Transistor and FET Curve Tracer

Design of an adapter that permits you to display the characteristic curves of any transistor or FET on conventional scope.

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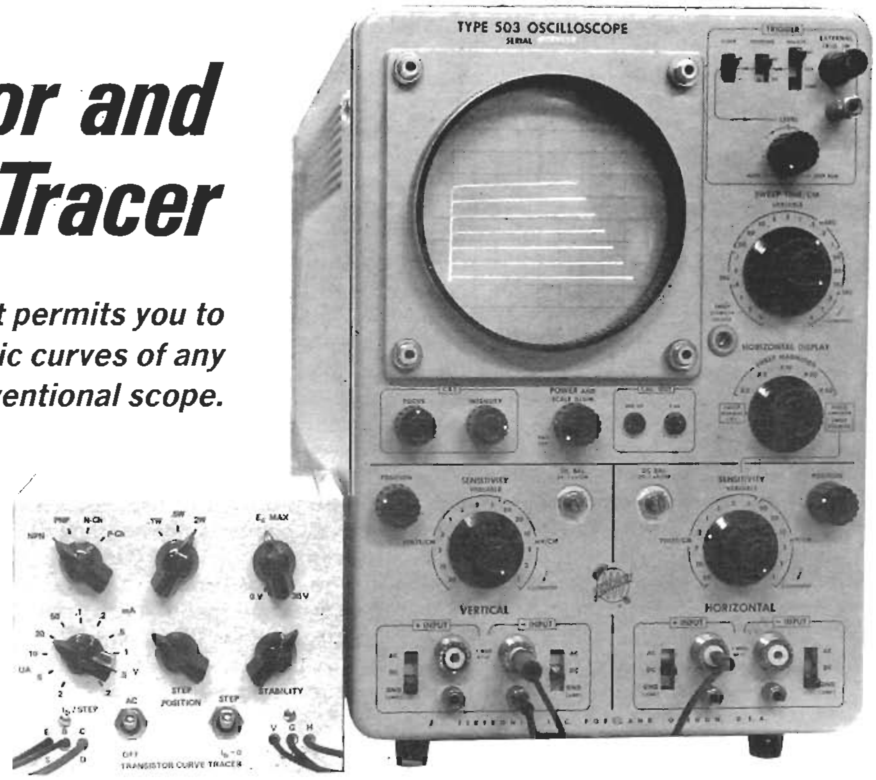


Curve tracer adapter being used to ▶ produce family of curves on scope.

NOTHING provides more information about a transistor than its family of collector characteristic curves. Typical characteristic curves are often given in manufacturers' data sheets, but these are of limited value because transistor characteristics may vary by as much as a factor of three or four either way from unit to unit. Temperature variations also cause considerable change in transistor characteristics, especially with germanium types.

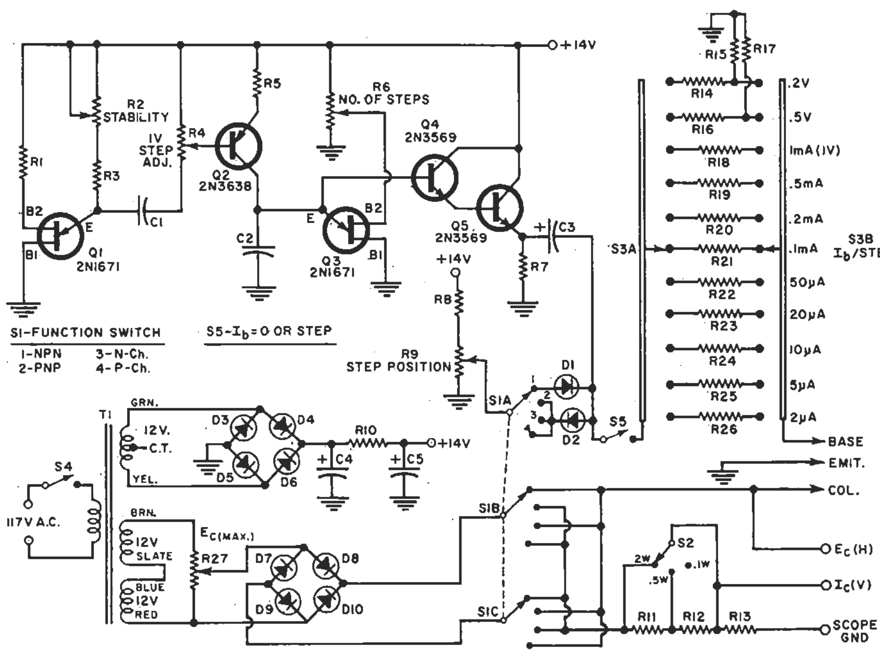
The adapter to be described will allow you to obtain an immediate display of the characteristic curves of any transistor or FET on a conventional oscilloscope. The following are some of the uses to which the curve tracer can be put:

