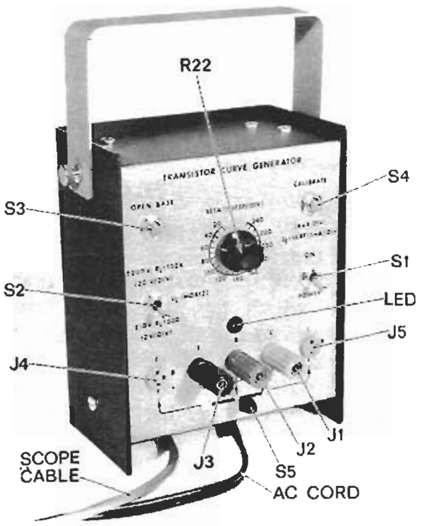
Build This Transistor Curve Tracer

Used with your scope, the transistor curve tracer lets you check transistors and other solid-state devices in-circuit as well as out-of-circuit

by CHARLES E. MULLETT, P.E. & CHARLES CARINGELLA, W6NJV



FRONT VIEW of the completed transistor curve generator. This compact instrument measures only 6" high x 4½" wide x 2½" deep.

TRANSISTORS AND OTHER SOLID-STATE devices are now found in all types of equipment. If you are involved in designing or servicing such equipment, the transistor curve generator described here will be a valuable addition to your test equipment. If you already own an oscilloscope, you will want to build this sophisticated, yet easy-to-use test instrument. For the circuit designer, and even the experimenter, the combination of scope and transistor curve generator form a versatile tool for evaluating transistor and other solid-state device parameters. Service technicians will find the curve generator indispensable and a real time saver when troubleshooting and servicing all types of equipment, since the unit checks transistors and other solid-state devices *in-circuit*, as well as out of circuit.

Using high-gain silicon Darlington-amplifier transistors, silicon programmable unijunction transistors, silicon pnp transistors, and a ±15-volt integrated circuit (IC) regulator in the transistor curve generator circuit, simplifies what would normally be a rather complex design. The clean straightforward design results in an instrument that is easy to build, and even easier to use. Even the panel indicator light is solid-state! An LED (Light-Emitting Diode) is used to indicate when the power is on.

When used with an oscilloscope, the transistor curve generator displays the dynamic characteristics of both npn and pnp transistors, field-effect transistors, diodes, Zener diodes, tunnel diodes, and other devices. It can be used with almost any scope that has a vertical sensitivity of 0.1 V/cm, a horizontal sensitivity of 2 V/cm, and a minimum bandwidth of 100 kHz.

The instrument includes all the circuits needed to generate the base steps and collector sweeps, and the internal regulated power supply operates from the 117-volt ac line.

The number of front panel controls have been kept to a minimum, making the unit almost as easy to operate as a vom! Several unique features are built into the transistor curve generator:

1. Simultaneous calibration of the vertical and horizontal channels in the scope is done by simply pressing the CALIBRATE button on the front panel. This eliminates any guesswork in analyzing the scope traces.

2. Direct readout of transistor beta is available on the front-panel dial of the BASE DRIVE control.

3. Both npn and pnp transistors can be tested consecutively without changing any controls or switches.

There are two transistor test sockets and a set of three binding posts on the front panel for testing various semicon-

PARTS LIST

All resistors are ½-watt carbon. Tolerances are 10% except as noted.
R1—330 ohms
R2—150 ohms
R3, R10—4,700 ohms
R4—1,800 ohms
R5—68,000 ohms
R6, R19—47 ohms
R7—33,000 ohms
R8—1,000 ohms
R9—15,000 ohms
R11, R14, R18, R20, R21—10,000 ohms
R12—47,000 ohms
R13—390 ohms
R15—82 ohms
R16—100 ohms, miniature circuit board trimmer (Mallory MTC12L1 or equal)
R17—820 ohms
R22—100,000-ohm potentiometer, see text (Allen-Bradley type "J")
R23—1,500 ohms
R24—100,000 ohms, 5%
R25, R26—12 ohms, 5%
R27—910,000 ohms, 5%
R28—110,000 ohms, 5%
R29—20 ohms, 5%
R30—390 ohms, 5%
R31—620 ohms, 5%
C1—0.1μF, miniature disc
C2—.01 μF, mylar
C3—.002 μF, mylar
C4, C7, C8—.05 μF, mylar
C5, C6—100 μF 35-volt, printed circuit type electrolytic
C9, C10—10 μF, 25-volt, printed circuit type electrolytic
C11, C12—270 pF, ceramic capacitor
D1, D2, D3, D4, D5, D6—1N914 silicon diode
IC1—Dual-polarity tracking regulator (Silicon General SG3501T)
J1—Red binding post
J2—Blue binding post
J3—Black binding post
J4, J5—Transistor socket (TO-5 type)
LED—Light-emitting diode, with mounting clip (Monsanto MV5020 series, red solid-state lamp)
P1—Ac power plug
Q1, Q9—Motorola MPS-A14, npn silicon Darlington amplifier
Q2, Q10—Motorola MPS-A65, pnp silicon Darlington amplifier
Q3, Q5, Q6, Q7—Motorola 2N3905 pnp silicon
Q4, Q8—Motorola MPU-131, silicon programmable unijunction
S1—dpdt miniature toggle (JBT type JMT-223 or equal)
S2—3-pole double throw minature toggle (JBT type JMT-323 or equal)
S3, S4—spdt pushbutton (Switchcraft 953 or equal)
S5—3-position miniature lever (Oak 3991-63-184)
T1—power transformer: primary 117 volts; secondary windings: 33 volts ct rms @ 20 mA; and 170 volts rms @ 2 mA.
Printed circuit board
Cabinet with handle
AC power cord
Strain relief for ac power cord
Thumb screws, 6-32 x ¼" (2)
Knob
Small tapped angle brackets (tapped for 6-32 screws) (8)
MISC—Shielded cable, screws, hex nuts, lockwashers, flat washers, hook-up wire, solder

