THE LINEAR IC
CURVE TRACER

Operating the 577 with a
178 Linear IC Test Fixture

Contents

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INTRODUCTION TO CURVE TRACERS

For 15 years prior to the introduction of the 178, curve tracers have been used primarily to evaluate discrete semiconductor devices. Within this time, the use of curve tracers has grown and today it is accepted as a standard in the field of semiconductor measurements. No other single class of instruments has been able to match its unique features, range of measurements and versatility.

Your 178 now extends curve tracer measurements to include many parameters of linear integrated circuits. It is designed to operate in a 577-D1 (storage) curve tracer mainframe, making the 577 family the most versatile line of curve tracers ever.

Curves Rather Than Numbers

Your ability to plot a characteristic curve rather than obtain a numerical answer is one of your curve tracer's truly unique features. A curve is actually a set of answers plotted over a measurement range. You are not limited by numerical values at isolated points, but see how and why parameters change throughout a device's operating range. The result is more information and insight. Your curve tracer's CRT is actually a window on effects that remain hidden from test sets that provide numerical or go, no-go answers.

From Lab to Production Line

The versatile curve tracer finds applications that range from the laboratory to the production line. In the laboratory the curve tracer is really the star among other available instruments for evaluating components. Here, speed is not nearly as important as the wealth of information a curve tracer reveals about the device-under-test and the curve tracer has no equal here.

The production line also finds the curve tracer an indispensable tool to keep things running smoothly. When automated equipment starts to reject a large number of components, the curve tracer is immediately brought into action to discover what these rejected components "look like". Thus the curve tracer pinpoints the problem area. Small batches and special tests are two other production line applications where the curve tracer finds use alongside even the most sophisticated automatic system. Often, an entire batch can be completely tested to a single special specification in less time than it would take to program the automatic system to include that test.

Incoming inspection groups often sharpen their pencils to compute curve tracer economics as applied to their particular situation. Although a high speed, automatic test set may look attractive on first analysis, allowance for many real life situations usually tips the business analysis in favor of curve tracers. Sometimes overlooked is allowance for equipment down time (both breakdown and routine maintenance and calibration) and allowance for future testing needs which are seldom well-defined beforehand. Because of these two situations, several curve tracers with their higher labor cost can prove to be a wiser investment than a single, high-speed, automatic test set. First, equipment failure cannot seriously threaten the capacity of several test stations equipped with rugged curve tracers. Down time on a single station would be a small percentage of total capacity, and even that rare occurance can be avoided at low cost with a spare. As for future capability, few, if any instruments can match the curve tracer's flexibility and measurement range. Added to this, its plug-in versatility permits future expansion to meet the ever-changing requirements of our advancing technology.

HOW THE 178 TESTS LINEAR IC'S

Operational amplifiers make up the greatest single class of linear integrated circuits. In order to test amplifiers, the 178 Linear IC Test Fixture departs from the approach used in standard curve tracers: open-loop testing. In a standard curve tracer the device-under-test (DUT) is subjected to one or more test voltages or currents and the response is displayed upon the CRT. However, the operational amplifier's high gain (over 100db is common) makes open-loop, large-signal response difficult to measure. For this reason the 178 tests amplifiers in a closed-loop configuration.

In closed-loop testing, the amplifier or DUT becomes a part of a feedback loop. This feedback loop controls the input voltage of the DUT so that the DUT's output voltage is at the required value. The required output voltage of the DUT is determined by the control settings on the 178 front panel. In one of the test functions, GAIN, the output of the DUT is required to follow a sweep generator's signal and is displayed on the Horizontal axis of the CRT. The required input voltage to the amplifier DUT is measured and displayed on the Vertical axis of the CRT while the DUT output is swept. The characteristic curve displayed in this test condition is the DUT's input voltage as a function of its output voltage. The amplifier's GAIN can be determined from this display.

It should be noted that the closed-loop testing reverses the roles of dependent and independent variables compared with open-loop testing. In open-loop, the input is forced and the output is measured. In closed-loop the output is forced and the input is measured.