● Determine the a.c. and d.c. *beta*, collector-to-emitter saturation voltage, collector breakdown voltage (up to 35 volts), and dynamic collector output resistance of a transistor.

● Observe the effects of temperature on transistor characteristics, either by applying heat externally or overbias-

R1—330 ohm, ½ W res.
R2—500,000 ohm pot ("Stability" control)
R3, R21—10,000 ohm, ½ W res.
R4—100 ohm trimmer ("1-V Step Adj.")
R5—33 ohm, ½ W res.
R6—10,000 ohm trimmer ("No. of Steps")
R7, R18—1000 ohm, ½ W res.
R8—1800 ohm, ½ W res.
R9—1000 ohm trimmer ("Step-Position" control)
R10—47 ohm, ½ W res.
R11—470 ohm, 1 W res.
R12—2700 ohm, ½ W res.
R13—100 ohm, 10 W res.
R14, R16, R17, R24—100,000 ohm, ½ W res.
R15—25,000 ohm, ½ W res. (selected, see text)
R19—2000 ohm, ½ W res. (selected)
R20—5000 ohm, ½ W res. (selected)
R22—20,000 ohm, ½ W res. (selected)
R23—50,000 ohm, ½ W res. (selected)
R25—200,000 ohm, ½ W res. (selected)
R26—500,000 ohm, ½ W res. (selected)
R27—500 ohm, 2 W pot ("$E_{C(max.)}$" control)
C1—0.05 μF, 200 V ceramic capacitor
C2—0.2 μF, 200 V Mylar capacitor
C3, C4—300 μF, 25 V elec. capacitor
C5—500 μF, 25 V elec. capacitor
S1—2-deck, 4-pole, 5-pos. selector sw. (3 poles, 4 pos. used) Centralab PA-1013 or equiv.
S2—S.p. 3-pos. selector sw. (Centralab 1461 or equiv.)
S3—2 deck, 11-pos. selector sw. (Centralab PA-1005 or equiv.)
S4, S5—S.p.s.t. toggle sw.

Fig. 1. Schematic of tracer. Q1, Q2, and Q3 comprise staircase generator, while Q4 and Q5 form Darlington emitter-follower providing current to drive the base of the test transistor. Collector sweep voltage comes from D7-D10 full-wave bridge.



T1—Transformer: 117 V pri.; three 12-V sec. at 0.1 A each (Stancor P-8351)
D1-D10—Silicon diode, 100 p.i.v. (1N628 or equiv.)

Q1, Q3—2N1671 unijunction transistor
Q2—2N3638 "p-n-p" silicon transistor
Q4, Q5—2N3569 "n-p-n" silicon transistor

ing the transistor and allowing it to generate its own heat.

- Observe the base-emitter input characteristics of a transistor.
- Observe the E *vs* I curves of diodes, zener regulators, and photocells.
- Selectively match transistors on input or output characteristics.
- Spot transistors with low breakdown or high saturation voltages as well as those with low *beta* or high leakage; the first two tests are usually not available on meter-type transistor testers.

