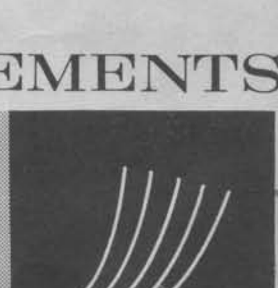
SOME TRANSISTOR MEASUREMENTS USING THE TYPE 575



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INTRODUCTION

This material has been prepared primarily to acquaint the new user of the Tektronix Type 575 Transistor Characteristic-Curve Tracer with the fundamental measurements of transistor parameters and characteristics. It is intended to augment the Type 575 Instruction Manual.

We will not attempt to relate the broad field of solid-state physics to transistor characteristics, nor will we translate the characteristics to circuit design equations. This information is beyond the scope of this booklet and may be found in current publications. The Type 575 is intended for measuring the transistor characteristics which exist well below alpha cut-off, commonly measured between DC and 1000 cycles; hence we will not consider any high-frequency measurements.

We have chosen to give examples of measuring the four "hybrid", or h, parameters from the characteristic curves, although the admittance, impedance or other parameters could be measured on the Type 575 as well. Further, we have given examples predominantly in common emitter configuration, although there are no restrictions so far as the Type 575 is concerned in making measurements using common base or common collector configurations with either PNP or NPN transistors.

In most cases, a word description of the function being performed on the transistor will be used. A glossary of symbols is given in order to avoid confusion in the changing language of the transistor art.

The visual display of a family of transistor characteristic curves using oscilloscopic techniques employing synchronously stepped and swept voltage-current sources offers certain advantages over the DC point-by-point measurement technique:

(1) Small irregularities in the characteristics are visible which may escape observation by the point-by-point method.

(2) The extremes in the variation of a parameter value may be observed without altering the operating conditions.

(3) The changing magnitudes of two parameters may be observed simultaneously, as well as the dependence of one upon another.

(4) The short duration and lower duty cycle of the peak sweeping voltages or currents applied to the transistor produce less thermal rise than does the steady-state DC condition which occurs in point-by-point measurements. Inaccuracies due to thermal gradients are thereby minimized.

(5) For the same reason as noted in (4), the maximum ratings of the transistor may be observed without exceeding the safe limit of its power dissipation; thus incipient junction-breakdowns are minimized.

(6) Observation, comparison, or a permanent record by photographic techniques of the transistor characteristics may be made more rapidly than by the point-to-point plot, thus affording a savings in manpower and economy.

(7) A resistive load line may be constructed in the family of characteristic curves so that dynamic performance data for the transistor may be forecast.

Transistor characteristic curves may be found to deviate from the published "nominal" characteristic curves considerably more than found even in vacuum tubes. The Type 575 contains certain built-in calibration checks which assure the accuracy of the instrument. The theory of self-checking is explained in the section devoted to Functional Operation. Detailed checks and adjustment procedures are given in the Instruction Manual for the Type 575.

The Type 575 user is encouraged to read the section devoted to the Functional Operation of the Type 575 to aid in developing measurements peculiar to his own individual design or testing problem. In this way, he may fully utilize the versatility of the instrument.

FUNCTIONAL OPERATION OF THE TYPE 575

Two signals are developed in the Type 575 to be applied to the transistor. One is constant current or constant voltage steps, and the other is a variable amplitude half-sine wave. The two are synchronized so that for the duration of one step, or one-half step, there is one excursion of the half-sine voltage from zero (ground) to maximum and back to zero.

We will first direct our attention to the Base Step Generator shown to the left on Figure 1.

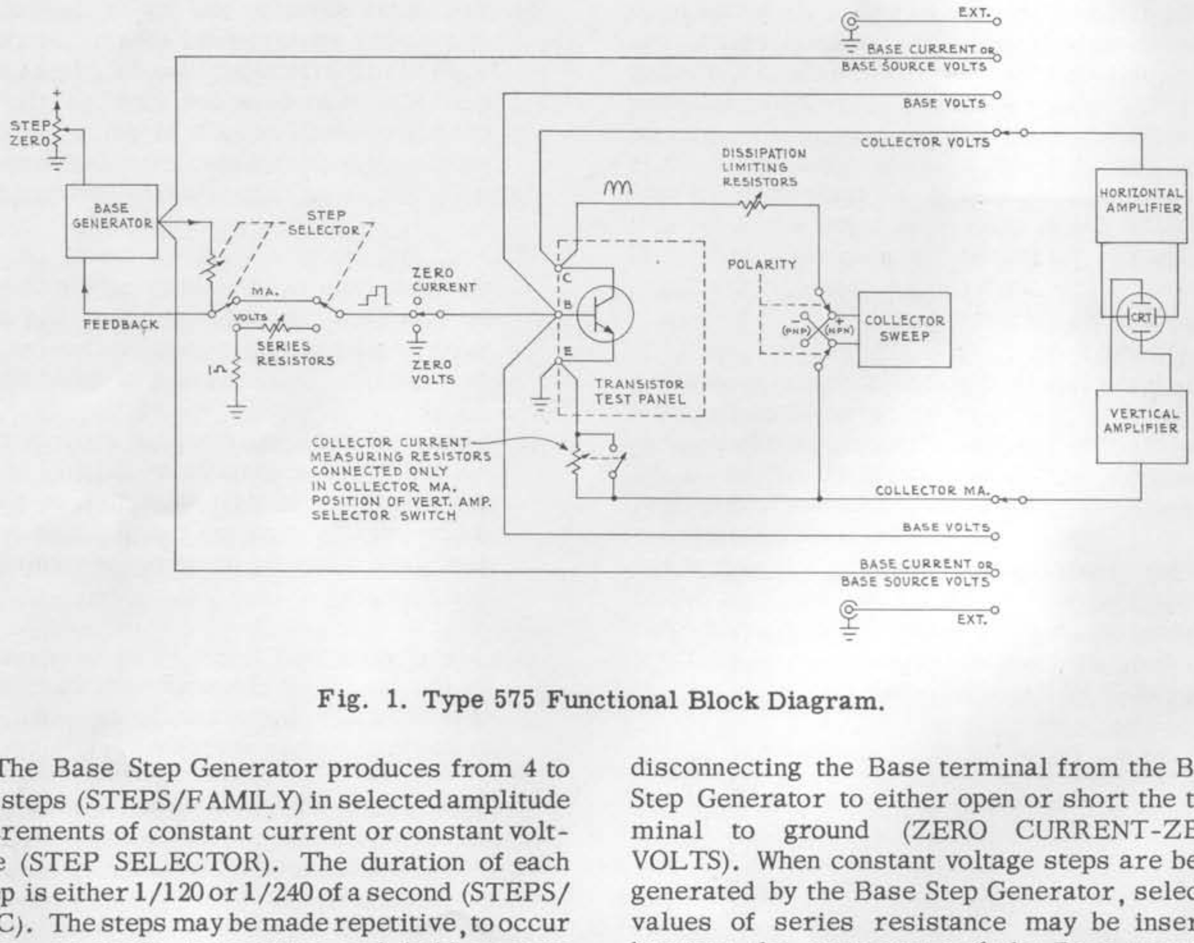


Fig. 1. Type 575 Functional Block Diagram.

The Base Step Generator produces from 4 to 12 steps (STEPS/FAMILY) in selected amplitude increments of constant current or constant voltage (STEP SELECTOR). The duration of each step is either 1/120 or 1/240 of a second (STEPS/SEC). The steps may be made repetitive, to occur once, or made inoperative and held at zero step level (REPETITIVE-SINGLE FAMILY OFF). The steps may be made positive or negative in polarity (POLARITY) with the zero step value adjustable by a small amount positive or negative from ground (STEP ZERO) to start the stair-steps on the zero current or zero volts input curve.

The output of the Base Step Generator is fed through a switch to the Base (B) terminal of the test fixture. The switch provides a means of disconnecting the Base terminal from the Base Step Generator to either open or short the terminal to ground (ZERO CURRENT-ZERO VOLTS). When constant voltage steps are being generated by the Base Step Generator, selected values of series resistance may be inserted between the generator and the Base terminal (SERIES RESISTOR). The output impedance of the Base Step Generator when producing constant voltage is one ohm, and when producing constant current the output impedance is, of course, very high.

The Collector Sweep source of half-sine voltage is shown at the right of Figure 1. The peak collector sweep voltage is variable in amplitude (PEAK VOLTS) from zero to 20 volts rated at 10 amps, or from zero to 200 volts rated at one amp (PEAK VOLTS RANGE). A fuse is provided to protect the collector supply from overload. The polarity of the half-sine shaped voltage excursions may be made positive or negative from ground (POLARITY + NPN-PNP). The duration of sweep from zero to maximum and back to zero is always 1/120 of a second.

The collector supply, which has a source impedance of .25 ohms in the twenty-volt range or 15 ohms in the 200-volt range, may be fed directly to the collector terminal of the test fixture, or variable resistance values may be inserted (DISSIPATION LIMITING RESISTORS). The collector supply ground return is direct to ground except when the Vertical display switch is in one of the COLLECTOR MA positions, at which time current measuring resistances are inserted. The value of resistance is dependent upon the position of the COLLECTOR MA switch and varies from .1 ohm in the 1000 Ma/ Division position to 10 K-ohms in the .01 Ma/ Division position. The specific value of resistance on each position of the switch is given in tabular form on the chart on top of the instrument. Thus the collector load resistance (load line) is known at all times by summing the resistance inserted manually (DISSIPATION LIMITING RESISTOR), the supply source impedance, and the collector current measuring resistance, determined as explained above.

The third terminal of the transistor test fixture marked "E" is ground. The transistor test board, which is not entirely shown in Figure 1, has a switch for transferring all connection from the left-hand terminals and socket to the right-hand terminals and socket with a neutral Off position. Another switch is provided to switch the sockets only from grounded base to grounded emitter.

This completes the generator functions of the Type 575, and we will now discuss the display portion of Figure 1.

The Horizontal display switch (HORIZONTAL-VOLTS/DIV) may select any one of four inputs: (1) BASE CURRENT OR BASE SOURCE VOLTS, (2) BASE VOLTS, (3) COLLECTOR VOLTS, (4) EXTERNAL.