The following are available from Caringella Electronics, Inc., P.O. Box 327, Upland, Ca. 91786. California residents must add 5% sales tax.
Printed circuit board—No. TCG-1, drilled and printed with part numbers, $14.95 postpaid
Power Transformer—No. PT-1431, $9.95 postpaid
Set of semiconductors— $17.00
Complete kit—No. TCG-1K, Includes cabinet with printed panel, all parts and hardware, wire, and solder. Complete step-by-step instructions, $79.95 +$1.50 for handling and shipping.

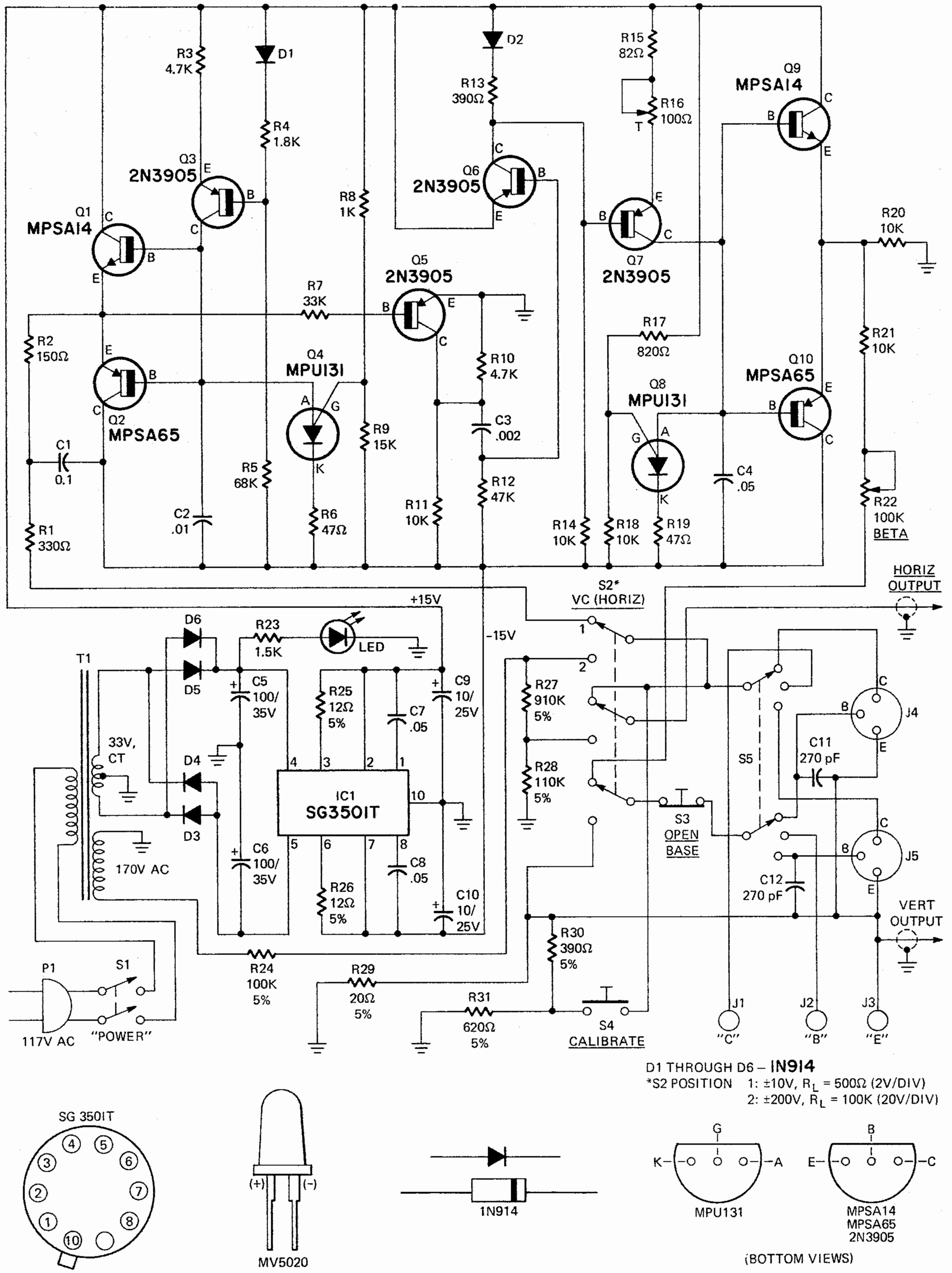
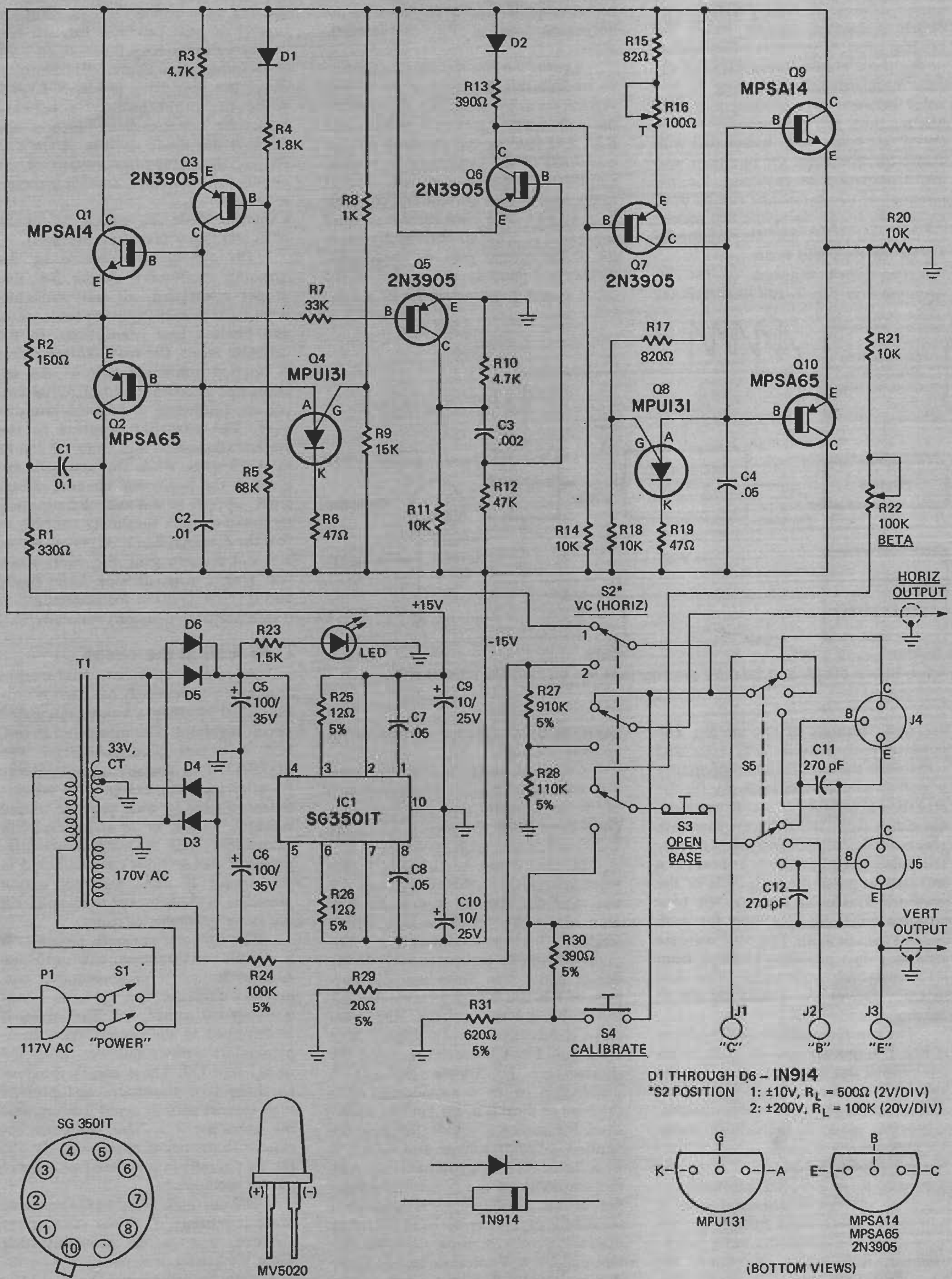