Circuit Description

The basic function of the adapter is to supply a continuously sweeping voltage of the proper polarity to the collector of the transistor under test, while a staircase waveform is fed through a resistor to the base to produce the "steps" of base current. A different line in the family of curves is traced at each step of the staircase. For simplicity the sweeping voltage is an unfiltered, full-wave rectified 60-Hz sine wave obtained from *T*1 (Fig. 1). Fig. 3 shows the relationship of the collector sweeping voltage to the base driving voltage. Although they are shown in synchronism, there is no particular need to keep them in step, since the locus of points created by the two voltages will be the same for practically any staircase repetition rate. *Q*1, *Q*2, and *Q*3 comprise the staircase generator, while *Q*4 and *Q*5 form a very high input impedance Darlington emitter-follower to provide the necessary current to drive the base of the test transistor without loading and consequent distortion of the staircase-generator output.

*Q*1 is a conventional unijunction relaxation oscillator. *C*1 discharges through *R*2 and *R*3 until the emitter of *Q*1 reaches approximately 8 to 10 volts. *Q*1 then fires, conducting heavily from emitter to base 1 and passing a sharp negative spike through *C*1 to the base of *Q*2. *Q*2 is a constant-current source which is gated on by the negative spikes. *C*2 receives identical current pulses from the collector of *Q*2 for each negative spike produced by *Q*1, and therefore *C*2 charges by equal voltage steps at every spike. *Q*3 resets the staircase generator by discharging *C*2 when the voltage across it reaches the firing voltage of the unijunction.

*D*1 and *D*2 are clamping diodes which shift the d.c. level of the base-driving staircase voltage either positive or negative as required by the test transistor. *R*9 provides control over the d.c. level shift so that one of the staircase steps may be adjusted to a level which will give zero base current (zero gate voltage in the case of an FET test).

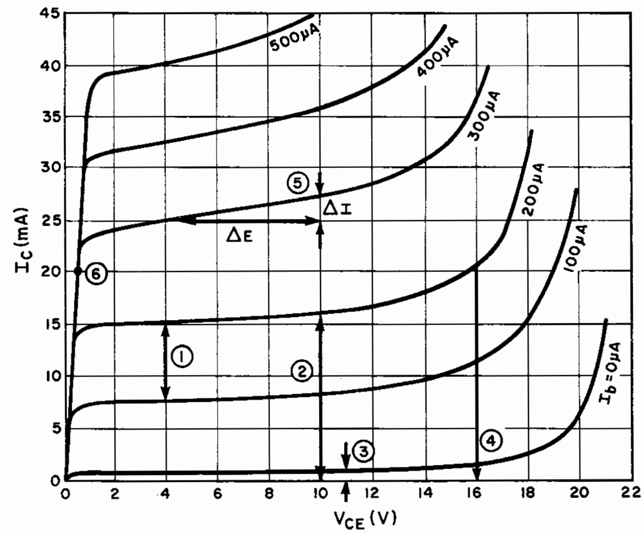


Fig. 2. Readings obtainable from characteristic curve display.
(1) A.c. beta = $\Delta I_c/\Delta I_b$ = (15—7.5 mA)/(200—100µA) = 75 (at E_c = 4 V, I_c = 12 mA).
(2) D.c. beta = I_c/I_b = 16 mA/200µA = 80 (at E_c = 10 V, I_c = 16 mA).
(3) I_{CEO} leakage = 1 mA at 11 V. Collector cutoff current, I_{CBO} is approximately equal to I_{CEO}/beta.
(4) Collector-emitter breakdown voltage = 16 V (at I_b = 200 µA).
(5) Collector dynamic output resistance = ΔE/ΔI = 6 V/2.5 mA = 2400 ohms (at E_c = 7 V, I_c = 25 mA). The commonly given parameter h_{OE} = ΔI/Δ E = 2.5 mA/6 V = 416 micromhos.
(6) Saturation voltage $V_{CE(SAT)}$ = 0.5 V at I_c = 20 mA.