In the BASE VOLTS or COLLECTOR VOLTS positions, the amplifier is connected to either the Base terminal or Collector terminal of the test fixture, respectively. The amplifier gain is controlled so that each major division on the CRT graticule corresponds to the value indicated on the selector switch.

In the BASE CURRENT OR BASE SOURCE VOLTS position of the Horizontal display switch, the horizontal amplifier is connected to the Base Step Generator output. Under these conditions, each major division on the CRT graticule corresponds to the value indicated on the Base Step Generator-STEP SELECTOR switch.

In the External position of the Horizontal display switch, the horizontal amplifier input is connected as a differential amplifier, to two coax jacks on the rear of the instrument. The scale factor for the CRT graticule on Ext. is fixed at 0.1 volts per major division, and the frequency response is 300 kc (3 db down).

It will be noted in Figure 1 that the Vertical display switch and vertical amplifier function in the same way as the horizontal circuits just discussed, when the (1) BASE CURRENT OR BASE SOURCE VOLTS, (2) BASE VOLTS, and (3) EXTERNAL positions are selected.

When the Vertical Amplifier is switched to COLLECTOR MA, however, it measures the voltage across the collector current measuring resistors. The vertical amplifier gain is held constant and the size of the current measuring resistance is changed by the COLLECTOR MA switch so that each major vertical division on the CRT graticule is the value indicated on the COLLECTOR MA switch.

Both the Horizontal and Vertical circuits have switches provided (AMPLIFIER ZERO CHECK-CALIBRATE) which ground the input to remove any signal for the purpose of positioning the beam on the CRT graticule. The same switches provide a calibrating voltage for checking horizontal and vertical amplifier gain.

It is worthy of note that the instrument provides many other ways of checking itself. For instance, one amplifier may be checked against the other by selecting a BASE VOLTS display on each amplifier and observing the angle of the diagonal row of dots. Either amplifier may check the Base Step Generator output voltage by selecting the same scale factor on the amplifier as the VOLTS/STEP on the STEP SELECTOR switch, and so on.

DISPLAY AND OPERATING CONSIDERATIONS

The polarities of the Base Steps and Collector Sweep signals are selected independently. The normal operating polarities for a transistor (reverse-biased collector and forward-biased emitter) are indicated on the front panel of the Type 575 to serve as a reminder to avoid possible damage to the transistor under test. The independent selection of base and collector signal polarities may be used to advantage. For instance, the emitter may be reverse-biased in order to measure the amount of current or voltage required to decrease the collector current I_{cbo} or I_{ceo} to a minimum value.

Some precautions which may be exercised in making measurements on a transistor of unknown limitations are: (1) Leave the TRANSISTOR A - TRANSISTOR B switch in the neutral (off) position when the initial signal amplitudes are selected and when the transistor is inserted, (2) In the initial selection of signals, start with small values of base steps and collector voltages with maximum sensitivity of the Horizontal and Vertical Display switches, (3) Use a minimum number of Base STEPS/FAMILY (four or five), (4) Insert a collector DISSIPATION LIMITING RESISTOR to limit the collector current to a safe value. The collector current measuring resistances are in series with the collector only when the Vertical Display switch is in the COLLECTOR MA position as shown in Figure 1. In order to preclude excessive collector current and possible damage to the transistor, it is important to select an adequate value of DISSIPATION LIMITING RESISTOR prior to switching the Vertical display switch from the COLLECTOR MA positions to any other position where collector current is not displayed. A chart, permanently attached to the top of the Type 575, provides a handy reference for choosing the DISSIPATION LIMITING RESISTOR for given values of collector-peak voltage and collector peak-power dissipation.

If it is not known whether the transistor is NPN or PNP, the beam may be centered on the CRT graticule and alternate PNP and NPN polarities applied to the transistor. The signals may be increased in small increments until it becomes apparent which characteristics are normal. As an added precautionary measure, the SINGLE FAMILY switch may be used in conjunction with the other precautions previously noted.

When NPN transistor characteristics are displayed, the Horizontal and Vertical POSITION controls should normally be adjusted to place the beam in the lower-left corner of the graticule. The family of characteristic curves appear in the first quadrant with positive values of currents and voltages increasing up and to the right. For PNP transistors, the Horizontal and Vertical POSITION controls are normally adjusted to place the beam in the upper-right hand corner of the graticule, and the family of characteristic curves then appears in the third quadrant. Increasing values of negative currents and voltages thus appear down and to the left, in keeping with convention.

The CALIBRATE position of the AMPLIFIER ZERO CHECK-CALIBRATE switch on the Horizontal and Vertical amplifiers deflects the beam down 10 divisions for the Vertical Amplifier and left 10 divisions for the Horizontal Amplifier. Thus, the beam position for the calibrate check should be in the upper-right-hand corner of the CRT graticule.

The STEP ZERO control permits adjustment of the base step generator to start from actual zero current or actual zero volts, rather than from some residual value of current or voltage. In this way, the absolute value of any base step is the product of the step number times the step incremental value indicated on the STEP SELECTOR switch. Proper adjustment is achieved when the "zero" current step from the base step generator is moved from a slightly forward residual current condition to a position that just coincides with the trace position obtained with the ZERO CURRENT-ZERO VOLTS switch in the ZERO CURRENT position. When the base step generator is supplying constant voltage steps, the ZERO VOLTAGE switch position would be applicable in the same way.

The faint traces which may appear between base steps and from the last step back to the zero step occur during the short transition interval between the steps. The transition traces will always occur at one end or the other in the family of curves, depending upon the position of the STEPS/SEC switch. Since they generally contribute nothing to the display and do not affect the calibration of the display in any way, a position of the STEPS/SEC switch is generally chosen to minimize their appearance. In some displays, the transition traces may serve a useful purpose, such as assisting in the construction of a load line in the collector family of curves.

A given parameter may be measured from one of several displays of the current and voltage relationships involved in the parameter. The display chosen depends upon the particular parameter and the characteristics of the transistor under test. The display that should be used is, of course, the one which yields the most accurate measurement or vivid display of that parameter. The user may sometimes prefer to measure other parameters that may be combined in a formula to produce a more accurate end result. A typical example is found in the relationship between α (Alpha), the common base forward current transfer ratio and B (Beta), the common emitter forward current transfer ratio. It can be seen from Figure 10 that the change in collector current for a given change in emitter current is very close to one. In common emitter, the change in collector current is considerably more than the change in base current, as can be seen in Figure 2. Since α and B are related by $\alpha = B/(B+1)$, we may find B to a greater degree of accuracy, as far as scaling is concerned, and solve for α.

A word may be in order regarding "small signal hybrid, or h, parameters". In small signal operation, linearity should exist over the operating range of the parameter and the value of the parameter should be independent of the signal amplitude. Ordinarily, the active region of a transistor without defects is quite uniform, and a cursory examination of the family of characteristics will verify that linearity exists over the operating range of the parameter. The versatility of the Type 575 provides for making "small signal" measurements as well as "large signal" measurements. In order to verify that the parameter value, or operating region, of the transistor is independent of the signal amplitude, additional measurements of the parameter may be made adjacent to, or within, the intended operating region and the resulting values compared. For instance, the base step values may be reduced and the number of steps increased to examine a smaller segment within the same operating region, etc.

We have selected a primary and an alternate display for measuring each of the four "h" parameters. We may arbitrarily categorize the displays as illustrating Output Characteristics shown in Figures 2, 3, 4, and 5, and Input Characteristics shown in Figures 6, 7, 8, and 9. Two "h" parameters are measurable from each display, consequently the displays in Figures 4, 5, 8, and 9 are the same as Figures 2, 3, 6, and 7, respectively.

The most commonly published and probably most useful families of curves are the Collector Family shown in common emitter configuration in Figure 2, and Input Characteristic Curves shown in common emitter configuration in Figure 6. A common base configuration for a Collector Family of characteristic curves is shown in Figure 10.

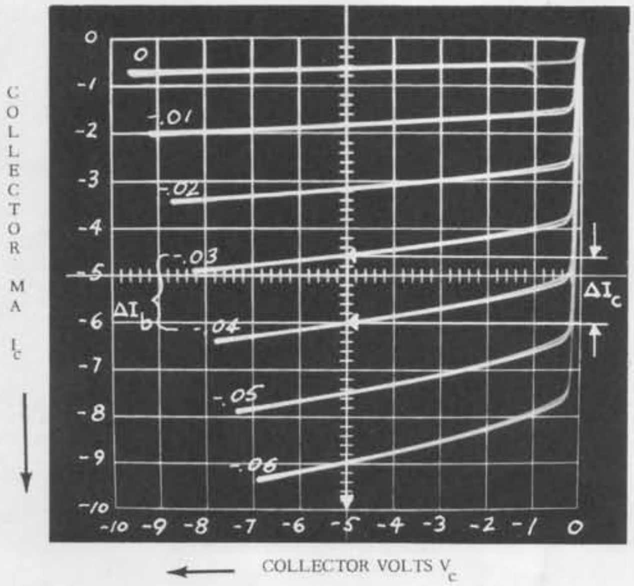
BASE to COLLECTOR CURRENT GAIN β, or COMMON EMITTER FORWARD CURRENT TRANSFER RATIO h_{fe}.

This parameter is determined by measuring the change in collector current produced by a change in base current at a specified collector voltage.

$$\beta \text{ or } h_{fe} = \frac{\Delta I_c}{\Delta I_b} \quad |V_c|$$

$$\beta \text{ or } h_{fe} = \frac{1.4 \times (1 \times 10^{-3})}{.01 \times 10^{-3}} = \frac{1.4}{.01} = \underline{140} \quad (V_c = -5 \text{ volts})$$

$$\alpha = \frac{\beta}{B+1} = \frac{140}{140+1} = \underline{.992} \quad (V_c = -5 \text{ Volts})$$



DISPLAY

Vertical:
Coll. Ma = 1.0 Ma/Div.

Horizontal:
Coll. Volts = 1.0 V/Div.

Step Selector:
Ma/Step = -.01 Ma/Step.