FIG. 1—COMPLETE SCHEMATIC DIAGRAM. "V_C" switch, S2, is shown in the normal mode, which is the ±10-volt, R_L= 500-ohm position. Switch S5 is the three-position lever switch. The LED is powered from the +15-volt unregulated side of the power supply.



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ductor devices. A three-position lever switch is located directly below the binding posts. It switches either socket, or the three binding posts into the circuit. Standard ¾-inch spacing is provided between each binding post. The binding posts will accommodate a variety of test leads, each terminated with clamp-on type clips, for in-circuit testing. Comparing or matching the parameters of two transistors can be done quickly by simply using the two sockets on the front panel, and flipping the lever switch back and forth.

The block diagram of the instrument is in Fig. 2, and illustrates the five basic sections of the circuit. The power supply delivers +15 volts and −15 volts to the signal generating circuits, as well as a ±200-volt sinewave for the breakdown test. A ±12-volt sawtooth waveform from the collector sawtooth generator also triggers the pulser circuit. The pulser circuit produces a short (17 μ sec) current pulse for each cycle of the sawtooth. This pulse advances the base staircase generator one step for each cycle of the sawtooth. The base staircase generator then produces 12 steps, from −12 volts to +12 volts. The test switches deliver the proper signals to the device under test.

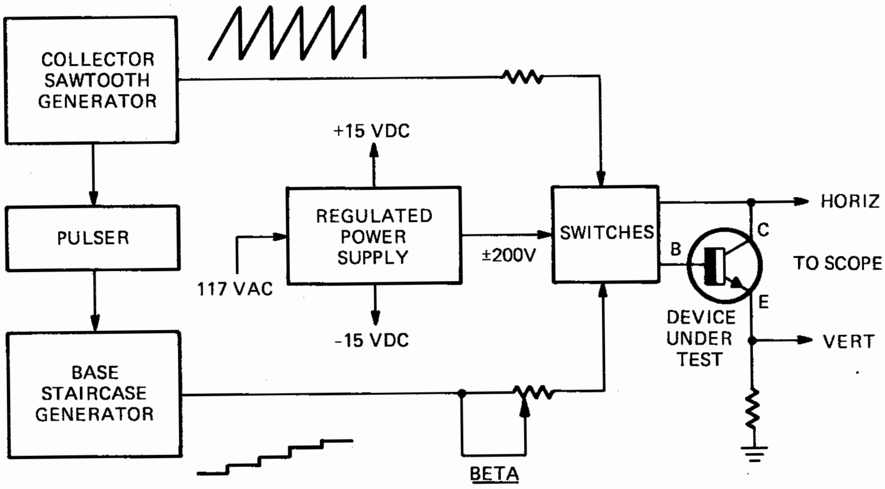

FIG. 2—BLOCK DIAGRAM of the curve generator illustrates the five basic sections of the circuit.

The complete schematic diagram is in Fig. 1, as are the base connections for the various transistors, diodes, and the light-emitting diode. Operation of the instrument consists of three modes: **1.** Normal mode **2.** Breakdown mode **3.** Calibrate

Normal Mode (V_C switch, S2, in the ±10-volt, R_L = 500-ohm, position)

Base current is delivered from a staircase of 2-volt steps from −12 volts to +12 volts through the BETA potentiometer, R22, which determines the base current per step.

Collector voltage is supplied from the sawtooth generator through a 500-ohm fixed load impedance. Collector voltage is delivered to the scope's horizontal amplifier and is displayed as the horizontal axis of the characteristic curves.

Emitter current through the transistor under test is displayed on the scope's vertical axis by sampling the current through resistor network R29, R30, and R31, and feeding the resulting voltage waveform to the oscilloscope's vertical amplifier. Since emitter current is equal to the sum of base current and collector current, and since base current is small compared to collector current (by a factor of the current gain, or "beta") the display is a good approximation of the usual collector characteristics of a transistor, namely, collector current versus collector voltage.

Collector voltage is swept from −12 volts to +12 volts during each step of the base current staircase.

Breakdown Mode (Vc switch, S2, in the ±200-volt, R_L = 100K, position)

In this mode, a ±200-volt sine wave is applied to the collector of the test transistor through R24, a 100,000-ohm source resistor. This high source resistance limits test current to a maximum of 2 mA to prevent damage to the device under test. Since the sole purpose of this test is to determine the collector breakdown voltage, the base drive is disconnected. To display both open-base breakdown (BV_{CEO}) and the shorted-base breakdown (BV_{CES}), a pushbutton switch is provided to open the base or short it to the emitter, as desired. Resistors R27 and R28 sample the applied collector voltage and reduce it by a factor of 10 for compatibility with the sensitivity of the horizontal amplifier of the oscilloscope. A horizontal sensitivity of 2 volts/division will then display 20 volts/division from the device under test. Vertical deflection in the display is again derived from the emitter current resistor network, R29, R30, and R31.

Note that in BASE SHORTED (pushbutton not depressed) one polarity of the sine wave displays BV_{CES}, while the other half-cycle produces forward bias on the collector-base junction. In BASE OPEN (pushbutton depressed) one polarity of the sine wave produces BV_{CEO}, while the other half-cycle forward biases the collector-base junction and displays this diode drop in series with BV_{EBO}, the breakdown voltage of the emitter-base junction, another parameter of interest.

Calibrate Mode (V_C switch, S2, in the ±10-volt, R_L = 500-ohm, position)

The system is calibrated by depressing CALIBRATE switch S4. For proper calibration, all test transistors must be removed from the test sockets and binding post connections. In the calibrate mode, the sawtooth waveform is applied simultaneously to the oscilloscope's vertical and horizontal amplifiers, producing a diagonal line display. The sawtooth applied to the vertical channel swings from −0.2 volts to +0.2 volts, while the sawtooth applied to the horizontal channel swings from −4 volts to +4 volts. By adjusting the oscilloscope's sensitivity controls so that the diagonal line is displayed across a 4 x 4 division grid, the oscilloscope will read 2 volts/division horizontally and 0.1 volt/division (corresponding to 5 milliamperes/division) vertically.

Let's look at the circuit

A rather complex dual-output regulated power supply has been greatly simplified by using a unique integrated circuit regulator. The integrated circuit, IC1, is a new Silicon General type SG3501T. It is actually a dual-polarity tracking regulator designed to provide balanced positive and negative output voltages. A total of 24 active elements (transistors and a temperature-compensated Zener diode) are included in this unique IC. The regulator output provides +15 volts and −15 volts for the curve generator circuitry.

The collector sawtooth generator is a simple unijunction sawtooth oscillator. It uses a programmable unijunction transistor, Q4, fed from a constant-current source, Q3. The sawtooth is delivered to the output via a complementary emitter follower composed of Q1 and Q2. These are Darlington-amplifier type transistors and provide high current gain to avoid loading timing capacitor C2. The sawtooth oscillator frequency is approximately 550 Hz, and results in a flicker-free display on the oscilloscope.