Fig. 3. Relationship of base-driving staircase to collector voltage. Upper trace, 2 volts/division; lower trace 10 volts/div.

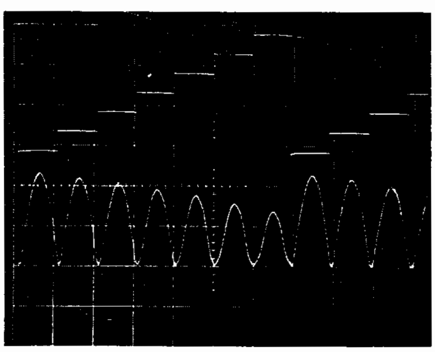


Fig. 4. Display for 2N3569 silicon "n-p-n" transistor. Waveform scales are 2 V/div. horiz., 2 mA/div. vert.; I_b = 10 µA/step.

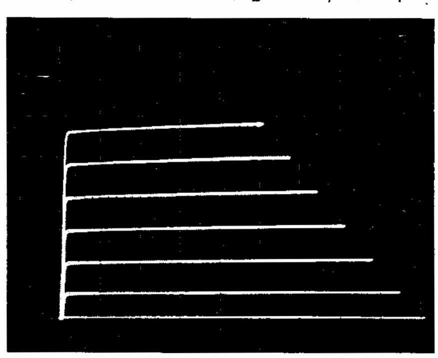
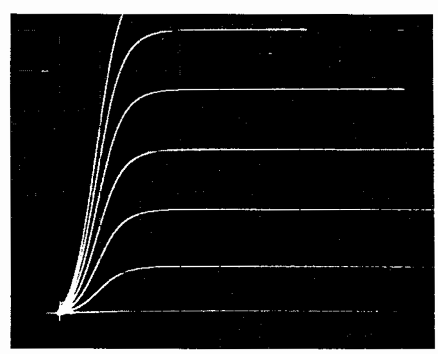


Fig. 5. Expanded detail of saturation region of 2N3569. Scales are 0.1 V/div. horiz., 1 mA/div. vert.; I_b = 10 µA/step.



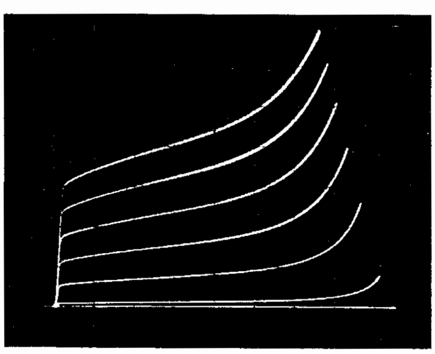


Fig. 6. Display for 2N404 germanium "p-n-p" transistor. Waveform scales are 2 V/div. horiz., 2 mA/div. vert.; I_b = 10 µA/step.

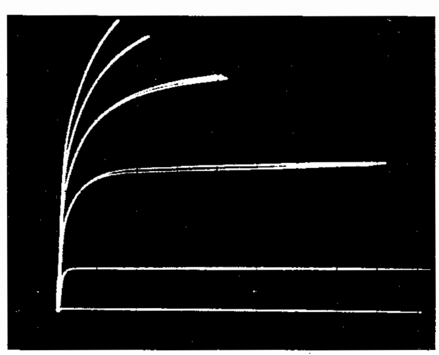


Fig. 7. Display for 2N3053 silicon "n-p-n" power transistor. The scales are 2 V/div. horiz., 20 mA/div. vert.; I_b = 0.5 mA/step.