Dissipation Limiting
Resistor = 200 Ohms.

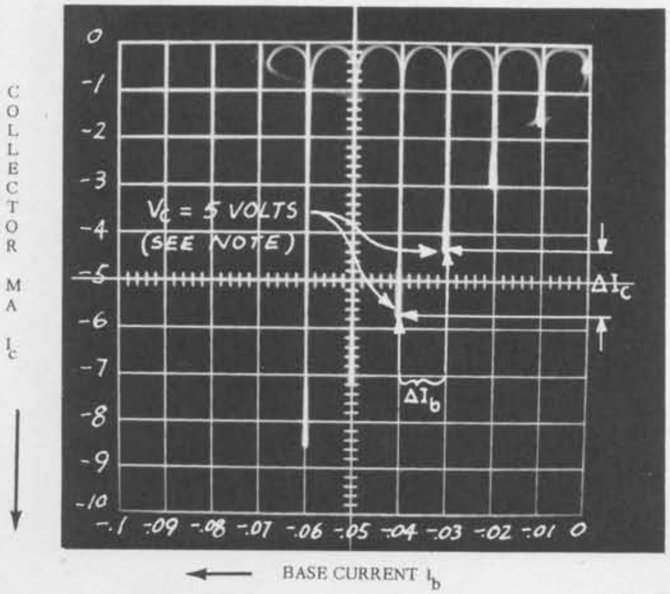
Fig. 2. Collector family of curves, I_c vs V_c, (I_b), for PNP transistor in common emitter configuration.

ALTERNATE DISPLAY FOR MEASURING β OR h_{fe}

$$\beta \text{ or } h_{fe} = \frac{\Delta I_c}{\Delta I_b} \quad |V_c|$$

$$\beta \text{ or } h_{fe} = \frac{1.4 \times (1 \times 10^{-3})}{.01 \times 10^{-3}} = \frac{1.4}{.01} = \underline{140} \quad (V_c = -5 \text{ Volts})$$

$$\alpha = \frac{\beta}{\beta + 1} = \frac{140}{140+1} = \underline{.992} \quad (V_c = -5 \text{ Volts})$$



DISPLAY

Vertical:
Coll. Ma = 1.0 Ma/Div.

Horizontal:
Base Current = .01 Ma/Div.

Step Selector:
Base Current = -.01 Ma/Step.

Collector Volts:
(See Note) = -5.0 Volts.

Dissipation Limiting
Resistor = 200 Ohms.

Fig. 3. Output characteristic curves, I_C vs I_b, (V_C), for PNP transistor in common emitter configuration.

Note: Collector PEAK VOLTS adjusted to produce 5.0 Volts for the third and fourth base step by switching Horizontal display to COLLECTOR VOLTS and reading value from graticule.

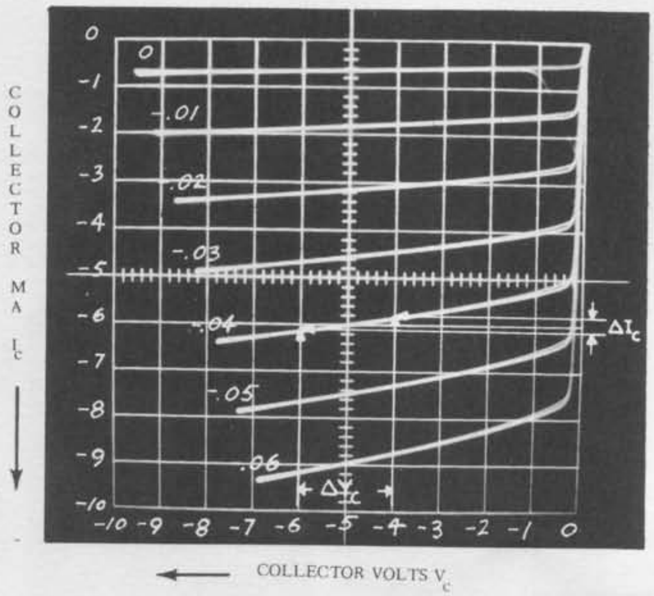
OUTPUT ADMITTANCE h_{oe}

The Output Admittance is determined by measuring the change in collector current produced by a change in collector voltage at a specified value of base current. The result is expressed in mhos.

$$h_{oe} = \frac{\Delta I_c}{\Delta V_c} \quad |I_b|$$

$$h_{oe} = \frac{.3 \times (1 \times 10^{-3})}{2} = .00015 \text{ mhos} = 150 \text{ } \mu\text{mhos}$$

$$(I_b = -.04 \text{ ma})$$



DISPLAY
Vertical:
Coll. Ma=1.0 Ma/Div.

Horizontal:
Coll. Volts=1.0 V/Div.

Step Selector:
Ma/Step=-.01 Ma/Step.

Dissipation Limiting
Resistor=200 Ohms.

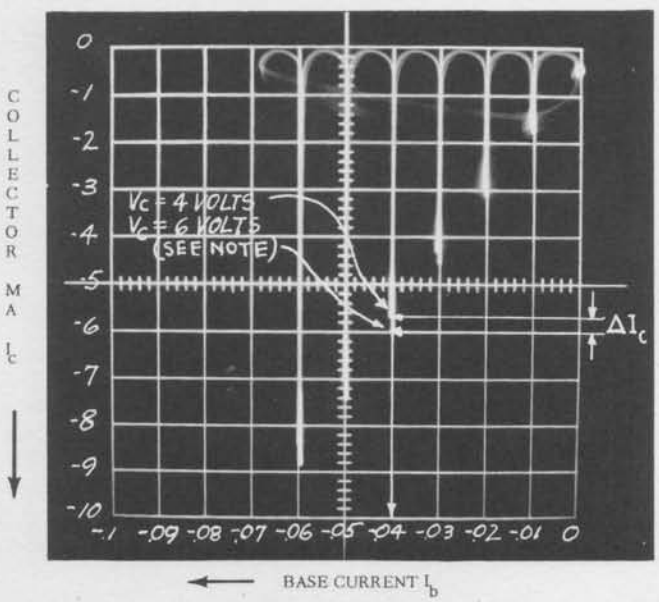
Fig. 4. Collector family of curves, I_C vs V_C, (I_b), for PNP transistor in common emitter configuration.

ALTERNATE DISPLAY FOR MEASURING h_{oe}

For the purpose of illustrating the h_{oe} measurement from the alternate display, a double exposure was made with all values constant except collector voltage which was increased from 4 to 6 volts for the second exposure.

$$h_{oe} = \frac{\Delta I_c}{\Delta V_c} \quad |I_b|$$

$$h_{oe} = \frac{.3 \times (1 \times 10^{-3})}{2} = .00015 \text{ mhos} = \underline{150\ \mu\text{mhos}} \quad (I_b = -.04 \text{ ma.})$$



DISPLAY

First Exposure

Vertical:
Coll. Ma=1.0 Ma/Div.

Horizontal:
Base Current=.01 Ma/Div.

Step Selector:
Base Current=-.01 Ma/Step.

Collector Volts:
(See Note)=-4 Volts.

Dissipation Limiting
Resistor=200 Ohms.

Second Exposure

Collector Volts increased
to -6 Volts.

Fig. 5. Output characteristic curves, I_C vs I_b with V_C = 4 volts and V_C = 6 volts, for PNP transistor in common emitter configuration.

Note:

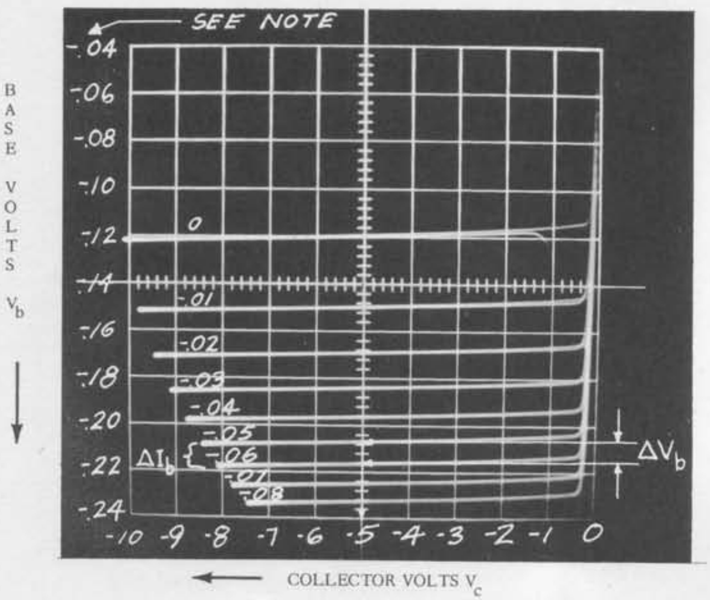
Collector PEAK VOLTS adjusted to produce 4 Volts and then 6 Volts for the fourth base step by switching Horizontal display to COLLECTOR VOLTS and reading value from graticule.

INPUT IMPEDANCE h_{ie}

The Input Impedance is determined by measuring the change in base voltage resulting from a change in base current at a specified collector voltage.

$$h_{ie} = \frac{\Delta V_b}{\Delta I_b} \quad |V_c|$$

$$h_{ie} = \frac{.4 \times .02}{.01 \times 10^{-3}} = \frac{.008}{10^{-6}} = \underline{800 \text{ ohms}} \; (V_c = -5 \text{volts})$$



DISPLAY

Vertical:
Base Volts=.02 V/Div.

Horizontal:
Coll. Volts=1.0 V/Div.

Step Selector:
Base Current=-.01 Ma/Step.

Dissipation Limiting
Resistor=200 Ohms.

Vertical Position:
(See Note) Up 2 Div.