The sawtooth is fed to Q5's base to make it saturate when the sawtooth is negative, and to be non-conducting when the sawtooth is positive. As a result, a square wave is produced at Q5's collector, with its positive-going edge coincident with the negative-going transition of the sawtooth. The positive transition of the square wave is coupled to Q6's base via capacitor C3. This cuts off Q6 until capacitor C3 charges through R12 to return Q6 to its normal saturated state. While Q6 is saturated, Q7 cannot conduct, so no current appears at its collector. During the brief "off" period of Q6, however, Q7's base voltage falls, causing it to conduct, with its collector current determined by potentiometer R16, which calibrates the base steps. This current is delivered to the base staircase generator, and its magnitude determines the amplitude of each step in the staircase.

The base staircase generator is another unijunction circuit similar to the collector sawtooth generator. Because capacitor C4 is fed from short pulses of current from transistor Q7, rather than from a constant-current source, its output is a staircase waveform with each "step" held at a fixed voltage by capacitor C4 between current pulses. Each current pulse raises the output voltage one step, until programmable unijunction transistor Q8 fires and the staircase begins again. Q9 and Q10 form another complementary emitter follower. R22 is the front-panel BETA control.

S5 is a two-pole three-position lever switch. It simply switches the base and collector signals to either test socket or the binding posts, which all are located on the front panel. S2, the V_C switch, is a three-pole double-throw toggle switch, and is used to select the NORMAL or BREAKDOWN test mode.

S3 is a normally closed pushbutton switch and is used for OPEN BASE operation. This opens the circuit to the base of the device under test.

CALIBRATE switch S4 is a normally open pushbutton switch. It connects the output of the collector sweep generator to the emitter circuit of the device under test and also loads this output. The result is a ±4-volt sawtooth at the horizontal output and a ±0.2-volt sawtooth at the vertical output.

Construction tips

The entire transistor curve generator circuit, with the exception of the various switches and controls, is assembled on a printed circuit board measuring only 3½" x 5". An actual-size drawing of the circuit board pattern, as viewed from the copper-foil side, is in Fig. 3. An X-ray view of the circuit board is in Fig. 4. This view clearly shows the location of all components mounted on the top side of the circuit board.

The following sequence should be followed in building up the circuit board assembly. First install the jumper wire on the board. Solder in the six diodes next. They should rest flat against the circuit board. The integrated circuit goes in next. Space the IC about ¼" above the circuit board. Make sure it is oriented properly on the board before soldering. Once it has been soldered in place, it is extremely difficult to remove. In this circuit, the IC runs slightly warm, but a heat sink is not necessary for safe operation. All of the transistors should be installed next. Space them about ¼" above the circuit board.

The resistors can all go on the board next. Mount them vertically, with one end of each resistor resting against the board. Next mount all of the capacitors. Be sure to observe the polarity of the electrolytics. R16, a printed-circuit type potentiometer, is installed next.

Power transformer T1 is installed last. The leads from the secondary windings are connected directly to the circuit board, while the 117-volt primary leads are run directly to switch S1. The high-voltage leads (blue leads) connect to holes **H** and **G** on the circuit board. Connect the low-voltage leads

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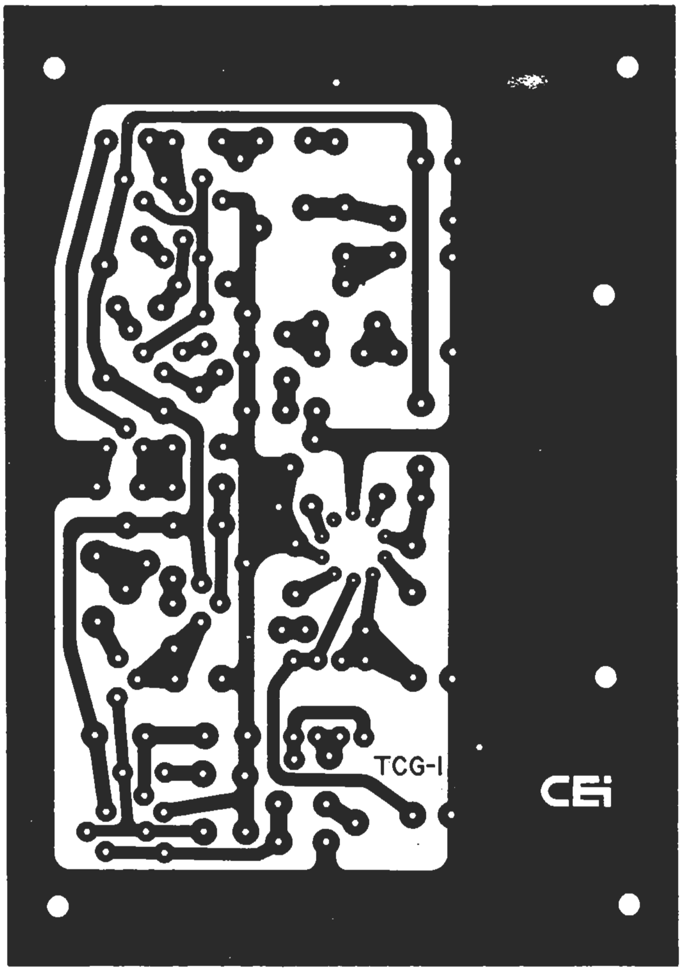

FIG. 3—THE PRINTED-CIRCUIT board pattern, as viewed from the copper side, is shown here actual size. The board measures 3½ in. x 5 in.

