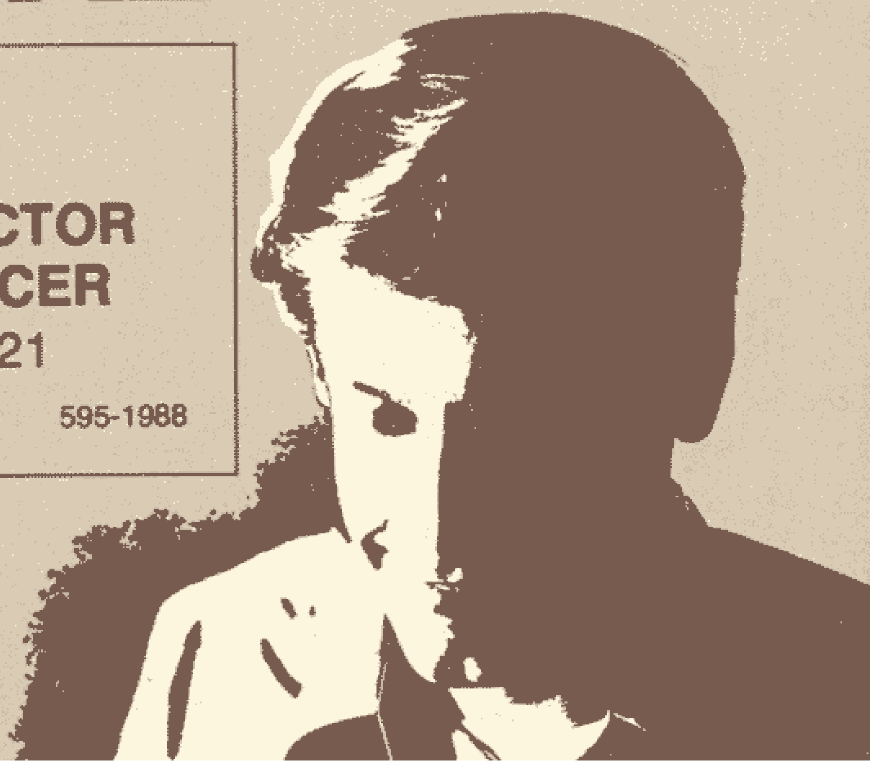
HEATHKIT® MANUAL

for the

SEMICONDUCTOR CURVE TRACER

Model IT-3121

595-1988



OPERATION

CONTROL FUNCTIONS

Refer to Figure 2-1 (fold-out from Page 48) as you read the description of each control function.

1. PILOT LAMP (PL1) – Indicates when the Curve Tracer is plugged in and turned on.

2. SWEEP VOLTAGE (R6, SW1) – Combination ON–OFF switch and SWEEP VOLTAGE control. Turns the unit on and off, and sets the value of the sweep voltage at "C" terminals.

3. HORIZONTAL SENSITIVITY (SW6) – While the oscilloscope monitors the sweep voltage on the device under test, this switch selects one of the nine voltage ranges for a proper display.

4. VERTICAL SENSITIVITY (SW7) – Selects one of nine current ranges so the oscilloscope can monitor the current (produced by the sweep voltage) passing through the test device.

5. POLARITY (SW3) – Selects either NPN or PNP (N-channel or P-channel).

	Sweep Voltage	Current Steps	Voltage Steps
NPN	positive	positive	negative
PNP	negative	negative	positive

6. SWEEP RANGE (SW2) – Selects sweep voltage of either 0-40 V (at up to 1 ampere maximum) or 0-200 V (at up to 200 milliamperes maximum). Always use the lower range unless more voltage is needed.

7. STEP SELECTOR (SW9) – Selects either VOLTAGE or CURRENT steps, and the polarity of the signal supplied to the B output terminals.

8. STEPS/FAMILY (R47) – Adjusts the number of steps from zero to nine.

9. STEP RANGE (SW8) – Selects either current steps or voltage steps, depending on the setting of the STEP SELECTOR switch. Provides 12 values of current steps or 5 values of voltage steps.

10. LIMITING RESISTOR (SW4) – Selects one of 11 resistors plus zero ohms. These current limiting resistors protect the device under test. Use the highest value that gives a consistent display.

11. LEFT TRANSISTOR SOCKET – For testing small transistors out of circuit. Active when the LEFT-RIGHT switch is at LEFT.

12. LEFT BANANA JACKS – Use these jacks with the supplied cables to test large semiconductors in and out of circuit. Active when the LEFT-RIGHT switch is at LEFT.

13. LEFT-RIGHT (SW5) – Selects either the left or right socket and jacks.

14. RIGHT BANANA JACKS – Use with the supplied cables to test large semiconductors in or out of circuit. Active when the LEFT-RIGHT switch is at RIGHT.

15. RIGHT TRANSISTOR SOCKET – For testing small transistor out of circuit. Active when the LEFT-RIGHT switch is at RIGHT.

16. H, G, V TERMINALS – Provide output connections to an oscilloscope.

H connects to the horizontal input.
G connects to ground.
V connects to the vertical input.

17. LOOP (R5) – Compensates for circuit capacitance to minimize looping in the display.

18. NORM-CAL (SW10) – In the CAL position, dots resulting from a precision staircase waveform are applied to the oscilloscope for calibration. The NORM position provides normal operation.

CURVE TRACER CHARACTERISTICS

Because of the great versatility of this Curve Tracer, in a few instances the display may be other than ideal. These can be caused by the limitations of the device being tested, interaction between the tested device and the Curve Tracer, and, in some cases, the Curve Tracer itself.

Refer to Figure 2-2 as you read the following information.

A. A coil-like loop may occur here with sweep voltages higher than 30 volts. Higher limiting resistance will minimize this effect.

B. Looping (double line) may occur with low sweep currents (.5 mA/div) and high sweep voltages (above 30 volts). Use the LOOP control to minimize this effect.

C. This hump may occur with certain transistors. Use a higher value of limiting resistance to minimize the hump.

D. A faint line at higher sweep voltages (above 30 volts) is more noticeable with less steps and can be minimized by adding more limiting resistance.

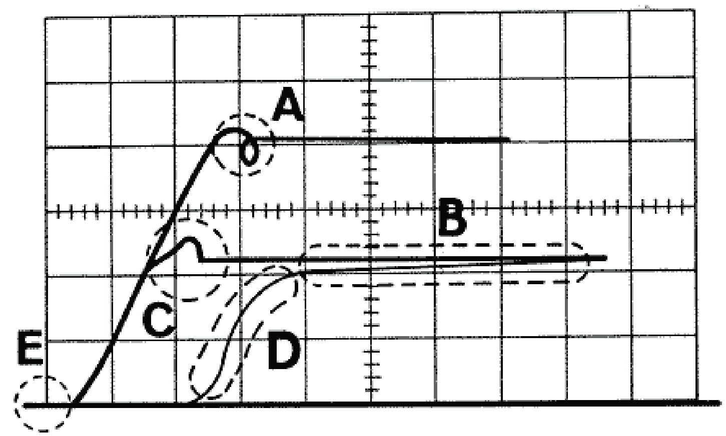


Figure 2-2

E. Some reverse voltage sweep will appear here on the .1 volts range for the low sweep range, and on the .1 volt/div through the 5 volt/div on the 200 volt sweep range.

APPLICATIONS

GENERAL INFORMATION

PRECAUTIONS

To protect the device being tested, always observe the following precautions.

- Keep the SWEEP VOLTAGE below the collector breakdown level except during the short time of a collector voltage breakdown test. Although the limiting resistors prevent destruction of the transistor, high internal temperatures from long periods of operation may cause the transistor to fail.

- Limit the testing of power transistors without heat sinks to a few seconds — just long enough to make an accurate reading. Excessive temperatures in the test device may result from longer periods of operation. Start and stop the tests by using the LEFT-RIGHT switch.

- Before you make a test, be sure the following controls are set as follows:

SWEEP VOLTAGE	Fully counterclockwise
SWEEP RANGE	0-40 V
LIMITING RESISTOR	5 k or higher
STEP RANGE	.02 mA/Step or less

Return the controls to these positions after each test. This will insure that no device will be accidentally destroyed.

- Completely remove power from the unit under test. The Curve Tracer supplies the complete test signal. Any additional signal or DC current may make the test inaccurate and could damage the unit.

TESTING BIPOLAR TRANSISTORS

The most common use of the Curve Tracer is to test NPN and PNP transistors. The family of curves of an NPN transistor is in a positive direction. That is, zero volts is at the left and zero current is at the bottom of the display. The curves sweep upward and to the right as collector voltage and current increases, and the sweep voltage is positive.

The curves of a PNP transistor, however, are in the negative direction. Zero volts is at the right and zero current is at the top of the display. The curves sweep downward and to the left as collector voltage and current increase, and the sweep voltage is negative.

Any test of an NPN transistor can be performed on a PNP and vice versa. The displays are merely inverted.

Transistors can be tested for:

- Current gain (DC and AC beta)
- Collector-to-emitter breakdown
- Collector-to-base breakdown
- Output admittance
- Saturation voltage
- Saturation resistance
- Cutoff current
- Leakage current
- Linearity and distortion
- Temperature effects
- Identifying germanium or silicon
- Matching
- Sorting and substitution

TRANSISTOR IDENTIFICATION

To test a transistor you need to know three things.

1. The basing configuration (E, B, C, or S, G, D). Figure 2-3 shows some of the more common configurations. If the transistor type number is available, the basing configuration can be found in the manufacturer's handbook. Also, a schematic may provide this information.

2. The type (NPN or PNP). This information can come from the circuit, schematic, manufacturer's handbook, or from the Curve Tracer as described on Page 66.