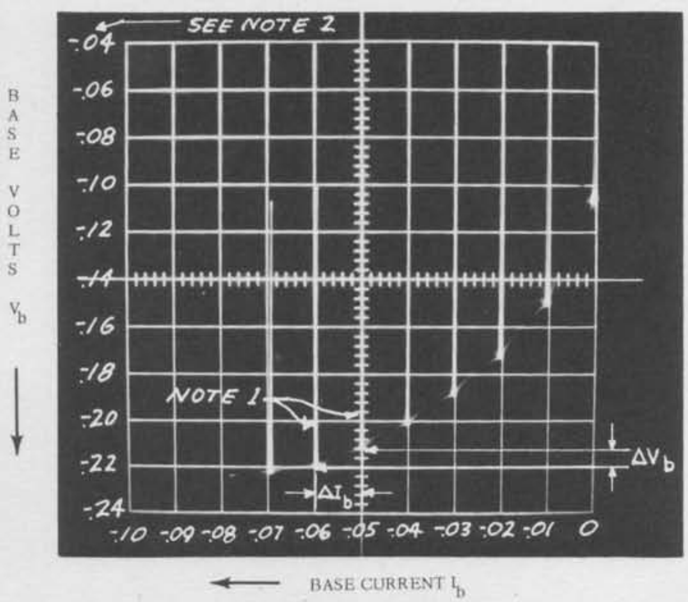
Fig. 6. Input characteristic curves, V_b vs V_c, (I_b), for PNP transistor in common emitter configuration.

Note: After establishing the display in the normal manner, the presentation was repositioned upward exactly two major divisions using one of the base steps as a reference. This was done in order to use the highest base volts sensitivity while maintaining the most useful portion of the curves on the graticule.

ALTERNATE DISPLAY FOR MEASURING h_{ie}

$$h_{ie} = \frac{\Delta V_b}{\Delta I_b} \quad |V_c|$$

$$h_{ie} = \frac{.4 \times .02}{.01 \times 10^{-3}} = \frac{.008}{10^{-6}} = \underline{800 \text{ ohms}} \; (V_c = -5 \text{ Volts})$$



DISPLAY

Vertical:
Base Volts=.02 V/Div.

Horizontal:
Base Current=.01 Ma/Div.

Step Selector:
Base Current=-.01 Ma/Step.

Collector Volts:
(See Note 1)=-5V/Div.

Dissipation Limiting
Resistor=0 Ohms.

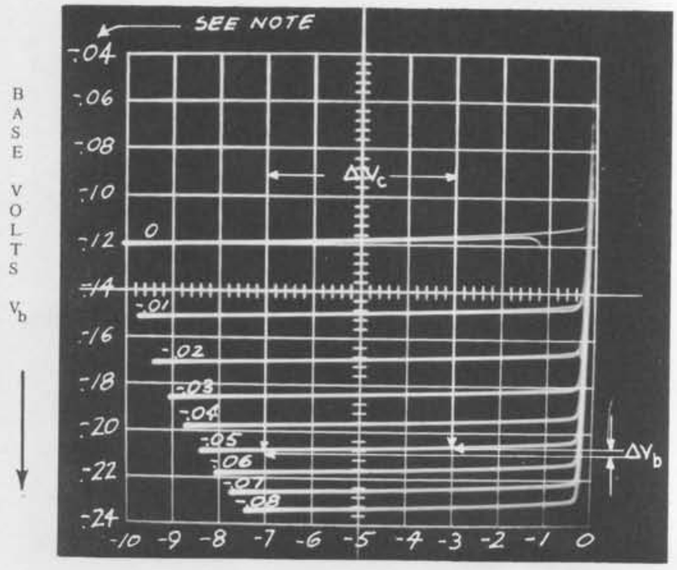
Vertical Position:
(See Note 2)=Up 2 Div.

Fig. 7. Input characteristic curves, V_b vs I_b, (V_c), for PNP transistor in common emitter configuration.

Note 1: Collector PEAK VOLTS adjusted to produce 5.0 Volts for the fifth and sixth base step by switching Horizontal display to COLLECTOR VOLTS and reading value from graticule.

Note 2: After establishing the display in the normal manner, the presentation was repositioned upward exactly two major divisions using one of the base steps as a reference. This was done in order to use the highest base volts sensitivity while maintaining the most useful portion of the curves on the graticule.

The Reverse Voltage Amplification Factor is determined by measuring the change in base voltage which accompanies a change in collector voltage at a specified base current.



DISPLAY

Vertical:
Base Volts=.02 V/Div.

Horizontal:
Coll. Volts=1.0 V/Div.

Step Selector:
Base Current=-.01 Ma/Step.

Dissipation Limiting
Resistor=200 Ohms.

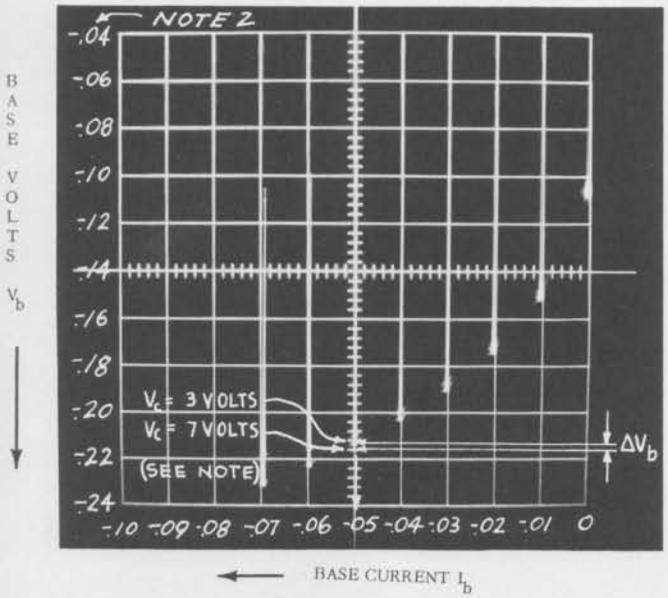
Vertical Position:
(See Note)=Up 2 Div.

Fig. 8. Input characteristic curves, V_b vs V_c, (I_b), for PNP transistor in common emitter configuration.

Note: After establishing the display in the normal manner, the presentation was repositioned upward exactly two major divisions using one of the base steps as a reference. This was done in order to use the highest base volts sensitivity while maintaining the most useful portion of the curves on the graticule.

ALTERNATE DISPLAY FOR MEASURING h_{re}

For the purpose of illustrating the h_{re} measurement from the alternate display, a double exposure was made with all values constant except collector voltage which was increased from 3 to 7 Volts for the second exposure.



DISPLAY

First Exposure

Vertical:
Base Volts=.02 V/Div.

Horizontal:
Base Current=.01 Ma/Div.

Step Selector:
Base Current=-.01 Ma/Div.

Collector Volts:
(See Note 1)=-3 Volts.

Dissipation Limiting
Resistor=0 Ohms.

Vertical Position:
(See Note 2)=Up 2 Div.

Second Exposure

Collector Volts increased
to -7 Volts.

Fig. 9. Input characteristic curves, V_b vs I_b with V_c = 3 volts and V_c = 7 volts, for PNP transistor in common emitter configuration.

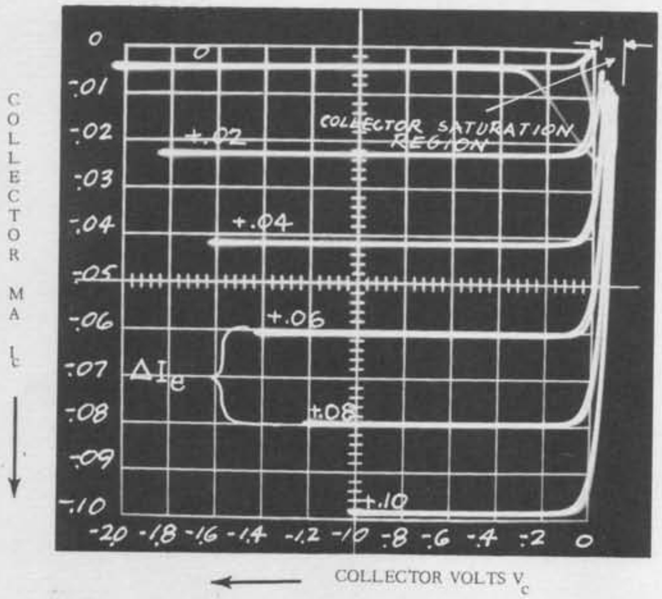
Note 1: Collector PEAK VOLTS adjusted to produce 3.0 Volts and then 7 volts for the fifth base step by switching Horizontal display to COLLECTOR VOLTS and reading value from the graticule.

Note 2: After establishing the display in the normal manner, the presentation was repositioned upward exactly two major divisions using one of the base steps as a reference. This was done in order to use the highest base volts sensitivity while maintaining the most useful portion of the curves on the graticule.

COMMON BASE CONFIGURATION

The parameters for the common base or common collector configurations may be handled in the same manner as just illustrated for common emitter configuration. From observation of the collector family of output characteristics in common base configuration, as illustrated in Figure 10, it is clear that h_{fb} or α which equals $\Delta I_c / \Delta I_e$ and h_{ob} which equals $\Delta I_c / \Delta V_c$ are difficult to scale from the graticule. This is quite normal, and it may be anticipated that variations between transistors will not appear as vividly as they would in common emitter operation.

The set of curves in Figure 10, by themselves, are principally informative in the "saturation region", which appears to the right of zero collector volts. It will be recalled that in common base configuration, unlike the common emitter configuration, the polarity of the emitter is opposite in sign to that of the collector. The apparent forward biasing of the collector in the "saturation region" results from emitter current and hence appears opposite in polarity to the applied collector voltage. Its magnitude may approach the magnitude of the emitter voltage; however, it can never exceed it.



DISPLAY

Vertical:
Coll. Ma=.01 Ma/Div.

Horizontal:
Coll. Volts=.2 V/Div.

Base Selector:
Base Current=+.02 Ma/
Step (Applied to Emitter).

Dissipation Limiting
Resistor=0 Ohms.

Fig. 10. Collector family of curves, I_c vs V_c, (I_e), for PNP transistor in common base configuration.

When it is desired to include the saturation region on the graticule scale, the display may be repositioned one or more major divisions with the Horizontal POSITION control without degrading the incremental scale calibrations. The AMPLIFIER ZERO CHECK switch may be used to establish a zero reference. An expanded display of the saturation region may be chosen by changing the Horizontal COLLECTOR VOLTS.