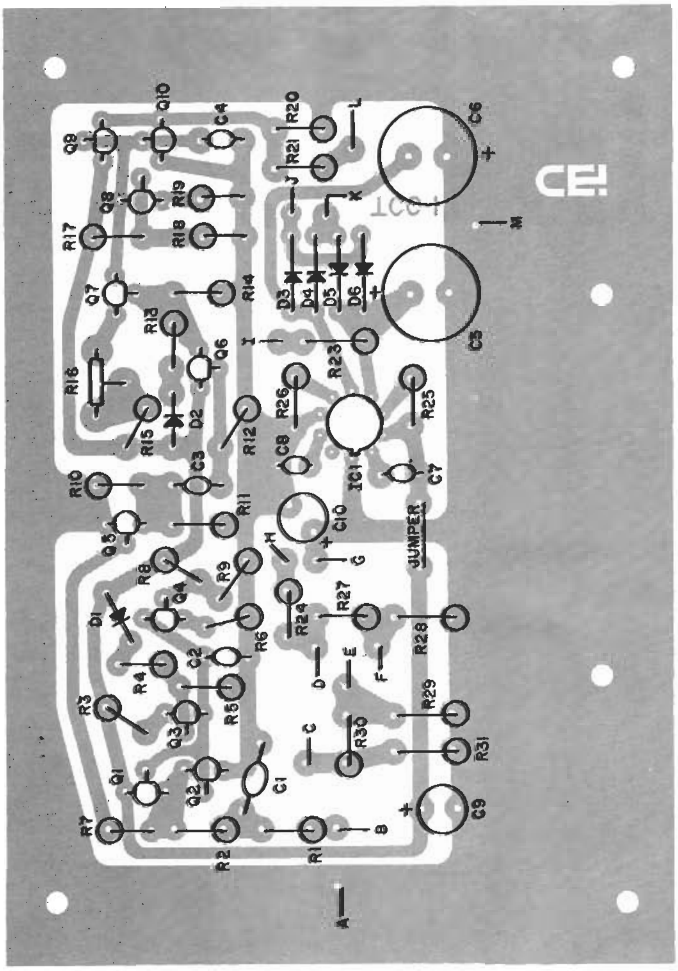

FIG. 4—X-RAY VIEW of the PC board showing the location of all components on the "top" side of the board. The holes identified by letters are for the connecting leads to the switches and control on the front panel.

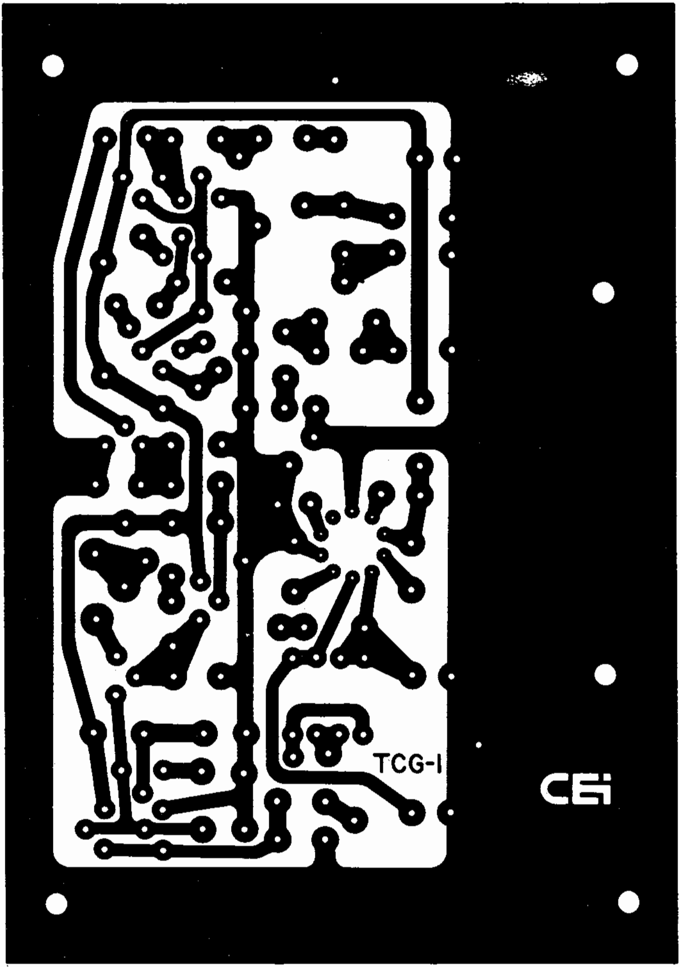

FIG. 3—THE PRINTED-CIRCUIT board pattern, as viewed from the copper side, is shown here actual size. The board measures 3½ in. x 5 in.

(red leads) to holes **J** and **K.** The center tap lead (red-yellow lead) is connected to hole **M;** ground.

The remaining holes on the circuit board are used for the connecting leads to the switches and control on the front panel. The leads from the circuit board assembly to the front panel can be formed into one 8-conductor cable. (Fig. 5)

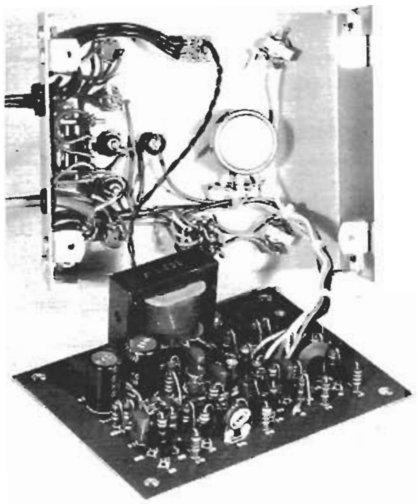

FIG. 5—INSIDE VIEW of the completed Transistor Curve Generator. An 8-conductor cable is used between the circuit board assembly and the front panel.