Measuring Parameters

Parameters of operational amplifiers are obtained from the CRT display much the same way as they are with conventional curve tracers. Whether measuring linear IC's or discrete semiconductor devices the operator first reads the CRT display and then makes any necessary calculations.

Figure 1 is a CRT display of an amplifier's input voltage versus its output voltage, its GAIN curve or transfer characteristic measured at essentially DC (actually 0.05 Hz). Zero volts on both axes is at center screen. Now consider points A and B. For an output swing from -10 volts to +10 volts, the input voltage is seen to change 200 microvolts. The gain of this amplifier is 100,000 or 100 db obtained by dividing output voltage by input voltage.

The vertical deflection is the voltage at the amplifier's inverting input with respect to it non-inverting. Therefore, the input voltage is shown positive for negative output voltage, and the curve occupies the second and fourth quadrants. The vertical line going off screen is caused by the closed-loop circuitry as the operational amplifier (DUT) reaches its limits. The sweep generator's test signal requires the DUT, in closed-loop configuration, to follow a signal beyond its output voltage limits. The supply voltages are plus and minus fifteen volts.

Figures 1 through 5

Input voltage vs output voltage, or GAIN curves, for five different operational amplifiers. Vertical deflection factor is 0.1 mV/div, horizontal 5V/div. Load resistance is 50K ohms in Figures 1 and 5, 1K ohm in Figures 2, 3 and 4.