In common base configuration, when the horizontal or vertical display switch is changed from the COLLECTOR positions to the BASE positions to show the emitter characteristics, the curves progress from the edge of the graticule to some point off the screen. This is a result of collector and emitter biasing polarities as mentioned before. The display will appear in the correct perspective by repositioning the trace to the opposite edge of the graticule. Repositioning the display may be accomplished as mentioned before by using the appropriate POSITION control in conjunction with the appropriate AMPLIFIER ZERO CHECK switch.

COLLECTOR CUTOFF

The collector current which flows with zero emitter current (common base) I_{cbo} or with zero base current (common emitter) I_{ceo} may be measured directly from the collector family of curves. The STEP ZERO adjustment should be accurately set, or the ZERO CURRENT-ZERO VOLTS switch may be held in the ZERO CURRENT position. This will open the element of the transistor that is connected to the Base terminal of the test fixtures to assure zero-current conditions. Typical measurements are shown in Figure 11 and Figure 12.

Small values of I_{cbo} or I_{ceo}, such as encountered in typical silicon transistors, may become difficult to measure on even the most sensitive COLLECTOR MA range. The section devoted to Modifications for Special Applications describes a circuit modification in the Type 575 to obtain one microamp per division on the COLLECTOR MA display; however, a simpler method may be employed quite successfully by using an external resistor in the " common" lead of the transistor and measuring the voltage drop across the resistor with the Vertical BASE VOLTS display. The input terminal of the transistor is not connected, but remains open to obtain zero input current. Depending upon conditions, it is possible to measure collector currents in the order of one-hundredth of a microamp. The method is described as follows:

Referring to Figure 1, it can be seen that with the ZERO CURRENT-ZERO VOLTS switch in the ZERO CURRENT position, the Base terminal is disconnected from the Base Generator; however, the Vertical Amplifier remains connected to the terminal when it is in the BASE VOLTS positions. With an external resistance between the Base terminal of the test fixture and the E (ground) terminal, we may measure the voltage across the resistance which, of course, is directly related to the current through it. For measuring I_{cbo}, the transistor is connected with the collector to the C terminal, the base connected to the Base terminal, and the emitter is not connected. For measuring I_{ceo}, the base and emitter leads of the transistor are merely interposed.

Using a 100 K ohms resistance produces the following vertical scale factors on the graticule:

Vertical Base Volts	Vertical Scale Factor
.01 Volts/Div.	.1 μamp/Div.
.02 " "	.2 " "
.05 " "	.5 " "
.1 " "	1.0 " "
.2 " "	2.0 " "
.5 " "	5.0 " "

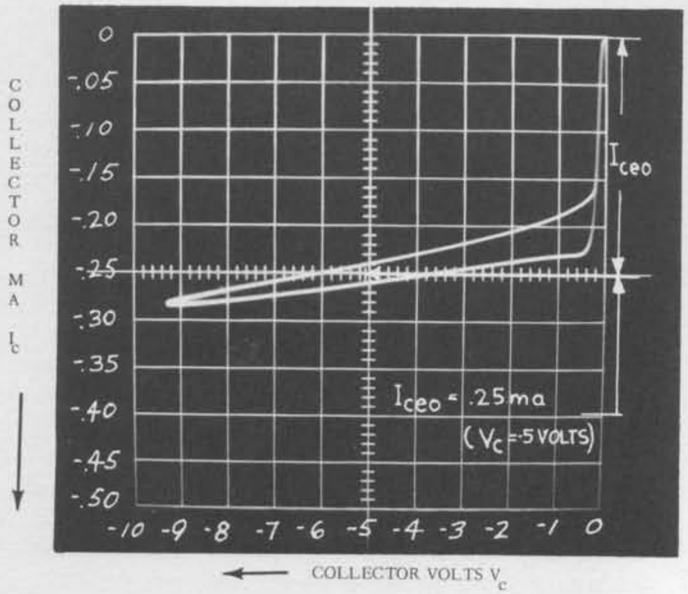
The resistor should be non-inductive (1/2 watt or 1 watt) and have a value of at least one percent tolerance to be compatible with the accuracy of the rest of the system. The transistor and resistor lead lengths should be kept short to avoid hum pickup in the external circuit, which would cause large " loops". Hum pick-up from stray magnetic fields can be minimized by using a grounded metal enclosure around the transistor, test terminals and resistor. The internal capacities of the transistor may also limit the minimum current-measuring capability by causing an intolerably large hysteresis loop in the current display. Where it is desirable to ignore the transistor internal capacity, the steady state dc value of the collector current may be considered to exist at the center of the hysteresis loop in the collector current display. This may be verified by decreasing the collector PEAK VOLTS until only the peak of the collector sweep occurs at the point in question.

Leakage current between transistor terminals in the external circuit or test board should be avoided since this would contribute an error to the actual leakage of the transistor itself.

It is advisable to check the Vertical Amplifier dc balance to preclude ambiguity when switching between BASE VOLTS ranges. Any shift may be eliminated by holding the AMPLIFIER ZERO CHECK switch up and adjusting DC BAL for minimum vertical movement of the trace as the Vertical BASE VOLTS switch is rotated through its six positions.

A typical display using this measuring technique is shown in Figure 13. A simplified schematic of the system is shown in Figure 14.

The reader may recognize from examination of the Type 575 System Functional Block Diagram, Figure 1, that it is possible to connect the Base SERIES RESISTORS between emitter and base by placing the STEP SELECTOR in the BASE VOLTS position. Zero input current or voltage from the Base Generator can be obtained by placing the REPETITIVE-OFF-SINGLE FAMILY switch in the OFF position providing the STEP ZERO control has been properly adjusted. This feature may be used to advantage in exploring the collector current that exists with various values of base to emitter resistance. It may also serve the purpose of the external resistor used for measuring low values of I_{cbo} and I_{ceo}. Limitations are imposed by the values indicated on the Base SERIES RESISTORS and their tolerance, which is 5 percent. As mentioned before, whenever the REPETITIVE-OFF-SINGLE FAMILY switch is used in the OFF position to obtain the zero current or zero voltage display, it is important that the STEP ZERO control be properly adjusted to assure zero input to the transistor from the Base Generator.



DISPLAY

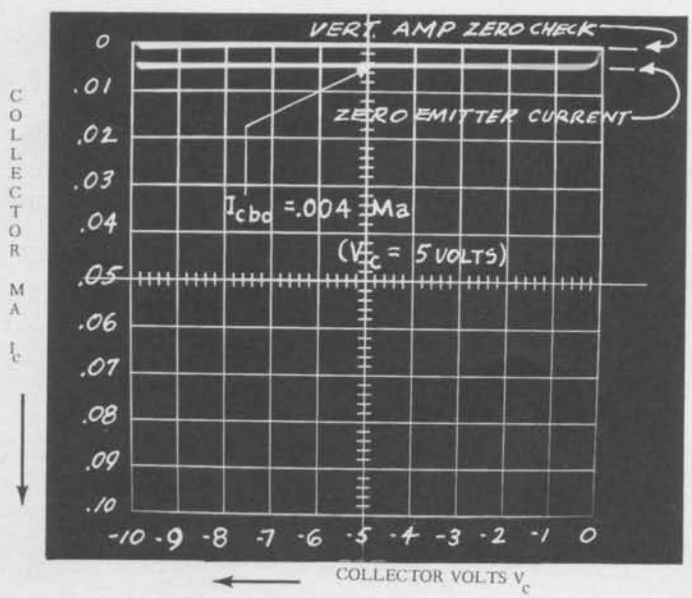
Vertical:
Coll. Ma = .05 Ma/Div.

Horizontal:
Coll. Volts = 1.0 V/Div.

Base Step = 0 Current
(Open Base).

I_{ceo} = .25 Ma
(V_c = -5 Volts).

Fig. 11. I_c vs V_c, (I_b = O, Emitter Open) curve for PNP transistor in common base configuration.



DISPLAY

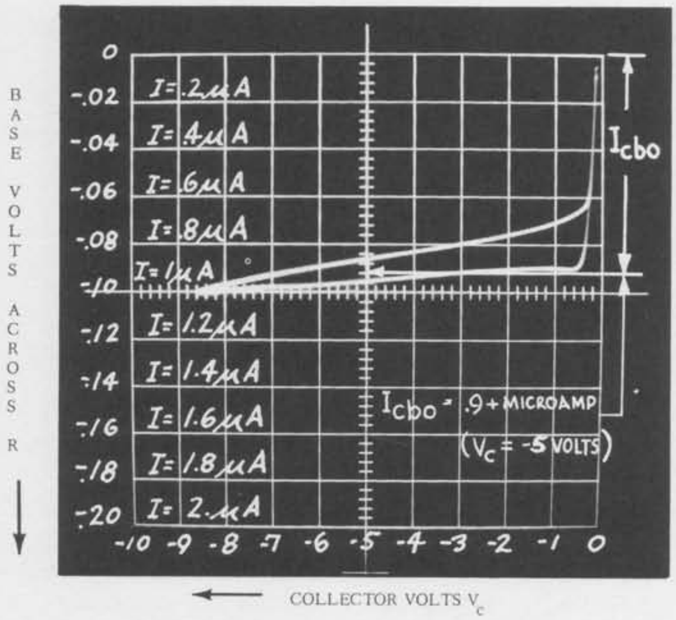
Vertical:
Coll. Ma = .01 Ma/Div.

Horizontal:
Coll. Volts = 1.0 V/Div.

Base Step = 0 Current
(Open Emitter).

I_{cbo} = .004 ma.
(V_c = -5 Volts).

Fig. 12. I_c vs V_c, (I_e = O Emitter open) curve for PNP transistor in common base configuration.



DISPLAY

Vertical:
Base Volts = .02 V/Div.
(across external 100 K resistor - see text).

Horizontal:
Coll. Volts = 1.0 V/Div.

Base Step = 0 Current
(Open Emitter).

I_{cbo} = .9+ microamp
(V_c = -5 Volts).

Fig. 13. I_c vs V_c, (I_e = O, Emitter open) curve for PNP transistor in common base configuration.