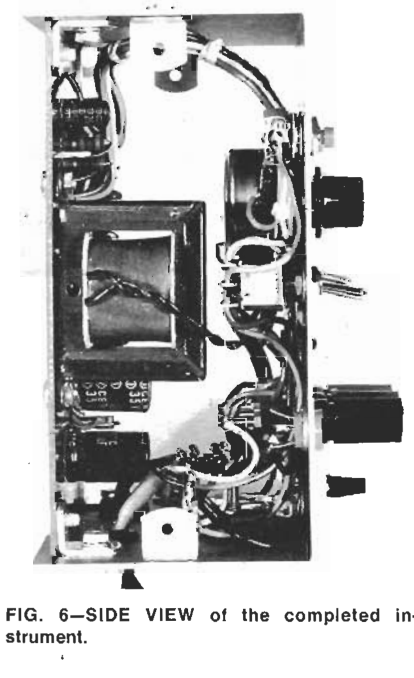

FIG. 6—SIDE VIEW of the completed instrument.

The cabinet can be made from .050" sheet aluminum formed into two "U" shaped pieces. One piece is used for the front panel, and the other piece for the cover. The handle should be fabricated from slightly heavier gauge sheet aluminum. Tapped angle brackets hold the cover to the front panel. A total of eight angle brackets is required. Four are used for the cover. The other four hold the circuit board assembly in place. (see Fig. 6) Using the screw which holds one of the angle brackets in place, install a solder lug for the chassis ground connection. This "ground" solder lug should be installed at the location nearest the point-of-entry of the shielded output cable.

Install two standard TO-5 transistor sockets on the front panel. Lever switch S5 is installed directly below the binding posts. Three colors are used for the binding posts—black for emitter connection J3; blue for base connection J2; and red for collector connection J1. The LED (*L*ight *E*mitting *D*iode) panel indicator light is located directly above the binding post. The type specified in the parts list comes with a plastic mounting clip. The two miniature toggle switches, S1 and S2, can be installed next.

BETA potentiometer R22 is installed last. This control must be a high-quality molded composition potentiometer, with a ±10% tolerance, such as the Allen-Bradley type "J". An actual-size drawing of the beta dial is shown in Fig. 7.

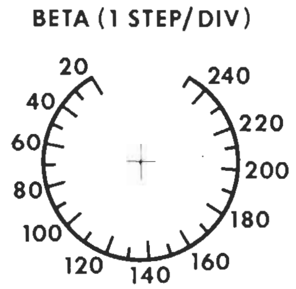

FIG. 7—ACTUAL SIZE DRAWING of the dial for the "BETA" control.

Once all of the parts have been installed on the front panel, the unit is ready for final wiring. These connections are made between the circuit board assembly and the front cover:

Hole A to chassis ground lug
B to S2
C to S4
D to S2
E to S2
F to S2
I to LED (positive or "plus" lead)
L to R22

The ac power cable is brought into the cabinet through the bottom of the front panel and connects to power switch S1. Use strain relief on the panel for the power cord. The oscilloscope connecting cable is not critical, and may be an ordinary 2-conductor shielded cable, or even two single-conductor shielded cables. One is used for the vertical output and the other for the horizontal output.

Using the generator

The LED panel indicator light should glow when the unit is turned on. This indicates that the unregulated +15-volt side of the power supply is working. Next, the +15-volt and −15-volt dc outputs from the power supply regulator should be checked. Using a vom, read these voltages at C9 and C10, with respect to ground, as shown in the schematic. If the voltages check out properly, proceed with the final adjustments.

Connect the transistor curve generator to your oscilloscope's vertical and horizontal inputs. Press the CALIBRATE button and a diagonal line trace should appear on the scope. The calibrating voltages are accurate to ±10%. Adjust the scope's vertical and horizontal sensitivity controls so the diagonal line is displayed across a 4 x 4 division grid. The oscilloscope is now calibrated and will read 0.1 volts/division vertically, which corresponds to 5 mA/division. The vertical axis displays the collector current of the test transistor. In the normal operating mode, the scope will read 2 volts/division horizontally, and in the breakdown mode, the scope will read 20 volts/division horizontally. The horizontal axis displays the collector voltage of the test transistor.

If you use an oscilloscope with triggered sweep, then its sweep generator should be turned off to eliminate the possibility of Z-axis modulation of the display.

The only internal adjustment required is to set trimmer resistor R16. This adjustment calibrates the base steps. First, plug a pnp transistor into one of the test sockets on the front panel, and an npn transistor into the other socket. Now, turn the BETA control fully counterclockwise (pointing to "240" on the dial). Flip lever switch S5 back and forth, so the pnp and npn transistor curves are alternately displayed on the scope. Adjust the trimmer resistor so only five curves appear for the pnp display, and likewise, five curves appear for the npn display. Switch back and forth between the two transistors until this has been done. The end result should look like the family of curves shown in Fig. 8. Fig. 8-a is the typical display for a pnp transistor. Fig. 8-b is the typical display for an npn transistor.

The base steps are now calibrated. Beta for the transistor under test can be read directly from the dial by simply turning the BETA control for a spacing of one division between curves in the display. The spacing between curves increases as the BETA control is turned clockwise.