3. The power class. See Figure 2-3. (Signal, intermediate power, or power.)

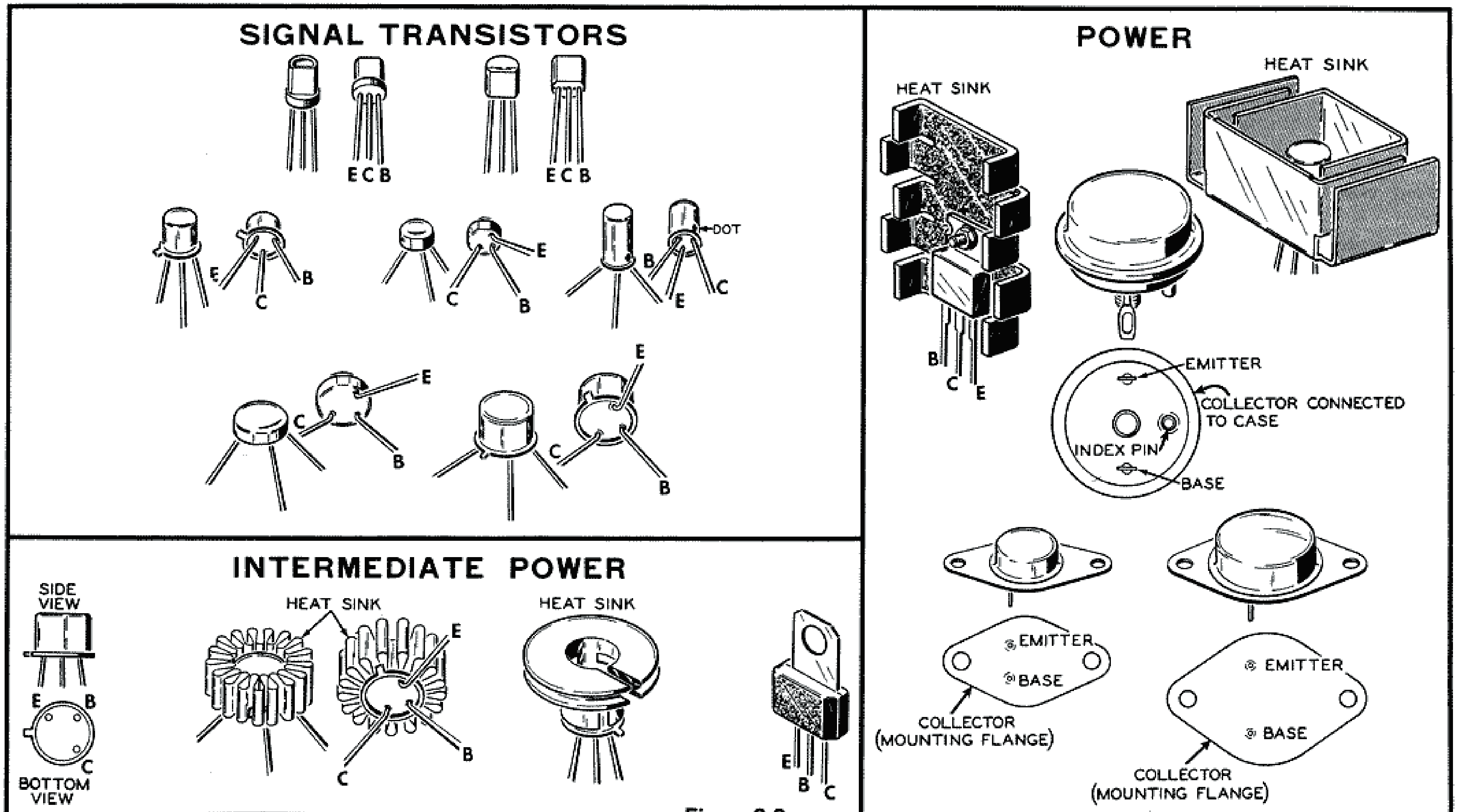


Figure 2-3

INITIAL DISPLAY

To obtain an initial display, set the Curve Tracer controls as shown below. Note that the switches marked with an asterisk are always in these positions for transistor tests. Refer to Table 1 and make other control settings according to the power rating of the transistor. Also, if the oscilloscope is not connected and calibrated, see "Oscilloscope Calibration" on Page 54.

SWEEP VOLTAGE	– Fully counterclockwise and off.
HORIZONTAL SENSITIVITY	– See Table 1.
VERTICAL SENSITIVITY	– See Table 1.
POLARITY	– Set for type of transistor.
SWEEP RANGE	– 0-40 V.
STEPS/FAMILY	– Fully clockwise.
*STEP SELECTOR	– Current.
STEP RANGE	– See Table 1.
LIMITING RESISTOR	– See Table 1.
LEFT-RIGHT	– Left.
LOOP	– Fully clockwise.
*NORM-CAL	– Norm.

	Base Step	HORIZONTAL SENSITIVITY	VERTICAL SENSITIVITY	LIMITING RESISTOR	SWEEP RANGE
SIGNAL	.002	1 V/div.	.5 mA/div.	5 k	0-40 V
INTERMEDIATE POWER	.02	1 V/div.	5 mA/div.	500	0-40 V
POWER	.2	1 V/div.	50 mA/div.	50	0-40 V

TABLE 1

( ) Turn the SWEEP VOLTAGE control clockwise only far enough to turn the unit on.

( ) Connect the transistor to be tested to the right socket, or to the E, B, C terminals with test leads.

( ) Set the LEFT-RIGHT switch to RIGHT.

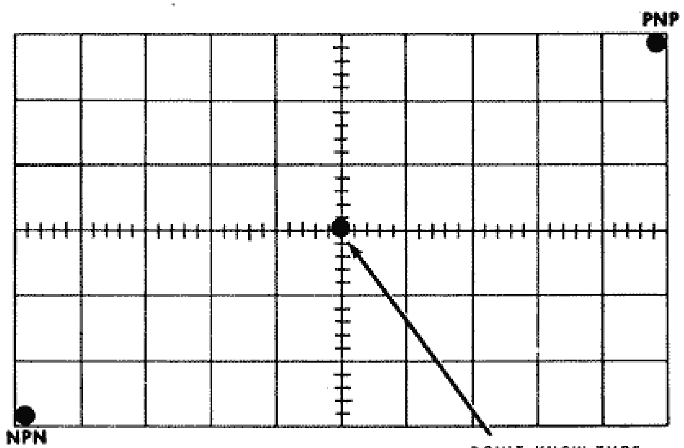


Figure 2-4

( ) If the transistor is an NPN, place the dot in the lower left-hand corner of the screen. If it is a PNP, place it in the upper right-hand corner of the screen. If you don't know if it is NPN or PNP, place the dot in the middle of the screen as shown in Figure 2-4.

NOTE: Perform the following numbered steps only if you don't know if the transistor is an NPN or PNP.

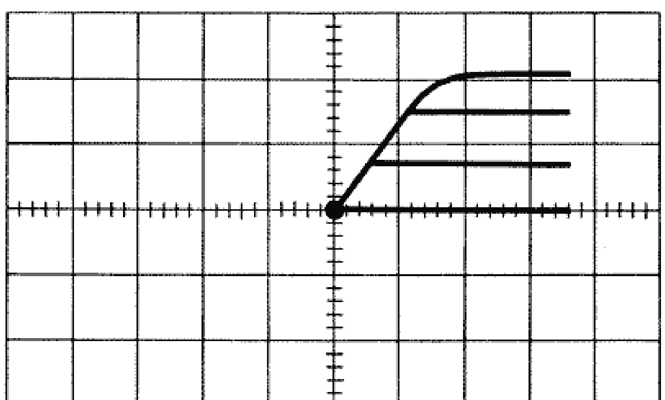


Figure 2-5

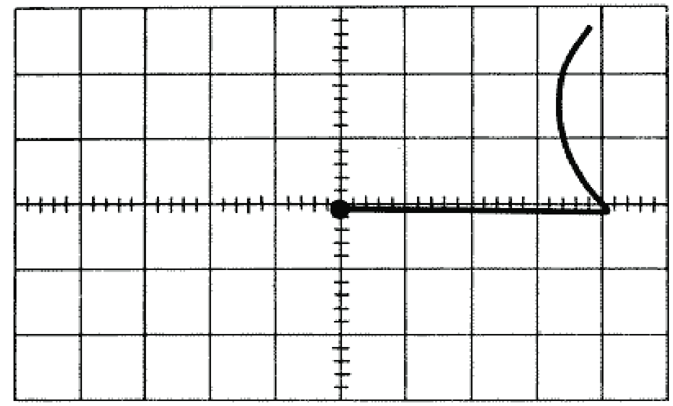


Figure 2-6

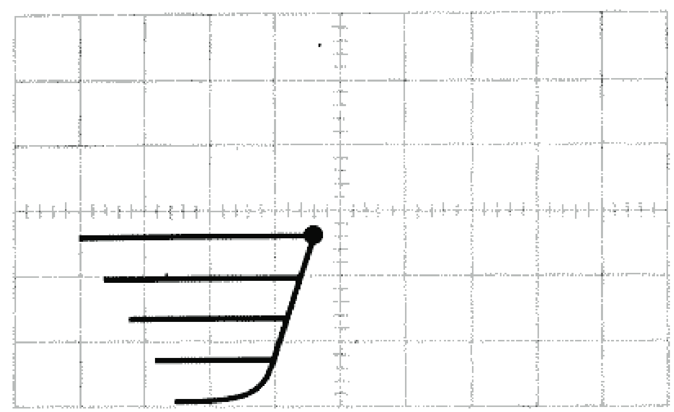


Figure 2-7

1. Slowly turn up the SWEEP VOLTAGE control. If the transistor is an NPN, curves will appear as shown in Figure 2-5. If it is a PNP, no curves will appear and breakdown, as shown in Figure 2-6, may appear. If this happens, switch the Polarity control to PNP. Then curves as shown in Figure 2-7 should appear.

2. Refer again to Figure 2-4, turn the SWEEP VOLTAGE control fully counterclockwise, and place the dot in the appropriate corner of the screen for NPN or PNP.

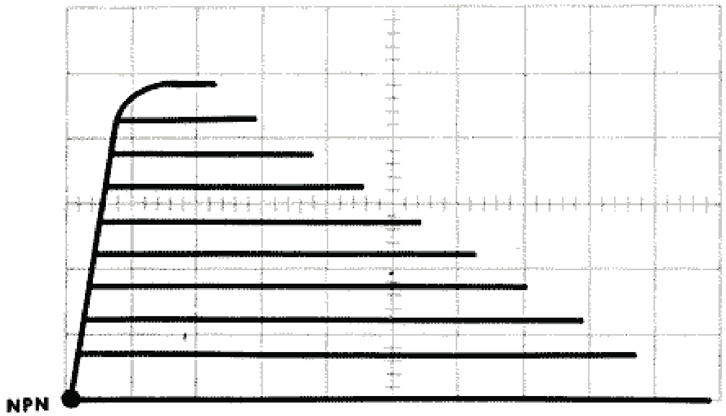


Figure 2-8

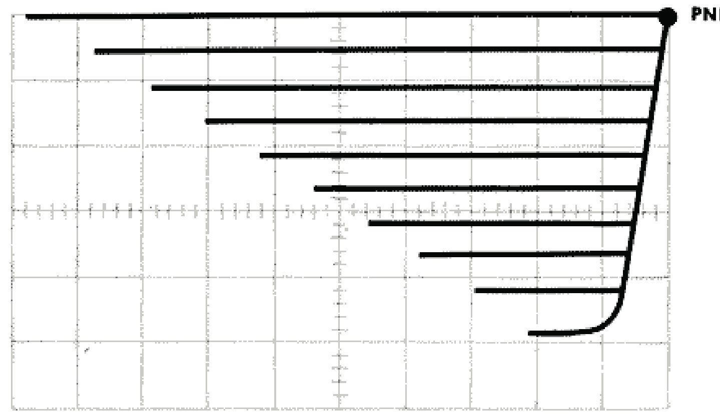


Figure 2-9

Figures 2-8 and 2-9 show typical displays of NPN and PNP transistors. They are identical – only inverted.

NOTE: If some curves go off the screen, switch the VERTICAL SENSITIVITY control to the next higher range (clockwise). Also, you may have to lower the LIMITING RESISTOR value. If the curves are to close together, select a more sensitive current range.