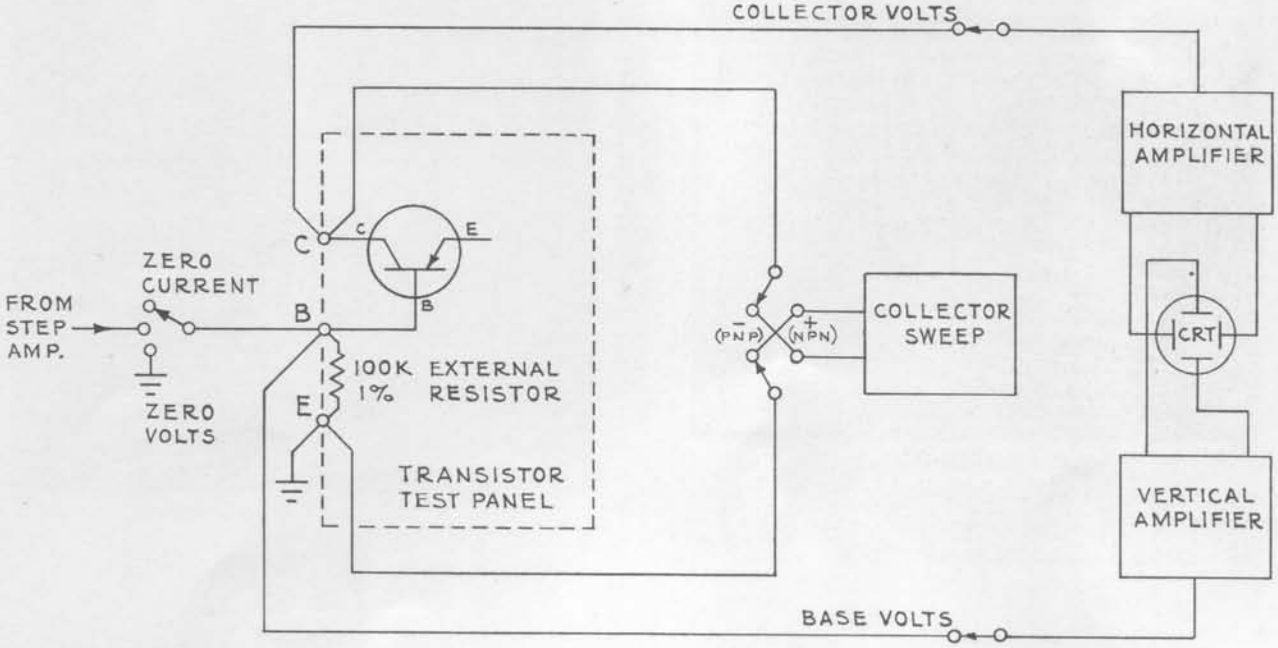


Fig. 14. System for measuring low values of I_{cbo} or I_{ceo}.

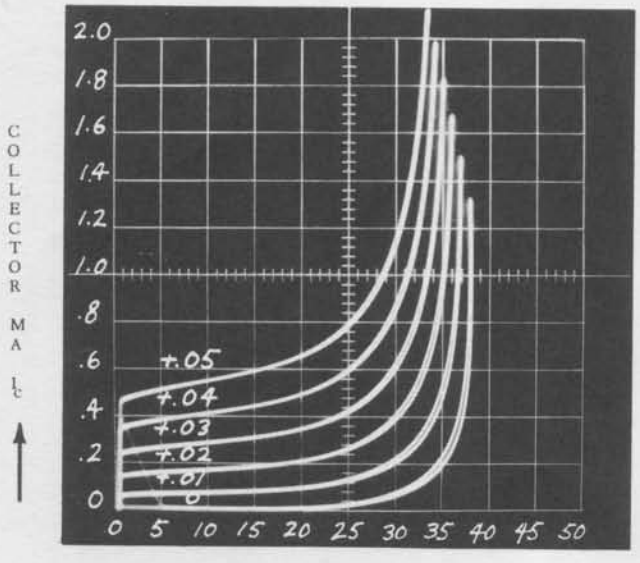
COLLECTOR BREAKDOWN VOLTAGES

As the voltage is increased on a reverse biased collector of a transistor, a point will be reached where the collector current increases rapidly and may become essentially independent of the collector voltage. We will show several measurements of the breakdown characteristics, but will not attempt to differentiate between the phenomena referred to as avalanche, punch-through, zener breakdown, or carrier multiplication, since they are largely dependent upon the configuration, type, and geometry of the transistor.

Figures 15, 16, and 17 show the breakdown characteristics for the same transistor under various operating conditions. It will be noted that the breakdown voltage varies depending upon how the transistor base and emitter are connected and what their source impedance is.

In each of the measurements, a value of collector DISSIPATION LIMITING RESISTOR was inserted to " catch" the collector current and prevent excessive thermal rise and possible damage to the transistor.

Under certain conditions, some transistors will exhibit a negative resistance characteristic in the breakdown region as occurred in Figure 16. In this particular case, oscillation is present in the upper portion of the negative resistance region. In some transistors, oscillation may occur in some other region of the characteristic curve and may be recognized by the faint and ragged, or erratic, behavior of the trace on the display. Point contact transistors are especially susceptible to oscillation under certain operating conditions and particularly in common emitter configuration, since Alpha is commonly greater than one, and they are inherently short-circuit unstable.



DISPLAY

Vertical:
Coll. Ma = 0.2 Ma/Div.

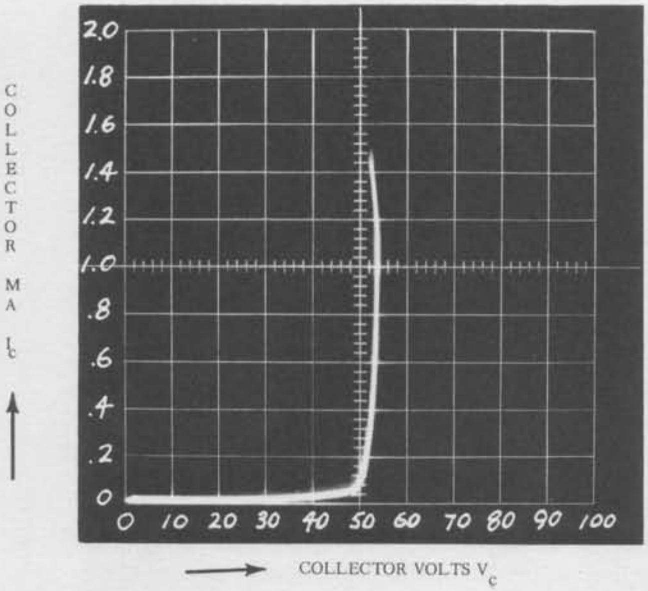
Horizontal:
Coll. Volts = 5 V/Div.

Step Selector:
Base Current = +.01 Ma/Step.

Collector Peak Volts
Range = 0 - 200 Volts.

Dissipation Limiting
Resistor = 5 K Ohms.

Fig. 15. Collector Breakdown characteristic curves, I_c vs V_c, (I_b) for NPN transistor in common emitter configuration.



DISPLAY

Vertical:
Coll. Ma = .2 Ma/Div.

Horizontal:
Coll. Volts = 10 V/Div.

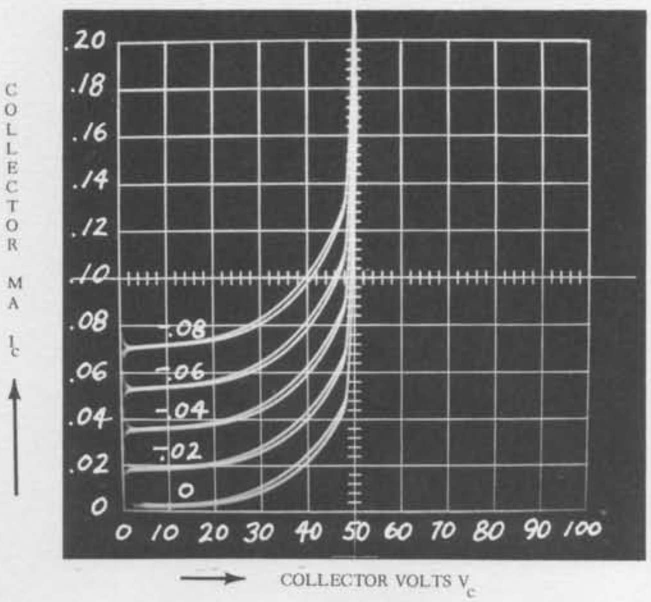
Base and Emitter=0 Volts (Ground).

Collector Peak Volts
Range = 0 - 200 Volts.

Dissipation Limiting
Resistor = 5 K Ohms.

Fig. 16. Collector breakdown characteristics, I_c vs V_c, (I_e and I_b = O volts), of NPN transistor with Emitter and base grounded.

Note: In the collector current region above 1.6 Ma, the trace which cannot be seen in the photograph becomes barely visible due to oscillation. Damage could occur to the transistor if this high current escaped observation and were allowed to exist too long. The Collector DISSIPATION LIMITING RESISTORS should always be inserted as one protective measure.



DISPLAY

Vertical:
Coll. Ma = .02 Ma/Div.

Horizontal:
Coll. Volts = 10.0 V/Div.

Step Selector:
Base Current = -.02 Ma/Step.
(Applied to Emitter)

Collector Peak Volts
Range = 0 - 200 Volts.

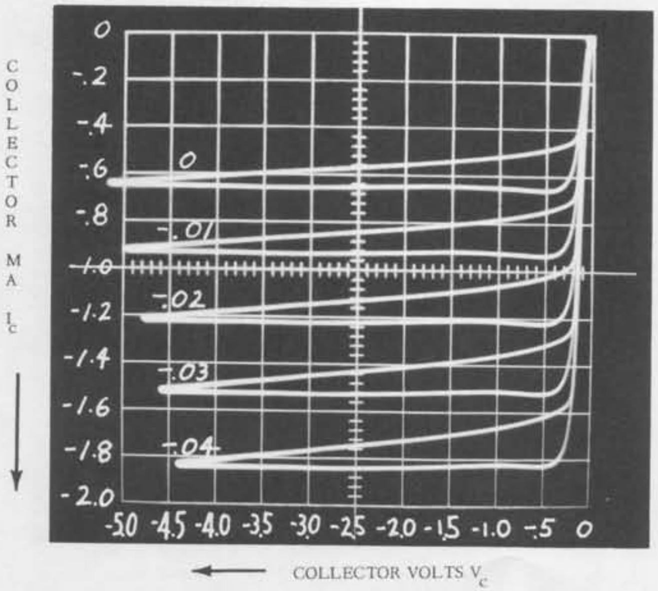
Dissipation Limiting
Resistor = 5 K Ohms.