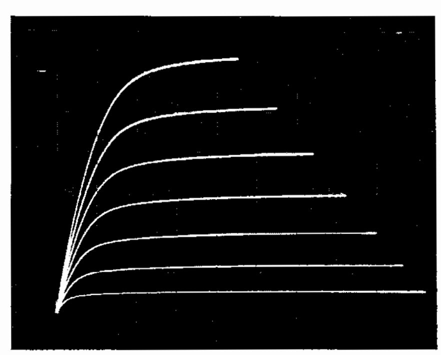
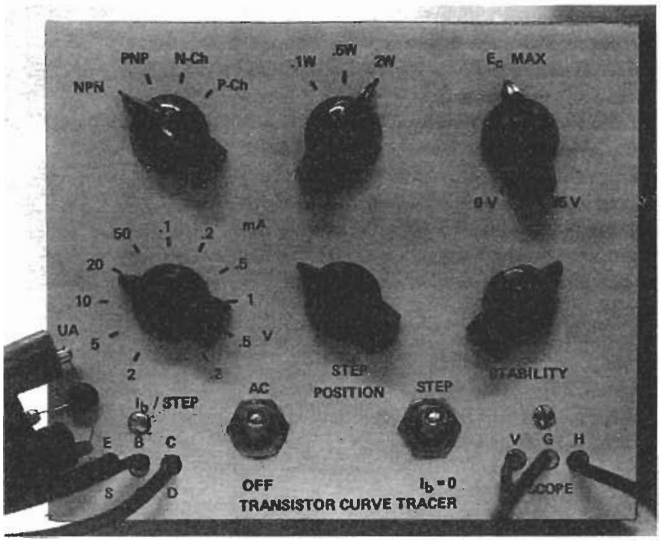
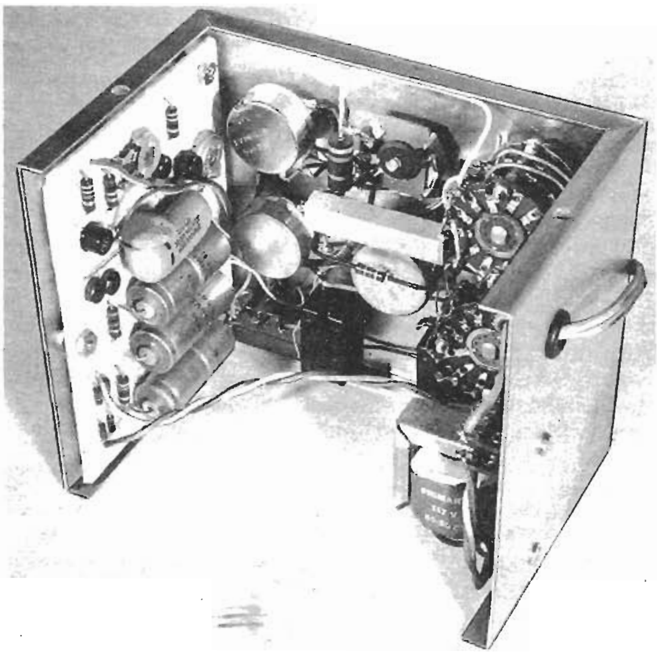


Fig. 8. Display for 2N3819 "n"-channel FET. Scales are 2 V/div. horiz., 2 mA/div. vert; E_{gate} = 0.5 V/step; 2nd line from top E_g = 0.



Close-up of the front panel of the transistor curve tracer.



Inside view of curve tracer showing the construction details.

*R*11, *R*12, and *R*13 are provided in series with the collector of the test transistor to prevent damage due to excessive power dissipation. *R*13 also serves as a current-sensing resistor, providing 0.1 volt to the vertical amplifier of the oscilloscope for each milliampere of collector current.

The parts for the adapter retail cost the author about $35, although few of them are critical and many substitutions can be made to take advantage of components already on hand. For example, nearly any unijunction transistor will do for *Q*1 and *Q*3, since differences in parameters can be offset by adjustment of trimmer potentiometers *R*4 and *R*6. *Q*2, *Q*4, and *Q*5 should be small-signal silicon types, but there are undoubtedly hundreds of types which will work as well as the particular ones used in this unit. Similarly, diodes *D*1 through *D*10 may be nearly any silicon junction type.