Table 2 gives ranges of operating parameters for transistors with different power ratings. Use Table 1 as a starting point to ensure that the device will be operated within its specifications. Always be cautious when you use ranges listed in Table 2 so that the device ratings are not exceeded.

	BASE CURRENT RANGE	COLLECTOR CURRENT RANGE	VOLTAGE RANGE
SIGNAL (Audio, RF, IF, etc.)	.002 through .1 mA/step	.5 through 5 mA/div.	STAY BELOW DEVICE BREAKDOWN
INTERMEDIATE POWER (Audio, Switching)	.02 through 1 mA/step	2 mA through 50 mA/div.	STAY BELOW DEVICE BREAKDOWN
POWER (Audio, Output, Regulator)	.2 through 10 mA/step	20 mA through 200 mA/div.	STAY BELOW DEVICE BREAKDOWN

TABLE 2

MEASUREMENTS

In-Circuit Tests — Many times these can only be made by comparing results with those known to be proper. If no curves can be obtained at all, remove the device from the circuit and then test the device.

Matching Transistors — It is often desirable to match transistors for gain, linearity, saturation, output admittance, etc. Use the LEFT-RIGHT switch to compare the curves. Matched devices have identical curves.

Sorting Transistors — To sort transistors, use the oscilloscope controls and place the CRT dot (with no input signal) in the center of the screen. Then NPN transistors will produce curves in the upper right-hand quadrant of the screen and PNP transistors will produce curves in the lower left-hand quadrant of the screen as you flip the NPN-PNP switch back and forth.

Integrated Circuits — Integrated circuits are often several transistors, diodes, etc. packaged together. These IC's may be tested if the internal devices can be identified and isolated to specific terminals of the IC. Note, however, that other circuit elements may produce loops in the curves, or other variations, of the display.

The following are examples of typical measurements and the control settings under which they were performed. Many of these use the extra MPSA20 (#417-801) transistor supplied with your kit; the control settings may vary widely for other devices.

NOTES:

1. All of these tests, unless they are described otherwise, were made with the NORM-CAL switch in the NORM position, the LOOP control adjusted for minimum looping, the LEFT-RIGHT switch in the LEFT position, and the SWEEP VOLTAGE control adjusted clockwise for a proper display.

2. If a transistor is open, only the base line will appear on the display. If the transistor is shorted, there will be a vertical line as in Figure 3-2 but there will be no base line.

Proceed to the heading of the test you are interested in.

SATURATION VOLTAGE [$V_{CE\ (sat)}$]

MPSA20:

HORIZONTAL SENSITIVITY	.1 volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	5 steps
STEP RANGE	.01 mA/Step
LIMITING RESISTOR	0

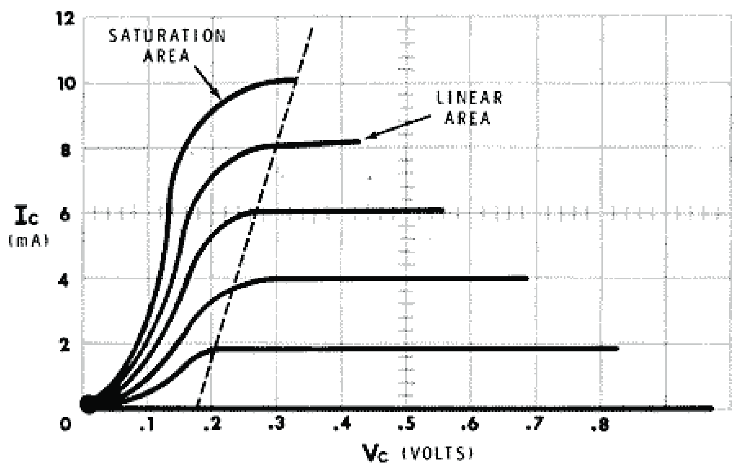


Figure 3-1

The collector saturation region of a transistor is that portion of the family of curves in the area of low collector voltage and current below the knee of each curve. The knee of each curve occurs at approximately the same collector voltage (from .18 to .32 in Figure 3-1). Collector voltage above the knee has little effect on collector current; the base current controls collector current in this area.

MPSA20: $V_{CE\ (sat)}$ = 0.25 VDC (MAX) @ I_c = 10 mA and I_B = 1 mA.

HORIZONTAL SENSITIVITY	.1 Volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	1 Step
STEP RANGE	1 mA/Step
LIMITING RESISTOR	0

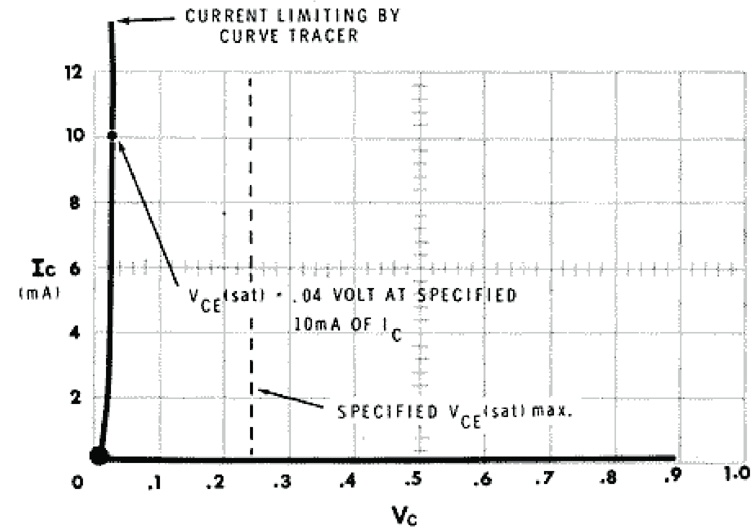


Figure 3-2

Transistor data sheets specify $V_{CE(sat)}$ as a maximum voltage at a given base current and collector current. In Figure 3-2 this value is .04 volt.

Saturation resistance, $r_{CE\,(sat)}$, can be calculated, if desired, by the formula $r_{CE\,(sat)} = \frac{V_C}{I_C}$ for a given value of base current in the saturation region. In Figure 3-2, $r_{CE\,(sat)} = \frac{.04\ V}{10\ mA} = \frac{40\ mV}{10\ mA} = 4\ \Omega$.

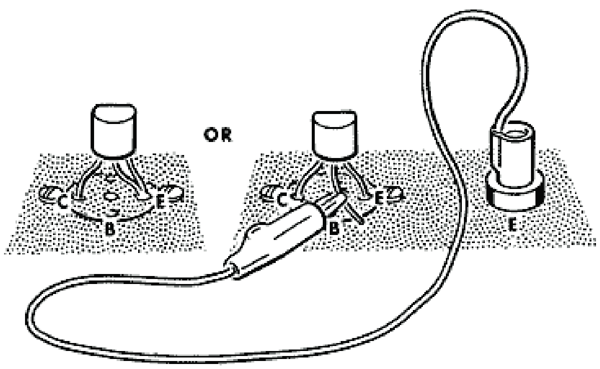
LEAKAGE CURRENT (I_{CEO}) and (I_{CES})

HORIZONTAL SENSITIVITY	5 Volts/Div.
VERTICAL SENSITIVITY	.5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	0
STEP RANGE	Any position
LIMITING RESISTOR	5 k

I_{CEO} is the collector to emitter leakage current that flows when the base is open (not connected). I_{CES} is the collector to emitter leakage current that flows when the base is shorted to the emitter.

I_{CEO} – Do not connect the transistor base lead to the Curve Tracer.

I_{CES} – Connect both the transistor base lead and emitter lead to the E connector of the transistor socket. See below.



The leakage current is proportional to the collector-to-emitter voltage and becomes greatest as the breakdown voltage is approached. For a good transistor, I_{CEO} is always greater than I_{CES}.

NOTE: Silicon transistors typically have leakage currents in the nanoampere region and will not display any leakage on the Curve Tracer. Germanium transistors are much more likely to show measurable leakage.

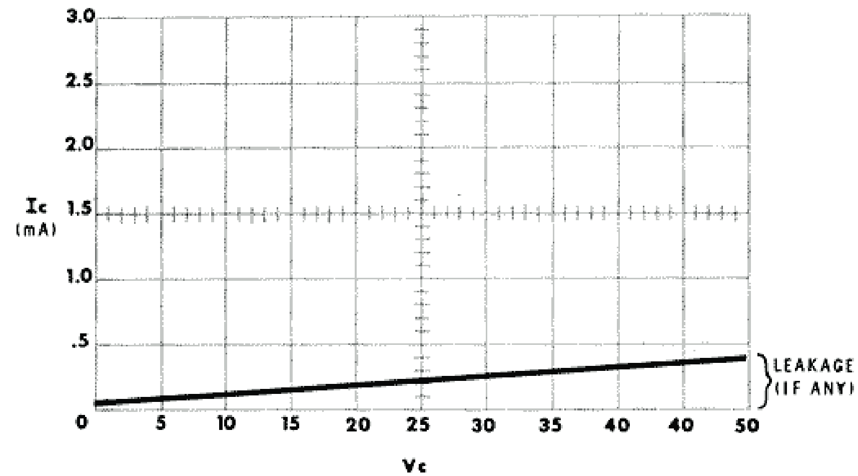


Figure 3-3

BREAKDOWN VOLTAGE

MPSA20: Minimum 40 volts at 1 mA of I_c

HORIZONTAL SENSITIVITY	5 volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	5 Steps
STEP RANGE	.005 mA/Step
LIMITING RESISTOR	5 k

The breakdown voltage is where the collector current becomes independent of the base current and rises sharply until limited by the Curve Tracer. If it were not for this limiting, the transistor would be destroyed. Keep the test short so the transistor is not damaged by too much heat. Increase the sweep voltage until the collector breakdown point is reached.

Most transistors can be tested for breakdown because of the high voltage capability (200 volts) of the Curve Tracer.

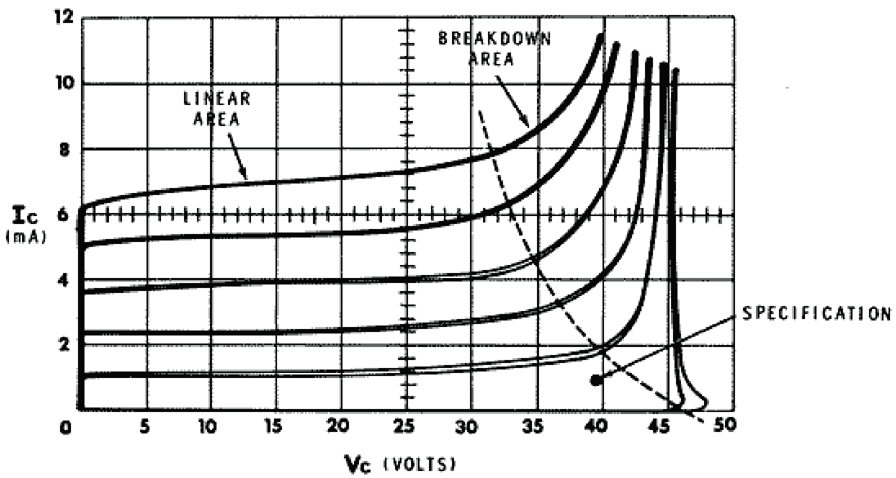


Figure 3-4

OUTPUT ADMITTANCE (h_{oe})

MPSA20:

HORIZONTAL SENSITIVITY	5 volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	5 Steps
STEP RANGE	.005 mA/Step
LIMITING RESISTOR	5 k

The output admittance of a transistor is the change in collector current (ΔI_c) that results from a specific change in collector voltage (ΔV_c) at a constant base current. Admittance is measured in μmhos and its "h" parameter in the common emitter configuration is $h_{oe} = \frac{\Delta I_c}{\Delta V_c} = \frac{\Delta I_c}{\Delta V_c} = \frac{.8\text{ mA}}{25\text{ V}} = 32\ \mu\text{mhos}$.