Fig. 17. Collector breakdown conditions, I_c vs V_c, (I_e), of NPN transistor in common base configuration.

MISCELLANEOUS DISPLAYS

COLLECTOR CAPACITY

The effect of collector capacity may become quite pronounced in some transistors. The loop resulting from the collector-to-base capacity causes a displacement current to add and subtract from the base current of the transistor. The effect is most pronounced in common emitter configuration with low base drive, high collector voltage, and the greatest expansion of the vertical COLLECTOR MA display. The capacity effect is more pronounced at the knee of the curve in the collector family because of the sudden change in collector current in the transistor. At the same time, the rate of change of the collector half-sine shape sweep voltage is maximum; that is, near the beginning and end of the cycle when a high value of collector peak voltage is used. As explained in a preceding section, the equivalent steady state dc value of collector current may be established by decreasing the collector PEAK VOLTS until only the peak of the collector sweep occurs at the point in question. The approximate magnitude of the capacity may be measured by adding a capacitor of 10 to 1000 micromicrofarads between the base and collector terminals. The transistor capacity is approximately equal to the capacity of the external capacitor when the vertical size of the loop is doubled. A comparison of Figure 18 and Figure 19 illustrates the effects of the collector to base capacitance.



DISPLAY

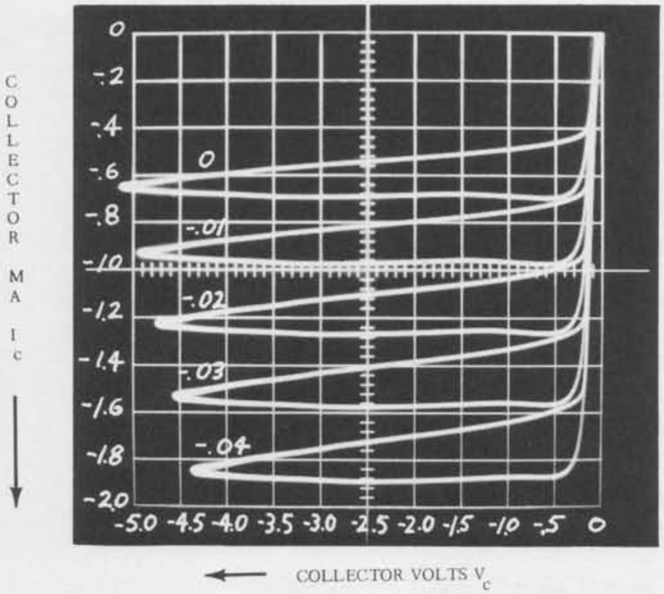
Vertical:
Coll. Ma = .2 Ma/Div.

Horizontal:
Coll. Volts = .5 V/Div.

Base Step = -.01 Ma/Step.

Note: Collector capacity appears as loops in the collector current display.

Fig. 18. Collector family of curves, I_C vs V_C, (I_b), for PNP power transistor in common emitter configuration.



DISPLAY

Vertical:
Coll. Ma = .2 Ma/Div.

Horizontal:
Coll. Volts = .5 V/Div.

Base Step = -.01 Ma/Step.

Note: External 560 $\mu\mu$f capacitor added between Base and Collector.

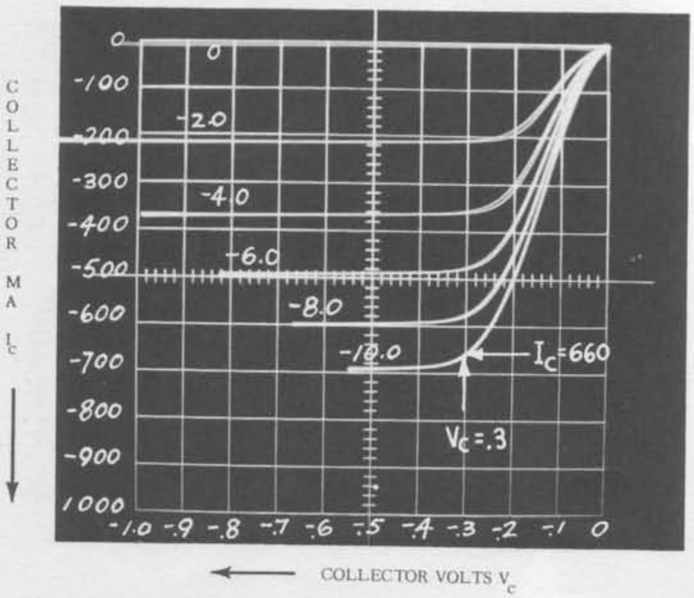
Fig. 19. Collector family of curves, I_c vs V_c, (I_b), for PNP power transistor with 560$\mu\mu$f additional capacitance between base and collector in the common emitter configuration.

SATURATION VOLTAGE AND SATURATION RESISTANCE

The collector voltage between zero and the "active region", or the point at which the collector current becomes essentially independent of the collector voltage is commonly referred to as the "saturation voltage". The ratio of this "saturation voltage" to the collector current at which it is measured is usually called the collector "saturation resistance". The input current and/or collector current should be specified to define the point at which the collector "saturation voltage" is measured. For collector "saturation resistance" the input current and collector current, or voltage, is generally specified. Large or small values of "saturation voltage" may be measured easily on the Type 575 by selecting the appropriate scale factor for the horizontal COLLECTOR VOLTS. A typical display is shown in Figure 20. The onset of saturation may be considered to occur at the knee of the curves.

$$V_{cs} = .3 \text{ volts} \quad \text{when } I_c = 660 \text{ ma and } I_b = 10 \text{ ma}$$

$$R_{cs} = \frac{V_{cs}}{I_c} = \frac{.3}{660 \times 10^{-3}} = \frac{.3}{.66} = .45^{+} \text{ ohms}$$



DISPLAY

Vertical:
Coll. Ma = 100 Ma/Div.

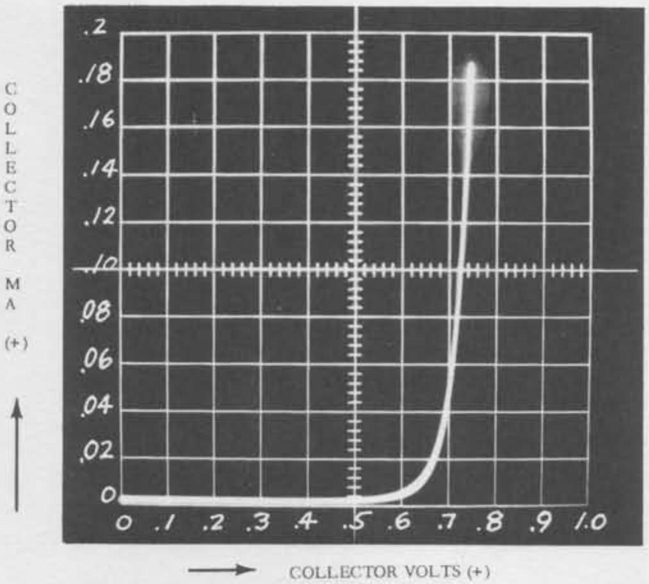
Horizontal:
Coll. Volts = .1 V/Div.

Step Selector:
Ma/Step = -2 Ma/Step.

Fig. 20. Collector family of curves, I_c vs V_c, (I_b) in the collector saturation region for a PNP transistor in the common emitter configuration.

DIODE CHARACTERISTICS

Forward conduction or reverse voltage breakdown of a diode may be displayed on the Type 575 by the simple expedient of using the collector sweep supply as a voltage source. The graticule will present the E-I plot when COLLECTOR MA is selected on the Vertical display and COLLECTOR VOLTS is selected on the horizontal display. Collector DISSIPATION LIMITING RESISTORS should be inserted to preclude excessive current through the diode. Appropriate selection of the positive or negative collector sweep voltage makes it unnecessary to remove and re-insert the diode when comparing forward and reverse currents. The collector sweep voltage is limited to 200 volts peak. Zener diode characteristics are shown in Figure 21 and Figure 22.



DISPLAY

Vertical:
Coll. Ma = .02 Ma/Div.

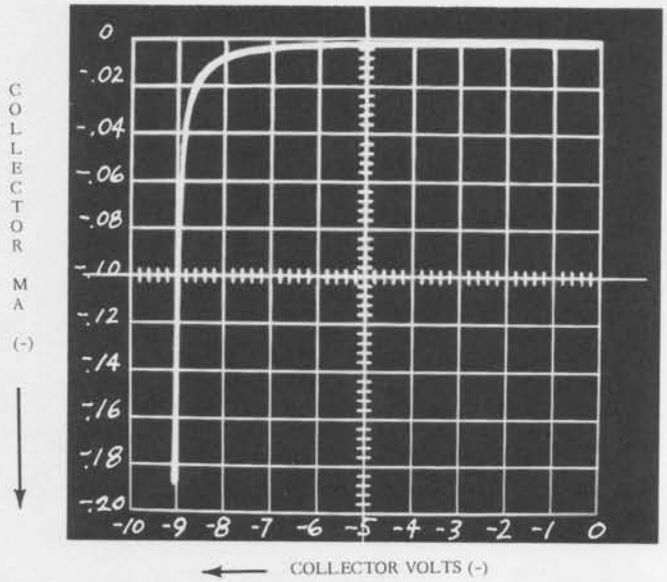
Horizontal:
Coll. Volts = .1 V/Div.

Dissipation Limiting
Resistor = 500 Ohms.

Diode Connections:

Cathode = E (ground).
Plate = C (Collector).

