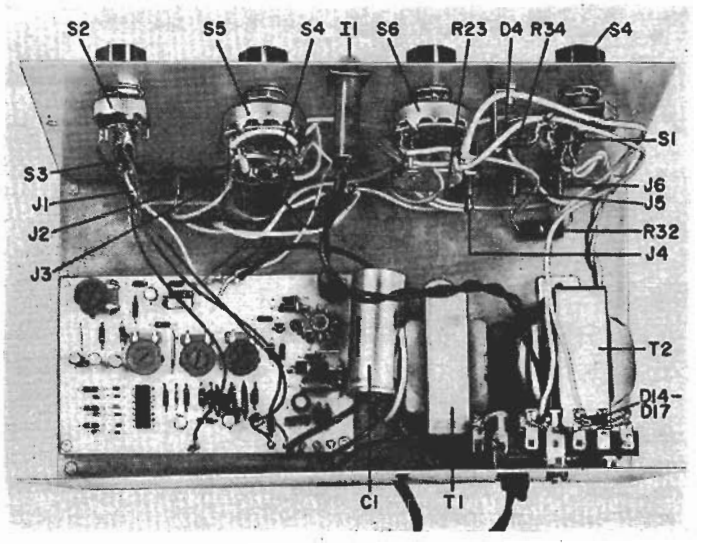


Photo of author's prototype. Note how C1 is not mounted on circuit board. Power supply components are mounted at right.

adjust *R8* for exactly 9 volts. Operating *S3* once should cause the voltage to drop to zero, and operating *S3* once more should bring the needle up near the 3-volt mark. Adjust *R25* to obtain exactly 3 volts. The next operation of *S3* should produce a 6-volt indication which is set by *R23*. The zero is automatic. Retest *S3* to indicate 0, 3, 6, and 9 volts at the emitter of *Q10*. When *S2* is placed in the AUTOMATIC position, the voltage will be an average 4.5 volts.

For most purposes, the base currents developed by these voltages can be assumed to be correct. However, it is actually one of these voltages minus the base-emitter drop of the transistor under test. For accurate calculations (if needed), the exact base currents can be found from the staircase voltage minus V_{BE} divided by *R23*, *R30*, or *R31*.

Operation. Connect the vertical, ground, and horizontal outputs to the proper terminals on the oscilloscope and set the scope for external horizontal input. To calibrate the scope graticule, place the CAL switch (*S7*) to the 10V position, set V_{CE} control (*R33*) to minimum, and place V_{CE} polarity switch on +. Rotate *R33* until the horizontal scope trace curves up. At this point, V_{CE} equals 10 volts (determined by diode *D4*). Adjustment of the scope horizontal gain enables calibration in volts per inch. Setting *S7* to the 1-mA position and adjusting the scope vertical control permits calibration in milliamperes per inch.

Insert a known good transistor in socket *SO1* and set polarity switch *S6* accordingly (+ for npn; − for pnp). Place switch *S2* on AUTO and select the desired base currents with *S4*. A family of four curves will be displayed on the scope. If you are using an ac-coupled scope, the curves will center about the zero axis; however, with a dc scope, the display will be more stable. Adjust *R15* for a stable display. ◈

I really don't think this is the way we should be deciding which of our designs is best for the project.