The output impedance of the transistor (collector resistance) is the reciprocal of its output admittance and is measured in ohms. To calculate it, transpose the current and voltage values used to determine the admittance.

$$\text{Output impedance} = \frac{\Delta V_c}{\Delta I_c} = \frac{28}{.8\text{ mA}} = 31{,}250\text{ ohms.}$$

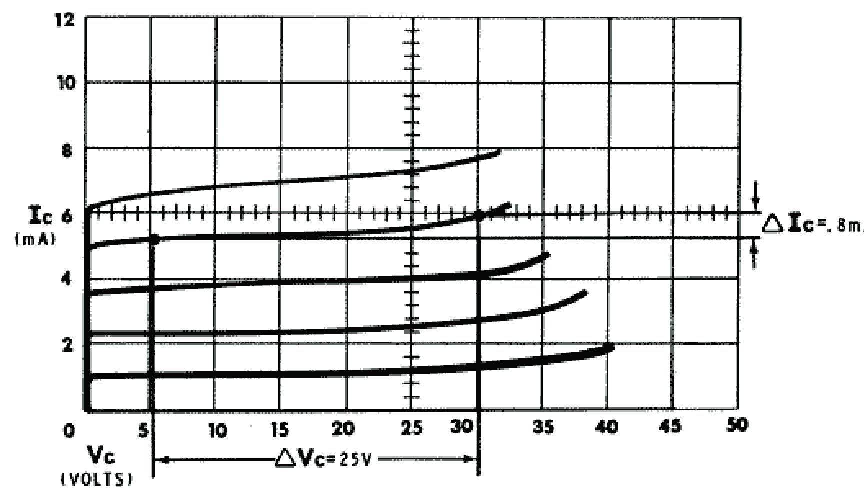


Figure 3-5

DC BETA (h_{FE})

MPSA20: 40-400, I_c = 5 mA, V_c = 10V

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	3 Steps
STEP RANGE	.05 mA/Step
LIMITING RESISTOR	100

Beta (β) is the ratio of collector current to base current and is equal to current gain. That is, for a given base current, a proportionally larger collector current is produced. DC beta is dependent upon what collector voltage and current points are picked. Even at specific values, DC beta can vary greatly in the same type device.

DC Beta is found by the formula:

$$\text{DC beta} = \frac{I_C}{I_B}$$

Therefore, the above example produces a beta of:

$$\beta = \frac{I_C}{I_B} \quad \beta = \frac{20\ \text{mA}}{.1\ \text{mA}} \quad \beta = 200$$

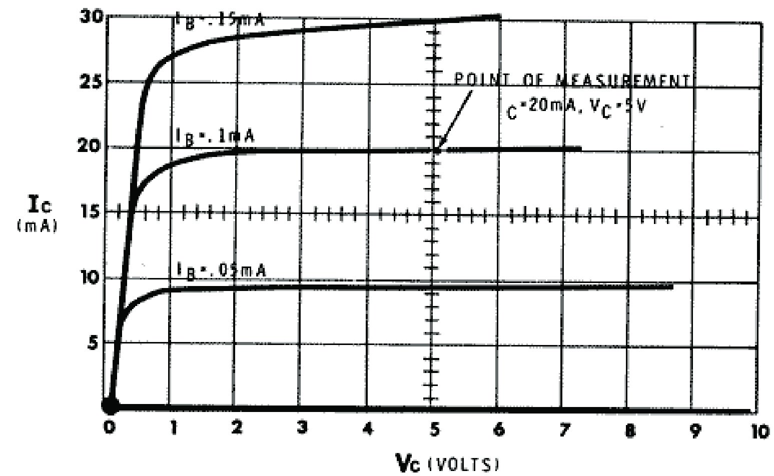


Figure 3-6

DC beta is indicated by capital FE in the term "h_{FE}," while AC beta is indicated by lower case fe in the term "h_{fe}."

AC BETA (h_{fe})

MPSA20:

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	3 Steps
STEP RANGE	.05 mA/Step
LIMITING RESISTOR	100

AC beta, or gain, is the ratio of change in collector current to the change in base current. This measurement is more useful because it is taken under actual operating conditions and performance can be more precisely predicted.

If the transistor data sheet is available, beta should be measured at the approximate collector current and voltage specified. If not, the STEP RANGE is usually adjusted for a display of the most evenly and widely spaced curves.

Gain is usually higher in the normal operating region of the transistor and is lower at collector currents above or below this region.

Calculate AC beta as follows:

1. Measure the difference in collector current (ΔI_c) between two curves at the same collector voltage.

2. Note the change in base current (ΔI_b) from the STEP RANGE switch. (.05 mA in this case.)

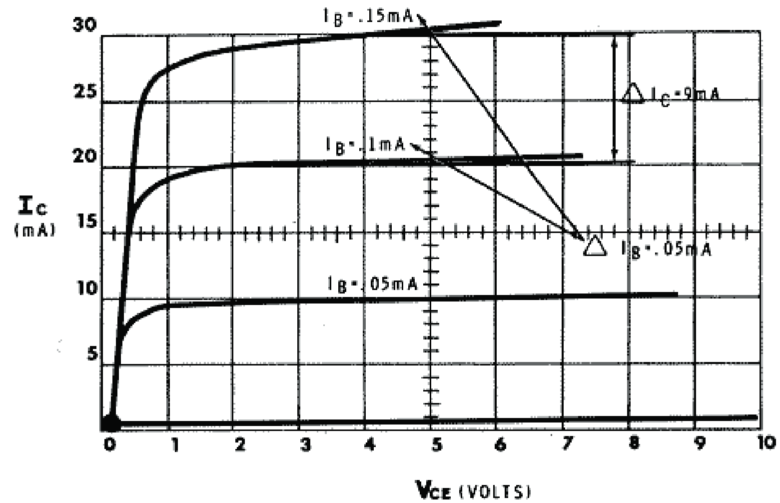


Figure 3-7

3. Then AC beta = $\dfrac{\Delta I_c}{\Delta I_b}$ at V_{CE} of 4 volts

$$\beta = \frac{9\text{ mA}}{.05\text{ mA}}$$

$$\beta = 180$$

LINEARITY AND GENERAL DISPLAY-LOW I_C

MPSA20:

HORIZONTAL SENSITIVITY	2 Volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	9 Steps
STEP RANGE	.005 mA/Step
LIMITING RESISTOR	1 k

Linearity is a measure of the transistor's ability to amplify, in exact proportion, a signal that appears at its base.

The step generator in the Curve Tracer produces precise steps. Therefore, if the device being tested is perfect, the spacing between curves will be constant – similar to the curves in Figure 3-8. These curves can be used to check both gain and linearity. Linearity is usually better with a low collector current.

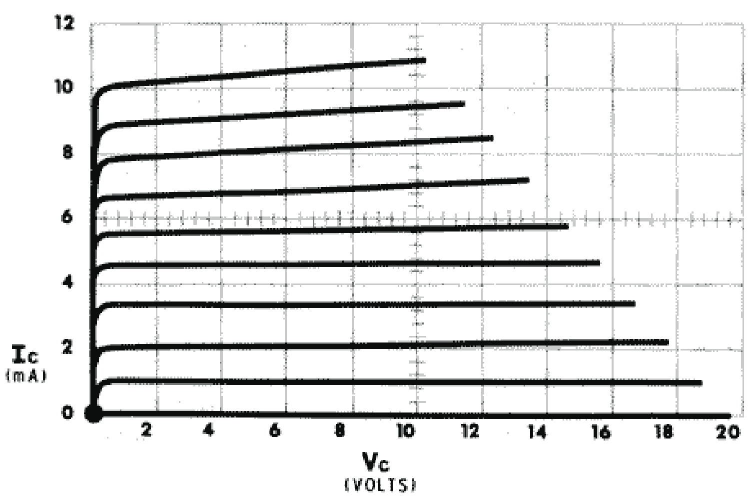


Figure 3-8

LINEARITY AND GENERAL DISPLAY–HIGH I_C

MPSA20: To maximum of 100 mA of I_c

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	20 mA/Div.
POLARITY	NPN
STEPS/FAMILY	5 Steps
STEP RANGE	.1 mA/Step
LIMITING RESISTOR	50

Nonlinearity increases with an increase in collector current. (Note the closer spacing of the upper curves.)

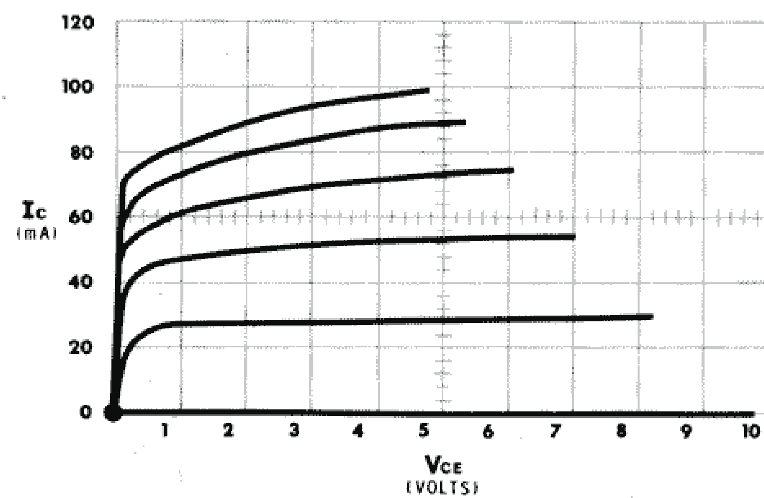


Figure 3-9

NONLINEARITY

MPSA20:

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	3 Steps
STEP RANGE	.05 mA/Step
LIMITING RESISTOR	100

Transistor gain is not necessarily constant, but is dependent on the point of measurement. If the transistor is operated in a nonlinear region, the gain is nonlinear and distortion is produced. This may be desirable or undesirable, depending on the application of the transistor.