Fig. 8-c shows the breakdown for a 2N2369 npn transistor. This is actually a double exposure. Reading left to right, the first and third lines on the trace are produced when the OPEN BASE pushbutton is depressed. When it is not depressed, the second and fourth lines ap-

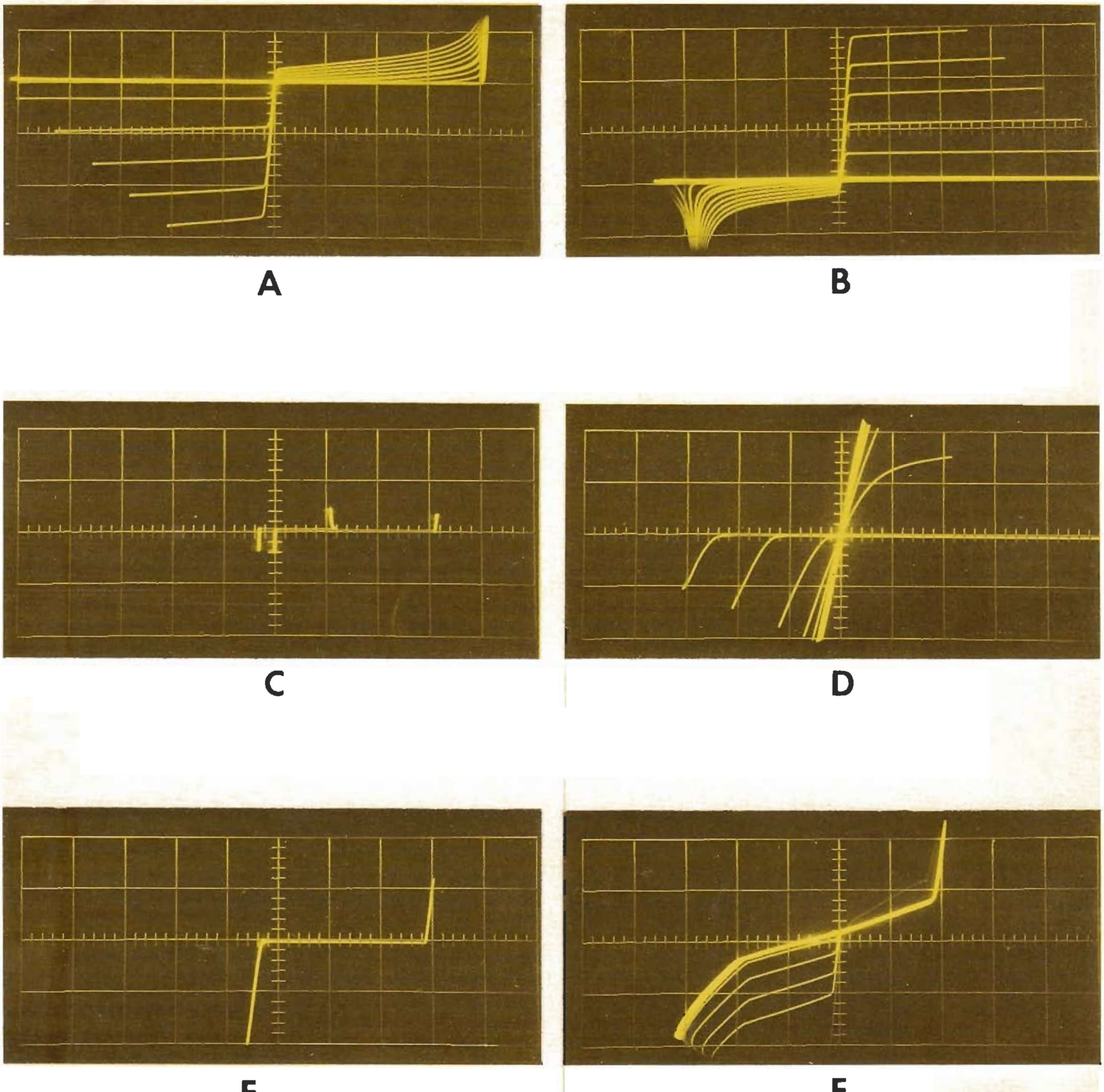

FIG. 8—TYPICAL OSCILLOSCOPE DISPLAYS shown here are as follows:a—pnp transistor, b—npn transistor, c—2N2369 breakdown test, with traces reading left to right, BV_{EBO} + C-B diode, C-B diode, BV_{CEO}, and BV_{CES} (Note that this photo is actually a double exposure), d—n-channel junction field-effect transistor, e—6-volt Zener diode, and f—pnp transistor "in circuit".

pear on the trace. Be careful when checking metal-can transistors in the breakdown mode. There is high voltage between the transistor case and ground since the collector is tied to the case in most types. The current is limited to only 2 mA, so it is not dangerous.

A typical n-channel junction FET is shown in the display in Fig. 8-d. When checking FET's, the drain is connected to the collector test point, the gate is connected to the base test point, and the source is connected to the emitter test point.

Diodes are connected between the emitter and collector test points, and may be oriented either way. A typical 6-volt Zener diode is shown in Fig. 8-e.

A typical pnp transistor, measured in circuit, is shown in Fig. 8-f. When making in-circuit checks, the power to the equipment under test should be turned off! In-circuit testing of transistors is strictly a "go/no-go" type of test, since the family of curves will vary drastically from those produced out-of-circuit. The transistor curve generator will spot defective transistors quickly and efficiently, and should make a worthwhile addition to any service facility. **R-E**