Resistors *R*14 through *R*26 are all standard-value components selectively picked from a junkbox for the values noted on the diagram (a high "4.7k" was used for the 5k-resistor, for example). Capacitors *C*3, *C*4, and *C*5 must be several hundred μF each, but there is nothing special about the particular values shown. Capacitor *C*2 is perhaps the most critical component; it must have a leakage resistance of 10 megohms or more if a clean CRT display is to be obtained.

The curve tracer is housed in a standard aluminum box with most of the electronic circuitry built on a 3″×5″ piece of perforated breadboarding stock. Resistors *R*4 and *R*6 are miniature trimmers mounted directly on the board. All other variable resistors and switches are mounted on the front panel. Resistors *R*14 through *R*26 are connected directly between corresponding pins of the two decks of *S*3. In wiring the transformer secondaries, it is important that the two series windings be connected in-phase as shown in Fig. 1. Reversal of one of the secondaries would result in the voltage canceling instead of adding as desired.

Calibration and Test

Once a thorough check of the wiring has been made, the adapter is ready for test and calibration. The power supply should be checked first; 14 volts should be measured across filter capacitor *C*5 and a drop of approximately 0.5 volt should appear across series resistor *R*10. Readings which differ significantly from these norms indicate a serious malfunction which should be located before further tests are conducted.

Next, a calibrated oscilloscope should be connected to the emitter of *Q*3. If all is well, a staircase waveform will be observed. *R*4 is then adjusted so that each step of the staircase represents a 1-volt increase. *R*6 is adjusted to provide the desired number of steps (this will be the same as the number of trace lines in the family of curves displayed on the screen).

It is recommended that a low-power silicon *n-p-n* transistor be used as a test transistor to gain some familiarity with the curve tracer. Set the function switch *S*1 to position 1 (NPN), the power switch *S*2 to .1 W, the E_C control *R*27 at midrange, the I_b/Step switch to 10 μA, the Position control *R*9 full counterclockwise, the Stability control *R*2 near the center of its range, and the $I_b = 0$-Step switch *S*5 to Step. It is a good idea to make these initial settings with the a.c. switch (*S*4) off to avoid inadvertently applying damaging voltages to the test transistor while switching ranges.

The E_C output of the adapter is connected to the external horizontal input of the scope and the I_C output is connected to the vertical amplifier. If the scope is calibrated, the horizontal scale can be read directly in volts, while on the vertical scale each volt represents 10-mA collector current. If the scope does not have both normal and inverting inputs, you may have to settle for a display which is either upside down or backwards from the usual position, but the same information can be obtained in any case.

With *S*4 "on," a characteristic-curve display should be obtained on the scope. The stability control is then adjusted to minimize the flicker of the display. The step adjust is set so that the first display line corresponds to the single line obtained when *S*5 is set to $I_b = 0$. A summary of the readings which can be taken from the display is given in Fig. 2.

Junction and insulated-gate field-effect transistors may be tested by connecting the emitter, base, and collector leads to the source, gate, and drain, respectively, of the FET. If there is a fourth "substrate" lead, it should be connected with the source. *S*3 must be set to one of the last three positions to provide the necessary gate-voltage steps. Again, the step-position control must be adjusted so that one of the display lines corresponds to the single line obtained when *S*5 is set to $I_b = 0$.

Transistor base-emitter input characteristics, as well as characteristics for rectifier and zener diodes, photocells, and other two-lead devices can be obtained by using the "emitter" and "collector" leads only to supply a sweeping voltage. *S*2 should be left on the .1-W position for such applications unless the device under test is capable of handling currents of 10 mA and above.

Typical curves produced by the instrument are shown in Figs. 3 through 8. ▲