To measure nonlinearity:

1. Plot an imaginary line along the ends of the curves. This is the "test load line."
2. Plot an "operating load line" in parallel with the test load line but intersecting the zero IC line at the desired operating V_{CE} for the transistor.
3. Measure and compare the changes in collector current (ΔI_c) between the curves on the operating load line. If the changes are the same, the transistor is linear at this point. If they are different,it is nonlinear at this point. In the above example there is some nonlinearity, and thus distortion at this point, because Δ 9 mA does not equal Δ 11 mA. As can be seen, an input signal of ±.05 mA will produce an output signal of +9 mA and −11 mA.

Nonlinearity should be measured along a load line rather than at a specific V_{CE} because it more nearly duplicates operating conditions. The transistor will operate with a load, not at a fixed V_{CE}. The load causes operation along the load line, since a change in collector current produces a change in collector voltage and vice versa.

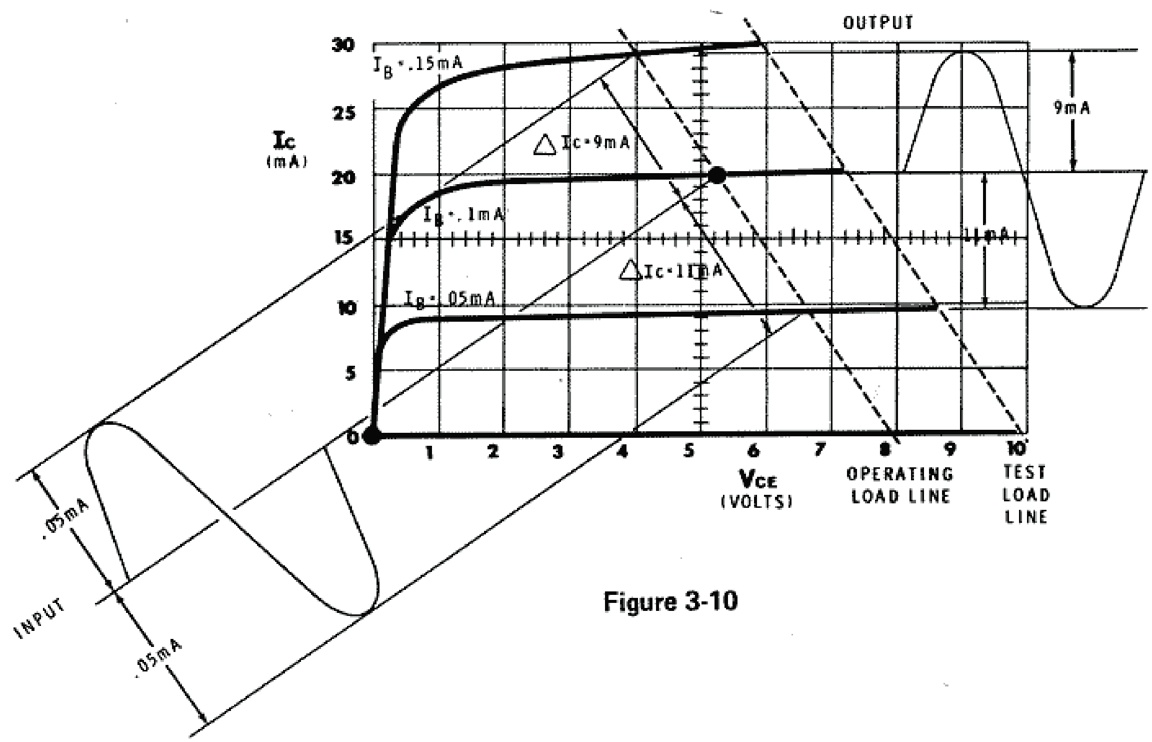


Figure 3-10

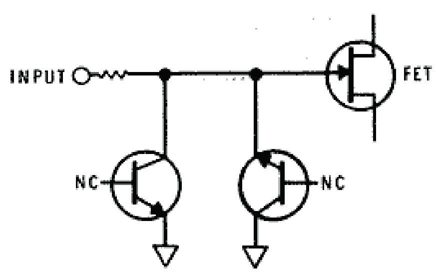
REVERSE C TO E BREAKDOWN

MPSA20:

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	PNP
STEPS/FAMILY	Counterclockwise
STEP RANGE	.002 mA/Step
LIMITING RESISTOR	500

This breakdown occurs when the reverse collector-to-emitter voltage becomes great enough to suddenly cause excessive collector current to flow.

Figure 3-11 is a typical display. However, other proper displays may have different slopes after the breakdown point. The collector-to-emitter breakdown of bipolar transistors is sometimes used in an input circuit to protect an FET from large signals, as shown below.



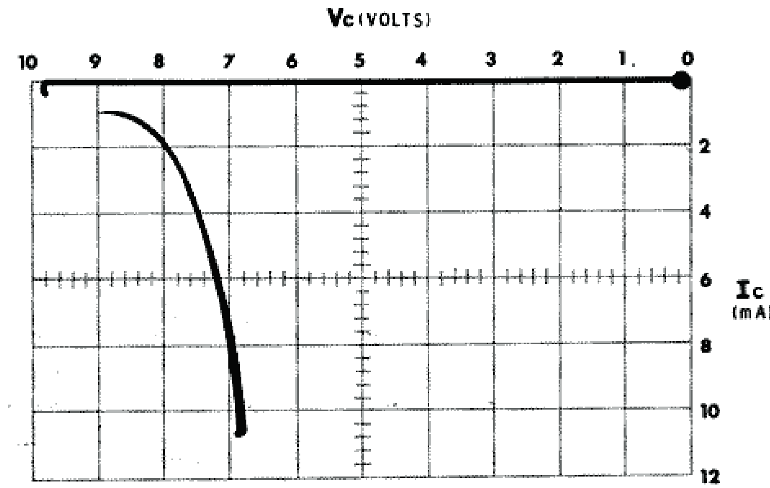


Figure 3-11

THERMAL HEATING

MPSA20:

HORIZONTAL SENSITIVITY	5 Volts/Div.
VERTICAL SENSITIVITY	50 mA/Div.
POLARITY	NPN
STEPS/FAMILY	4 Steps
STEP RANGE	2 mA/Step
LIMITING RESISTOR	50

Looping can be caused by collector capacitance and inductance, in certain cases by the Curve Tracer itself (see "Curve Tracer Characteristics"), and by thermal heating. If current causes heat that cannot be adequately dissipated, then looping is produced. In the forward sweep, heat is produced. This heat increases or decreases current flow (depending the temperature coefficient of the device). Therefore, on the return sweep, a different amount of current flows because of the time lag required for cooling to occur. This difference appears as looping.

CAUTION: Do not make a transistor produce excessive looping. This is not normal and may damage or destroy the device.

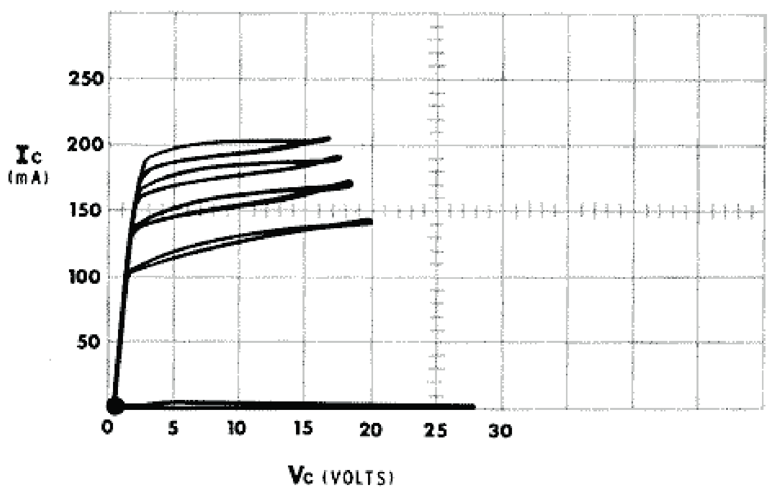


Figure 3-12

THERMAL RUNAWAY

MPSA20:

This test will damage or destroy the device.

HORIZONTAL SENSITIVITY	5 Volts/Div.
VERTICAL SENSITIVITY	50 mA/Div.
POLARITY	NPN
STEPS/FAMILY	4 Steps
STEP RANGE	.5 mA/Step
LIMITING RESISTOR	50

High current produces excessive heat and causes "thermal runaway." The curves will roll towards the top of the screen until the device is permanently damaged or destroyed.

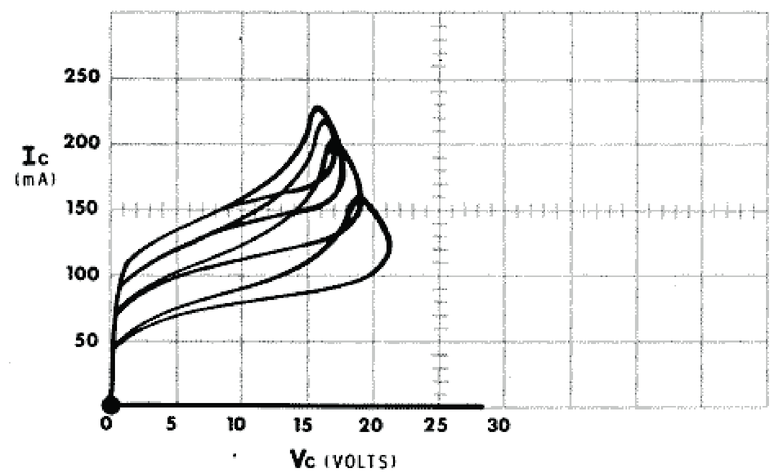
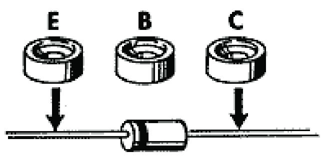
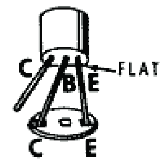


Figure 3-13

DIODE FORWARD CONDUCTION





MPSA20: Base to Emitter. Install the E and B leads of the transistor in the E and C socket holes as shown.

HORIZONTAL SENSITIVITY	.1 Volt/Div.
VERTICAL SENSITIVITY	.5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	Counterclockwise (has no effect)
STEP RANGE	.002 mA/Steps
LIMITING RESISTOR	1 k

Diodes conduct easily in one direction and do not conduct in the reverse direction. To test a diode, apply the sweep voltage across the device. The step voltage and current are not used, and the STEPS/FAMILY control is not used.

For diodes, only one curve is displayed. From this you can measure forward voltage drop and diode resistance. No current flows until the sweep voltage exceeds the junction barrier. This voltage drop is about 0.3 volt for germanium diodes and 0.6 volt for silicon diodes. Then, above this point, current increases rapidly as the voltage is increased.