Fig. 21. Zener diode forward conduction characteristic.



DISPLAY

Vertical:
Coll. Ma = .02 Ma/Div.

Horizontal:
Coll. Volts = 1.0 V/Div.

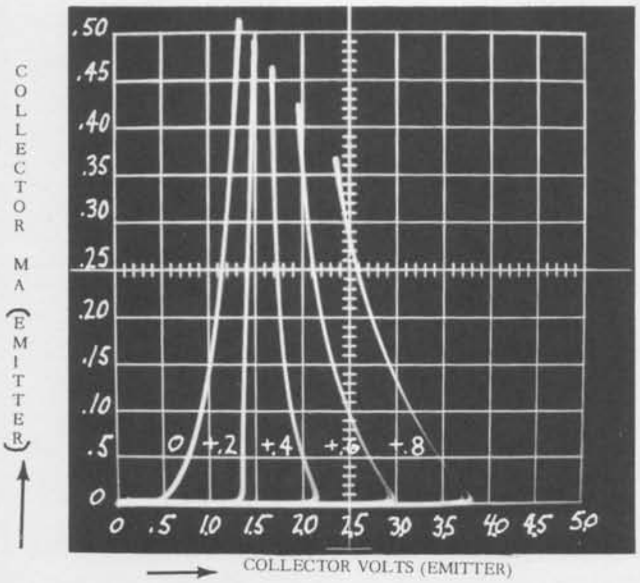
Dissipation Limiting
Resistor = 500 Ohms.

Diode Connections:

Cathode = E (ground).
Plate = C (Collector).

Fig. 22. Zener diode reverse breakdown characteristic.

The emitter characteristics of the double-base junction diode may be displayed on the Type 575 by connecting the emitter to the Collector (C) terminal, Base-two to the Base (B) terminal, and Base-one to ground terminal (E). The emitter current for zero Base Current input is established by the Collector Peak Volts and appears as the first vertical trace in the display. As the constant current base steps are increased, sufficient Base-two to Base-one bias is developed to produce a family of emitter characteristics, as shown in Figure 23. By selecting BASE VOLTS on the Horizontal display, the input bias voltage for each curve may be determined. The negative resistance characteristics of the emitter appear on the second, third, and fourth Base steps in Figure 23. The interbase family of characteristic curves shown in Figure 24 is obtained by connecting Base-two of the transistor to the Collector (C) terminal, the emitter to the Base (B) terminal, and Base-one to ground terminal (E). The graticule scale factors and the magnitude of the input current are given with each illustration.



DISPLAY

Vertical:
Coll. Ma = .05 Ma/Div.
(Emitter Current).

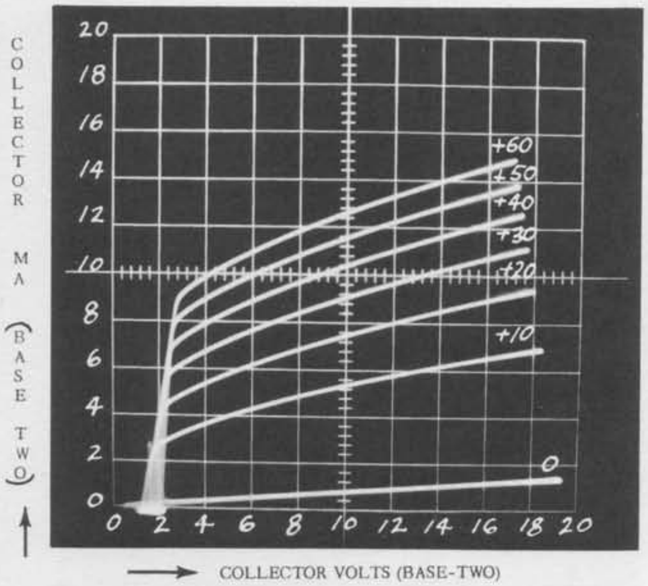
Horizontal:
Coll. Volts = .5 V/Div.
(Emitter Voltage).

Base Step = +.2 Ma/Step
(Applied to Base-two).

Dissipation Limiting
Resistor = 5 K Ohms.

Polarity = (+) NPN.

Fig. 23. Double-base junction diode emitter characteristic.



DISPLAY

Vertical:
Coll. Ma = 2 Ma/Div.
(Base-two Current).

Horizontal:
Coll. Volts = 2 V/Div.
(Base-two Voltage).

Base Step = +10 Ma/Step
(Applied to Emitter).

Dissipation Limiting
Resistor = 100 Ohms.

Polarity = (+) NPN.

Fig. 24. Double-base junction diode interbase characteristic.

MODIFICATIONS FOR SPECIAL APPLICATIONS

VERTICAL SCALE INCREASED BY A FACTOR OF TWO

It is possible to decrease the sensitivity of the vertical amplifier by one-half so that the value of each VERTICAL CURRENT OR VOLTAGE position is multiplied by a factor of two. For instance, the 1000 MA/DIV position of the COLLECTOR MA display is increased from 1 amp/division to 2 amp/division. This may be particularly useful for measuring collector current values between 10 and 20 amps. To accomplish this change it is only necessary to change the value of R429 from 11.48 K ohms to 32.31 K ohms. The one-percent resistor is located on the top of the Vertical display switch SW405C. The collector supply is capable of delivering 20 amps for short periods of time at low collector voltages. The collector supply power limitation is protected by a one-amp fuse in the primary circuit of the supply. The fuse is located on the front panel of the Type 575 with the COLLECTOR SWEEP controls.

VERTICAL SCALE DECREASED BY A FACTOR OF ONE-TENTH

The sensitivity of the vertical amplifier may be increased by a factor of ten so that the value of each VERTICAL CURRENT OR VOLTAGE position is divided by 1/10. In measuring small values of collector current, for instance, the vertical scale factor is changed from .01 ma/division to .001 ma/division. The change may be accomplished by shorting out R429, a one-percent, 11.48 K ohms resistor located on top of the Vertical display switch SW405C. The lead length should be held to a minimum to avoid hum pick-up. An alternate method of measuring small values of collector current is given in an earlier section devoted to measuring collector cutoff current.

SINGLE TRACE DISPLAY

Through the proper selection of the BASE STEP SELECTOR, STEPS/FAMILY, POLARITY and STEP ZERO controls on the Type 575, one of a family of base steps can be made to coincide with a predetermined value of input current or voltage, as long as it is within the maximum ratings of the base generator. However, if it is required that only one value of input current or voltage be selected for single trace display, it can be accomplished by substituting a fixed voltage to the step amplifier in place of the staircase steps from the step generator. The Step Generator, as we have used the term in preceding discussions, actually consists of a Step Generator followed by a Step Amplifier. Referring to the Step Generator schematic in the Instruction Manual for the Type 575, the fixed voltage should be applied to the 1 K resistor R175 which connects to grid pin 2 of V163 (6AN8) after removing the connection of R175 from the junction of R174 (1.2 Meg) and B174. The fixed dc voltage can be derived from a divider network and potentiometer to obtain a range of from -20 volts to +170 volts, which corresponds approximately to the zero step and the 12th step of the step generator. The division of current or voltage by the STEP SELECTOR switch is still effective since it is in the output of the step amplifier. The calibration of the single trace output current or voltage may be obtained by displaying the transistor characteristics in the normal manner and then substituting the fixed voltage to duplicate the trace desired. A more sophisticated circuit may be devised using precision resistors for fixed voltage taps which, when once calibrated, will not require further adjustment. The regulated voltages within the Type 575 may be used as a source for the divider arrangement as long as precautions are taken against drawing more than several milliamps current in the divider. It should be remembered that the average transistor current could be higher for single trace display than for the family of curves. The increased power dissipation of the transistor could cause shifting of the curve as a result of heating.

DEFINITIONS OF SYMBOLS

I_{cbo} Collector current when collector junction is reverse-biased and zero current flows in the emitter or it is open circuit.

I_{ceo} Collector current when collector junction is reverse-biased and zero current flows in the base or it is open circuit.

α DC or low-frequency forward-current gain or forward-current transfer ratio in common base configuration.

β DC or low-frequency forward-current gain or forward current transfer ratio in common emitter configuration.

h_{fe} Same as B (Beta).

h_{oe} DC or low-frequency output admittance in common-emitter configuration.

h_{ie} DC or low-frequency input impedance in common-emitter configuration.

h_{re} DC or low-frequency reverse voltage amplification factor in common-emitter configuration.

h_{fb} Same as α (Alpha).

h_{ob} DC or low-frequency output admittance in common-base configuration.

I_c DC or low-frequency value of collector current.

V_c DC or low-frequency value of collector voltage measured at the collector terminal of the transistor.

I_b DC or low-frequency value of base current.

V_b DC or low-frequency value of base voltage measured at the base terminal of the transistor.

I_e DC or low-frequency value of emitter current.

V_e DC or low-frequency value of emitter voltage measured at the emitter terminal of the transistor.

Δ A small increment of the symbol to which it is attached.

V_{cs} DC or low-frequency value of collector voltage at which the collector current becomes essentially independent of the input voltage or current.

R_{cs} Collector saturation resistance or the ratio of the collector saturation voltage to the collector current at which the collector saturation voltage was measured. (Specify input current or voltage at measuring point.)

REFERENCE LITERATURE

Committee Personnel, " IRE Standards on Solid-State Devices: Methods of Testing Transistors, 1956", Proc IRE, Vol. 44 (November 1956).

Transistor Issue, Proc IRE, Vol. 46, No. 6 (June 1958).

Hunter, L. P., Handbook of Semiconductor Electronics, McGraw-Hill, First Edition, 1956.

Lo, A. W., Edres, R. O., Zawels, J., Waldhauer, F. D., Cheng, C., Transistor Electronics, Prentice-Hall, 1955.

Shea, R.F., Transistor Circuit Engineering, Wiley and Sons, 1957.

Millman, J., and Taub, H., " Transistors in Pulse and Digital Circuits", Section 18-10, pp 548-607, Pulse and Digital Circuits, McGraw-Hill, 1956.

Kiver, M., Transistors in Radio and Television, Wiley and Sons, 1956.

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