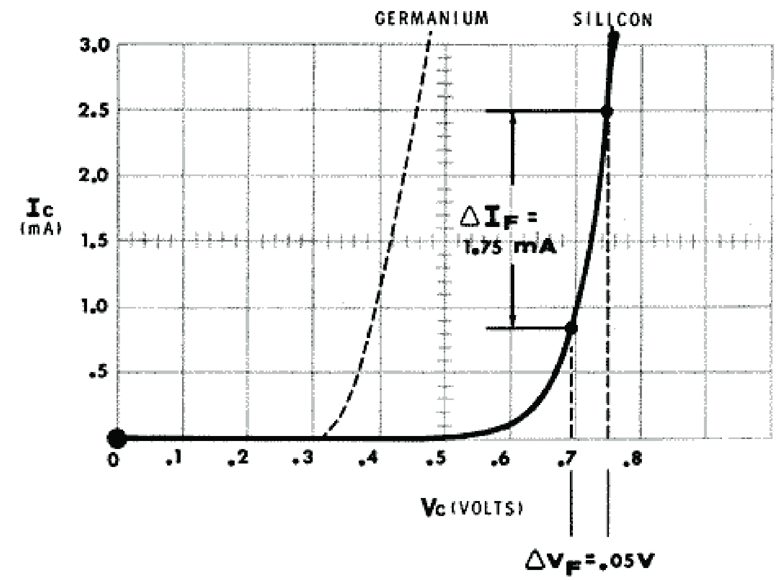


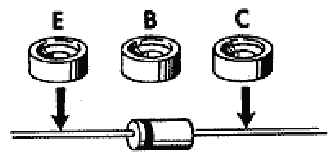
Figure 3-14

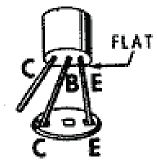
The dynamic resistance of a diode equals the change in forward voltage (V_F) divided by the change in forward current (I_F).

$$R_D = \frac{\Delta V_F}{\Delta I_F} = \frac{.05V}{1.75\ mA} = 28.57\ \Omega$$

When you test a conventional diode, connect it as shown.

DIODE REVERSE BREAKDOWN





MPSA20: Base to Emitter. Install the E and B leads of the transistor in the E and C socket holes as shown.

HORIZONTAL SENSITIVITY	1 volt/Div.
VERTICAL SENSITIVITY	.5 mA/Div.
POLARITY	PNP
STEPS/FAMILY	Counterclockwise (has no effect)
STEP RANGE	.002 mA/Step
LIMITING RESISTOR	1 k

Diode reverse breakdown is the voltage point where the diode begins to conduct current independent of voltage.

Position the dot in the upper right-hand corner.

When you test a conventional diode, connect it as shown. Be sure to use a sufficiently high limiting resistor so the diode is not damaged by excessive current. Germanium diodes may show leakage. (See upper left-hand corner of the Figure.)

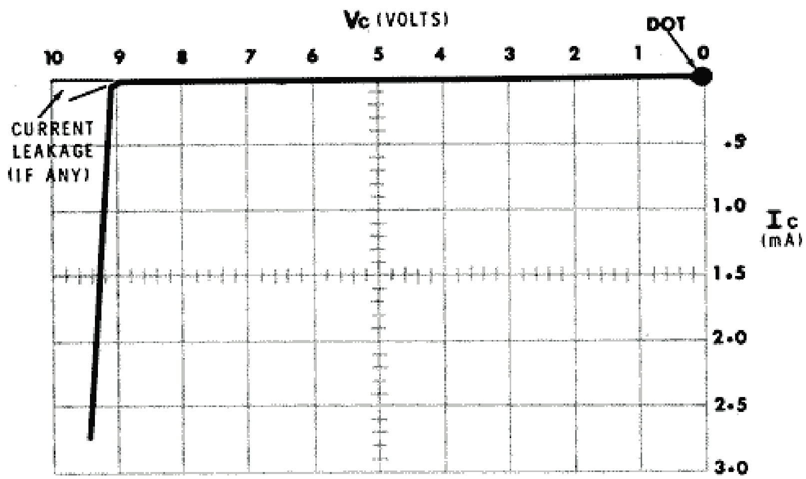


Figure 3-15

ZENER DIODES

HORIZONTAL SENSITIVITY	5 volts/Div.
VERTICAL SENSITIVITY	.5 mA/Div.
POLARITY	PNP
STEPS/FAMILY	Counterclockwise (has no effect)
STEP RANGE	.002 mA/Step
LIMITING RESISTOR	10 k

Zener diodes are like conventional diodes except that they are designed to operate in the reverse breakdown mode. The knee is the point where this breakdown begins. The sharper the knee, the better the zener is. Some zeners may have some leakage current before breakdown. This leakage can be measured as shown.

The dynamic impedance (the ratio of a change of voltage to a change of current in the breakdown region) can be determined by picking two points and calculating this ratio. The better zeners have a lower dynamic impedance.

$$Z \text{ (dynamic impedance)} = \frac{\Delta V_C}{\Delta I_C} = \frac{2.5\text{V}}{1.5\text{ mA}} = 1667\ \Omega.$$

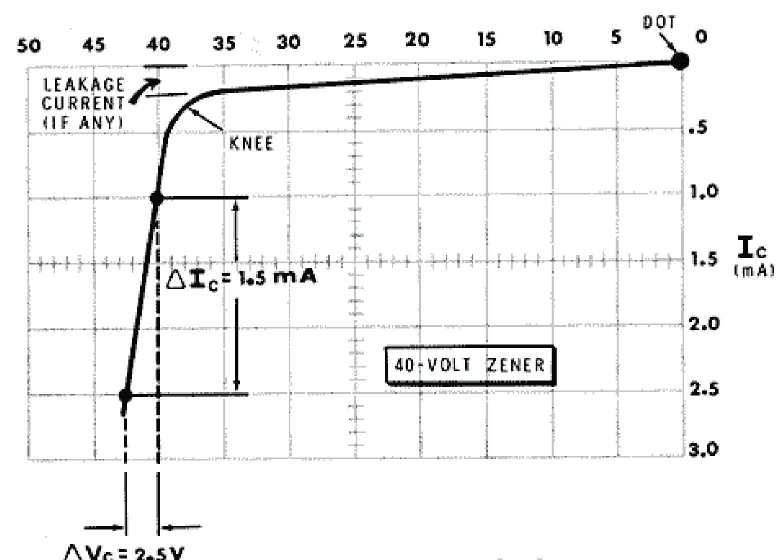


Figure 3-16

CURVE TRACER LIMITS

High-Voltage Transistor, To 200 Volt Limit

HORIZONTAL SENSITIVITY	20 Volts/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
SWEEP RANGE	0-200 V
STEPS/FAMILY	4 Steps
STEP RANGE	.02 mA/Step
LIMITING RESISTOR	10 k

NOTES:

1. Do not exceed the specifications of the device.
2. Be sure to set the SWEEP RANGE switch back to 0-40 V after you finish any high voltage tests.
3. Use as high a limiting resistance as practical.

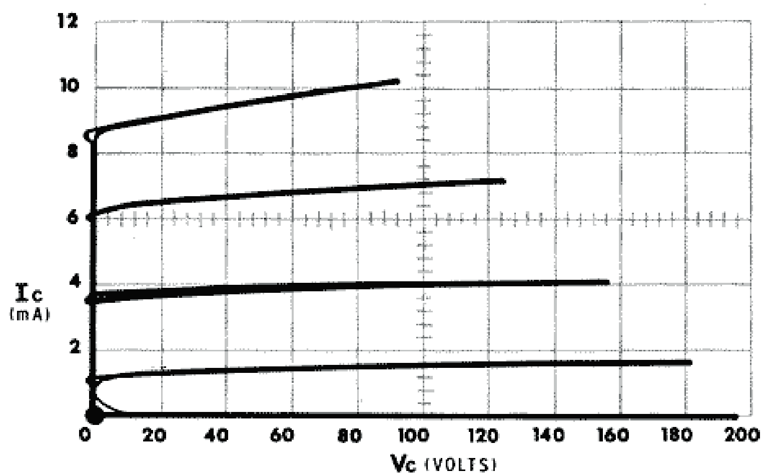


Figure 3-17

Power Transistor, To 1-Ampere Limit

HORIZONTAL SENSITIVITY	50 Volts/Div.
VERTICAL SENSITIVITY	200 mA/Div.
POLARITY	NPN
STEPS/FAMILY	8 Steps
STEP RANGE	2 mA/Step
LIMITING RESISTOR	10

The Curve Tracer limits the current above 1000 mA. This may produce distortion (crowding of the curves) at the top of the waveform.

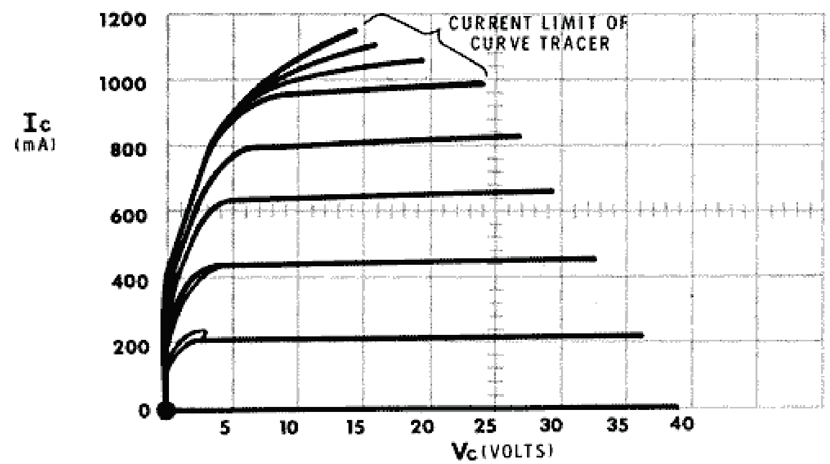


Figure 3-18

GENERAL FET DISPLAY

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	1 mA/Div.
POLARITY	N Chan.
STEPS/FAMILY	Fully Clockwise
STEP RANGE	.1 Volt/Step
LIMITING RESISTOR	1 k

Testing FET's (including MOS FET's) is similar to testing bipolar transistors (NPN's and PNP's). However, instead of a graph of collector current versus collector voltage at various base currents, FET curves are a graph of drain current versus drain voltage at various gate voltages.

To test an FET, the STEP RANGE switch is placed in a "VOLTS/STEP" position so the Curve Tracer will supply constant voltage steps rather than constant current steps. Also, the polarity of the step voltage is reversed in relation to the sweep voltage. The zero base current step of a bipolar transistor usually produces no collector current. However, in an FET, the zero gate voltage produces the highest drain current. Then each reverse bias voltage step results in less drain current. Therefore, what is the base line in regular transistors is the top line in Figure 3-19.

Some MOS FET's can be damaged by static electricity carried by the person handling the device. Therefore, discharge any static charge by touching ground with one hand before and while handling the MOS FET with the other hand.

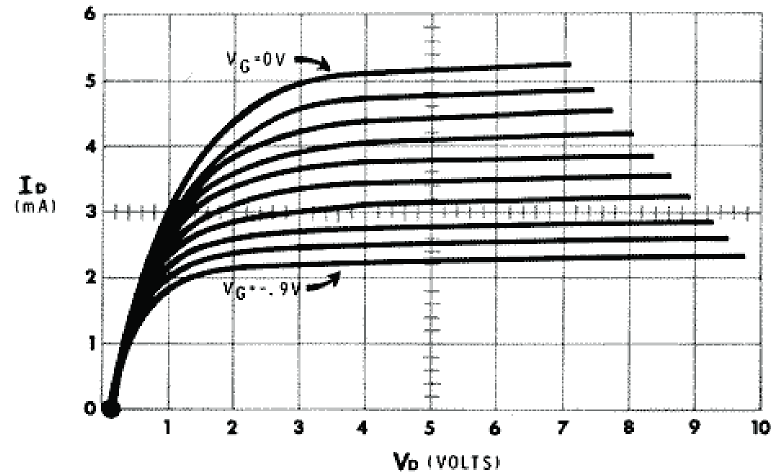


Figure 3-19

To test the few enhancement mode FET's, disconnect the gate lead from the Curve Tracer and connect a DC bias supply to provide forward bias voltage. Be sure the common of the supply is connected to the circuit ground of the Curve Tracer. (Connect a test lead between the supply and S jack of the Curve Tracer.)

When you test dual-gate MOS FET's, either ground or bias the gate not being tested-do not leave it open circuited.

FET PINCHOFF AND TRANSCONDUCTANCE

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	1 mA/Div.
POLARITY	N Chan.
STEPS/FAMILY	5 Steps
STEP RANGE	.5 Volt/Step
LIMITING RESISTOR	1 k

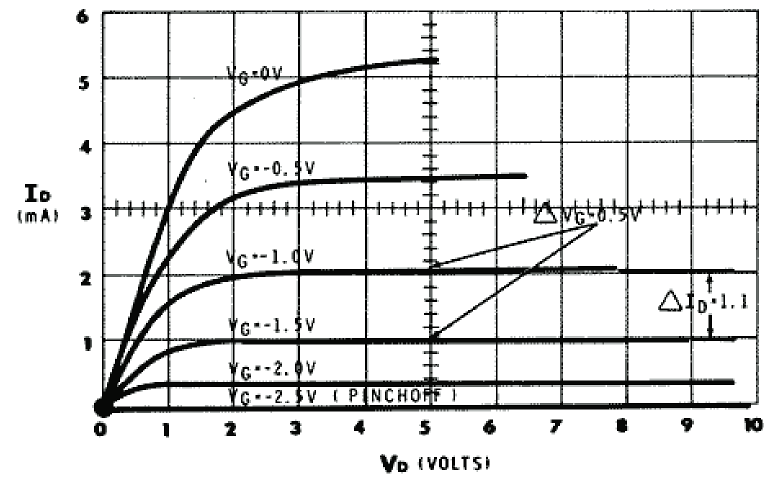


Figure 3-20

If the reverse bias voltage steps are of a high enough value, drain current stops and "pinchoff" is attained. The approximate value of pinchoff is found by noting which step produces no drain current (I_D). In the example, the 5th step (all higher steps will fall in the same place as the 5th step) produces no drain current. Thus pinchoff occurs between -2.0 volts (4th step) and -2.5 volts (5th step).

The gain of an FET is the gate-to-drain forward transconductance (gm). This is the ratio of change in drain current to the change in gate voltage at a given drain voltage. Transconductance is measured in µmhos.

To calculate gm:

1. Note the difference in drain current between two curves (ΔI_D) at the same drain voltage (V_D).

2. Note the change in gate voltage (ΔV_G) from the STEP RANGE switch.

3. Then gm - $\dfrac{\Delta I_D}{\Delta V_G}$

$$gm = \frac{1.1\text{ mA}}{.5\text{ V}} = \frac{1100\ \mu\text{A}}{.5} = 2200\ \mu\text{mhos at } V_D \text{ of 5 volts.}$$

NOTE: Like beta, gm depends on the point of measurement. As you can see by the nonlinearity of the curves in Figure 3-20, gm is not a constant.

FET BREAKDOWN (Figure 3-21)

HORIZONTAL SENSITIVITY	10 Volts/Div.
VERTICAL SENSITIVITY	1 mA/Div.
POLARITY	N Chan.
SWEEP RANGE	0-200 V
STEPS/FAMILY	4 Steps
STEP RANGE	.2 Volt/Step
LIMITING RESISTOR	10 k

As the sweep voltage is increased, a point is reached where the FET breaks down. At this point drain current becomes independent of gate voltage and rises sharply until limited by the Curve Tracer. If it were not for this limiting, the FET would be destroyed. Keep the test short so the transistor is not damaged by too much heat.

NOTE: FET's are more easily damaged by high voltage than are bipolar transistors.

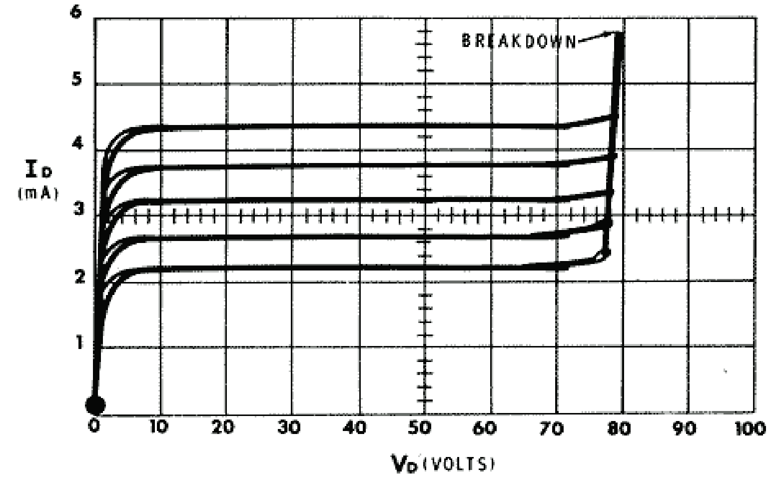


Figure 3-21

TUNNEL DIODE (Figure 3-22)

HORIZONTAL SENSITIVITY	.1 Volt/Div.
VERTICAL SENSITIVITY	2 mA/Div.
POLARITY	NPN
STEPS/FAMILY	Fully counterclockwise
STEP RANGE	———
LIMITING RESISTOR	1 k

Tunnel diodes are p-n junction devices with a negative resistance or "tunnel" region. The "tunnel" makes it possible to use the diode as an amplifier, oscillator, or pulse generator. The diode conducts very easily in one direction (at a much lower voltage than conventional signal diodes), but the tunnel is in the direction of the higher resistance. These diodes are normally operated at very low voltage and current levels.

NOTE: Carefully select the limiting resistor so the diode does not oscillate.

Connect the diode to a transistor socket: Cathode to the emitter connector, and anode to the collector connector. A trace will not normally be displayed in the negative resistance region.

The following characteristics can be measured directly from the display.

I_p – peak current, start of tunnel region

V_p – peak voltage, start of tunnel region

I_v – valley current, end of tunnel region

V_v – valley voltage, end of tunnel region

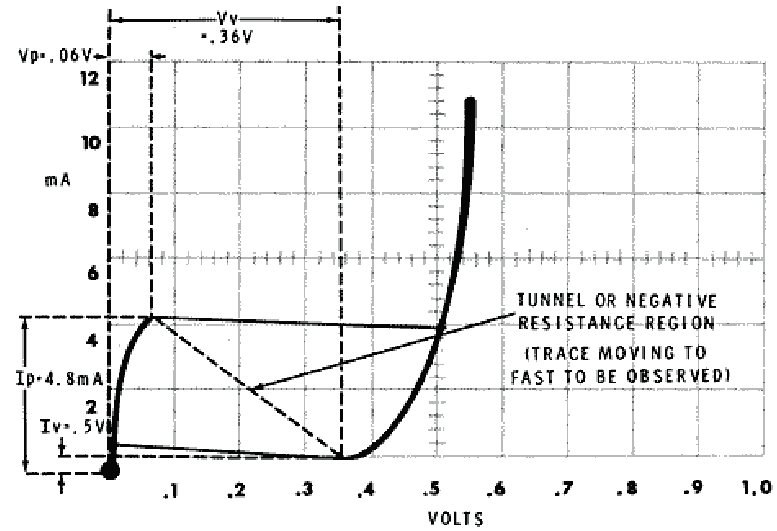


Figure 3-22

The average negative resistance can be calculated from these values.

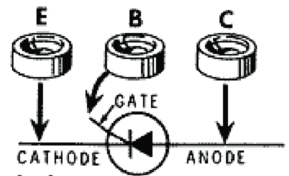
$$\text{Average negative resistance} = \frac{V_V - V_P}{I_P - I_V} = \frac{.36\text{ V} - .06\text{ V}}{4.8\text{ mA} - .5\text{ mA}} = \frac{.3\text{ V}}{4.3\text{ mA}} = 69.8\ \Omega.$$

SCR

An SCR (silicon controlled Rectifier or Thyristor) is a four layer p-n-p-n device with three terminals; cathode, anode, and gate. In the "on" state, the SCR behaves much like a diode. However, unlike a diode, the SCR also has an "off" state and does not conduct in either direction.

If the forward blocking voltage is exceeded, the SCR will turn on. The SCR will then stay on until the anode to cathode current drops below a certain value (called the holding current).

Forward Blocking Voltage And Holding Current



HORIZONTAL SENSITIVITY	20 Volts/Div.
VERTICAL SENSITIVITY	5 mA/Div.
POLARITY	NPN
STEPS/FAMILY	Fully counterclockwise
STEP RANGE	.002 mA/Step
LIMITING RESISTOR	10 k

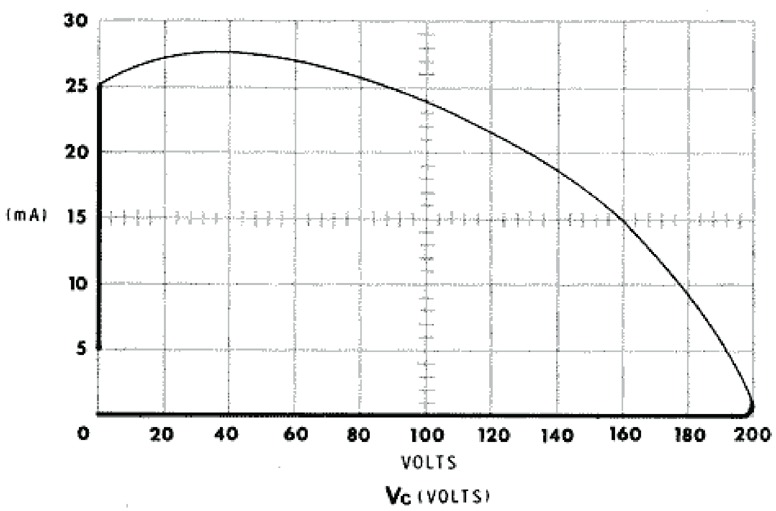


Figure 3-23

For the example in Figure 23, the forward blocking voltage is 200 volts and the holding current is 5 mA.

Reverse Blocking Voltage And Leakage Current

The procedure is the same as for testing a reverse biased diode. Be sure you are in the PNP mode and the STEPS/FAMILY control is fully counterclockwise.

Gate Trigger Current

The gate current needed to turn on the SCR depends on the anode-to-cathode voltage. The following example shows how to determine this current.

HORIZONTAL SENSITIVITY	5 Volts/Div.
VERTICAL SENSITIVITY	200 mA/Div.
POLARITY	NPN
STEPS/FAMILY	1 Step
STEP RANGE	.002 mA/Step
LIMITING RESISTOR	50

NOTE: To set the STEPS/FAMILY control for 1 step, position the NORM-CAL switch to the CAL position and adjust the STEPS/FAMILY control until two dots appear. Then reposition the switch back to the NORM position.

Turn the STEP RANGE switch clockwise until a vertical line appears as in Figure 3-24. The trigger current is then between the step range just selected and the previous step. If the 10 mA/step position is reached and no vertical line appears, turn the STEPS/FAMILY control slowly clockwise. When the line appears, use the NORM-CAL switch to determine how many steps were required and multiply the number by 10 mA.

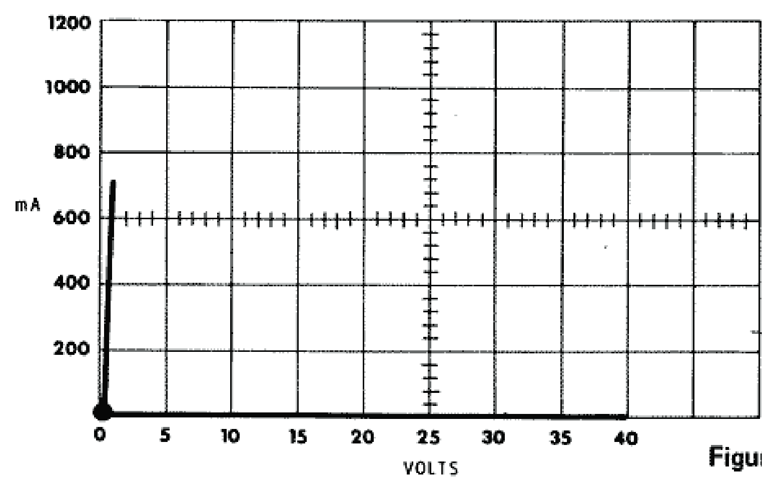
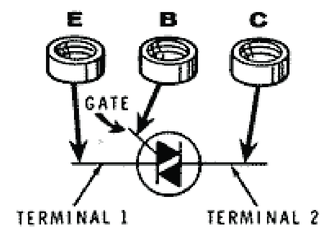
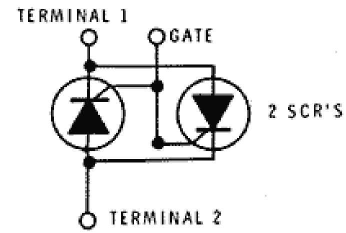


Figure 3-24

Forward Conduction

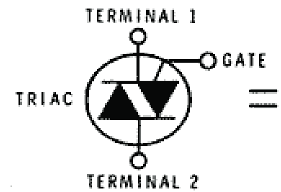
HORIZONTAL SENSITIVITY	.2 Volt/Div.
VERTICAL SENSITIVITY	50 mA/Div.
POLARITY	NPN
STEPS/FAMILY	1 Step
STEP RANGE	.05 mA/Step
LIMITING RESISTOR	0





The forward voltage drop of an SCR is similar to that of a forward biased diode and the voltage depends on the selected current.

With two volts applied, the forward voltage drop of the SCR in Figure 3-25 is approximately 0.9 volt at a current of 250 mA. From these values the instantaneous watts dissipated in the device can be determined. W = VI = .9V X 250 mA = .225 watts.



TRIAC

Triacs may be tested the same as SCR's except that the forward tests should be performed in both directions and there will be no reverse blocking voltage measurement. This is because a triac is the same as two SCR's in parallel, but oriented in opposite directions.

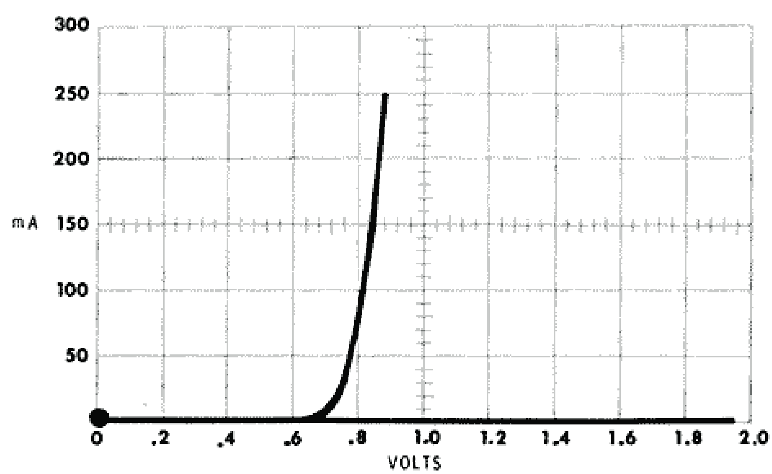


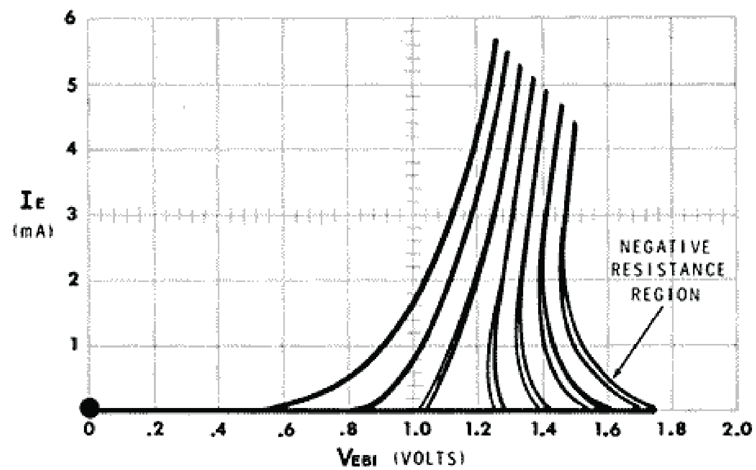
Figure 3-25

UJT

HORIZONTAL SENSITIVITY	.2 Volt/Div.
VERTICAL SENSITIVITY	1 mA/Div.
POLARITY	NPN
STEPS/FAMILY	6 Steps
STEP RANGE	.5 mA/Step
LIMITING RESISTOR	100

A unijunction transistor (UJT) is a single junction device with three terminals. Conduction between base 1 and base 2 is purely resistive until an emitter current is applied. A small trigger current applied to the emitter causes a negative resistance condition. The value of trigger voltage is dependent upon the voltage between base 1 and base 2.

When tested, the step current is applied from base 2 to base 1. This step current causes a step voltage across B_2 and B_1. The sweep voltage is applied to the emitter of the UJT. For each increase in B_2 B_1 voltage, more emitter trigger voltage is required. See Figure 3-26.



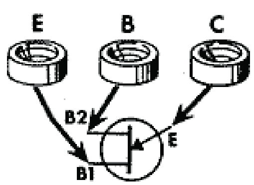


Figure 3-26

UJT (R_{BB})

HORIZONTAL SENSITIVITY	1 Volt/Div.
VERTICAL SENSITIVITY	1 mA/Div.
POLARITY	NPN
STEPS/FAMILY	0
STEP RANGE	Not used
LIMITING RESISTOR	1 k

Interbase resistance (R_{BB}) can be displayed by connecting base 1 and base 2 to the collector and emitter jacks of the Curve Tracer and leaving the emitter lead open circuited. This displays a linear trace of forward current (I_F) versus interbase voltage (V_{BB}). $R_{BB} = V_{BB}/I_F = \frac{9V}{3\ mA} = 3\ k\Omega$

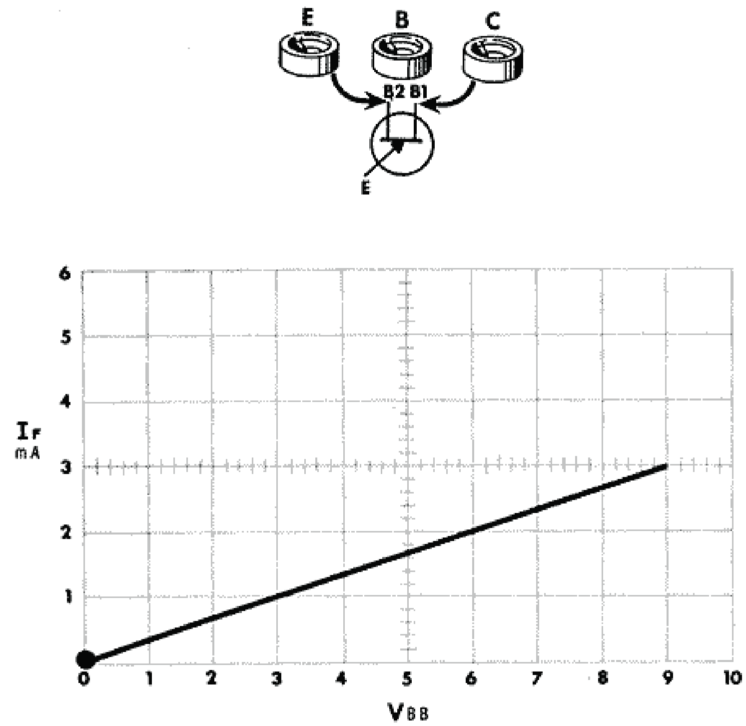


Figure 3-27

SPECIFICATIONS

Sweep Voltage Ranges	0-40 volts at 1 ampere maximum. 0-200 volts at 200 milliamperes maximum.
Sweep Voltage Sampling	.1, .2, .5, 1, 2, 5, 10, 20, and 50 volts/division ±3%.
Sweep Current Sampling	.5, 1, 2, 5, 10, 20, 50, 100, and 200 milliamperes/division ±3%.
Sweep Dissipation Resistors	0, 10, 50, 100, 500, 1000, 5000, 10 k, 50 k, 100 k, 500 k, 1 M ±10%.
Step Currents Available	.002, .005, .01, .02, .05, .1, .2, .5, 1, 2, 5, and 10 milliamperes/step, ±3%, ±250 nanoamperes offset current maximum.
Step Voltages Available	.05, .1, .2, .5, and 1.volt/step, ±3%, ±5mV maximum offset voltage.
Polarity Available	PNP and NPN (P Channel – N Channel).
Calibration Source	9 volts ±2% in 1 volt steps.
Oscilloscope Requirements	Vertical sensitivity of 1 volt/cm. Horizontal sensitivity of 0.5 volt/cm. Bandwidth to 20 kHz or greater. (DC-coupled oscilloscope is recommended.)
Operating Temperature Range	10°C to 40°C. Temperature variation, referenced at 25°C, will have a maximum effect of ±1% on all other specifications.
Line Voltage	110 to 130 or 220 to 260 VAC.
Dimensions	11-1/4" W x 10" D x 4-1/2" H.
Weight	Approximately 8-1/2 lbs.