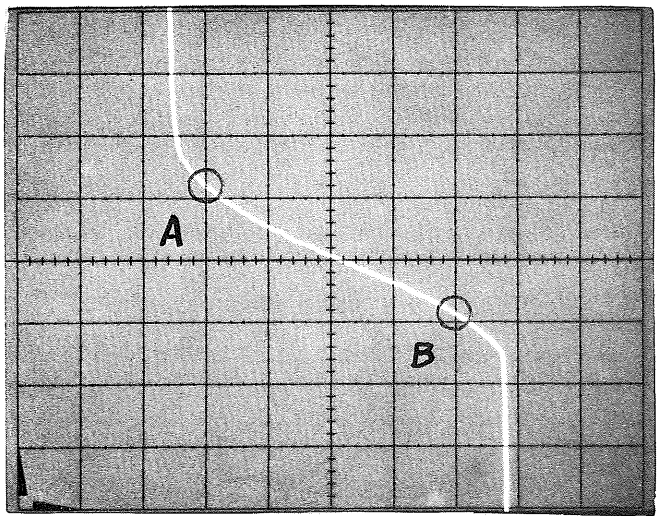


Figure 1

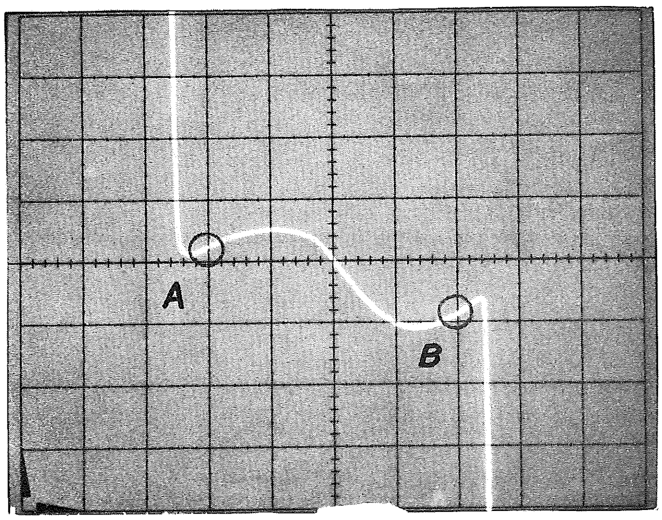


Figure 2

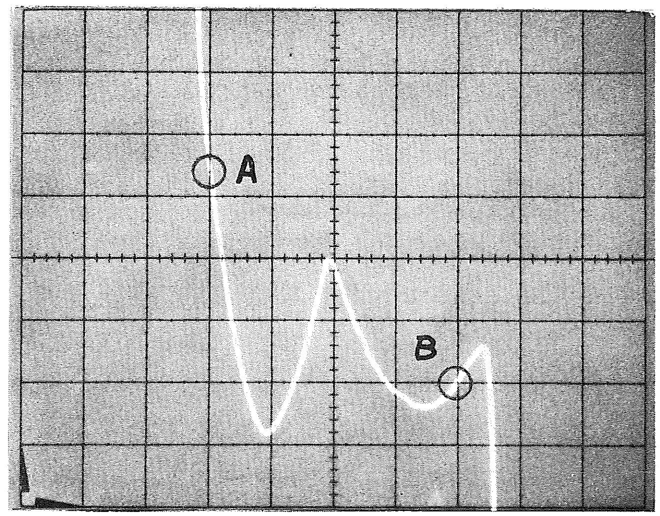


Figure 3

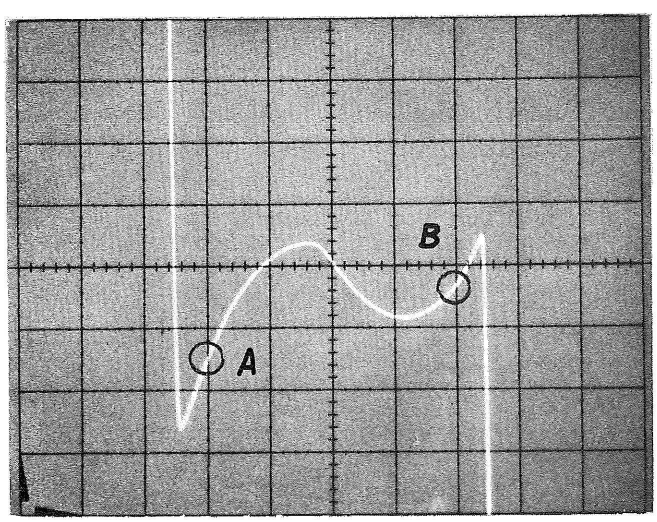


Figure 4

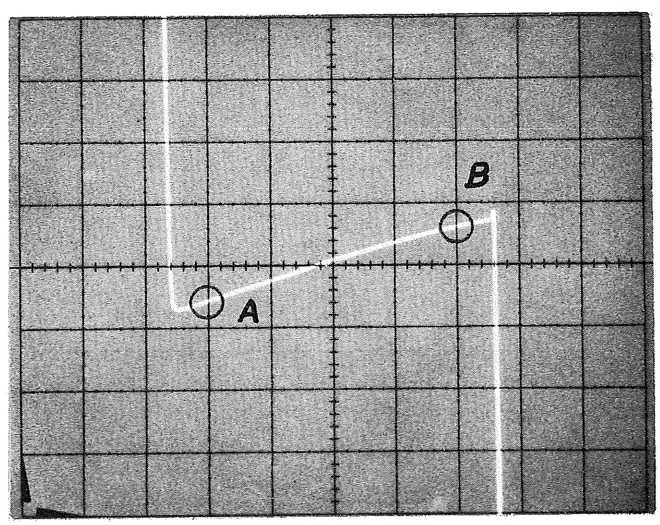


Figure 5

The Wealth of Information

The process described above for measure gain is not as quick as jotting down a number flashed to the operator by a tester's numerical readout. (For faster techniques than the measure-then-compute method described above, see "Production Line Methods" described in the Applications Section.) However, it is important to look beyond test speed and compare the kind of information provided by a Linear IC Curve Tracer and other types of integrated circuit testers.

A tester that provides a numerical answer is likely to measure large signal gain by making two "point" measurements, for example from points A and B on figure one. A curve tracer measurement, by contrast, not only shows points A and B, but how the amplifier responded at all points in between. It shows the manner in which it got from one point to the other.

In figure one, the curve between points A and B contains the information theoretically expected of an ideal amplifier: linear, constant slope with no spurious excursions. It is easy to assume that the expected information - that the input voltage is well behaved - is no important information at all. This misunderstanding can be shattered by examining four other GAIN curves.

Figures 2 through 5 show characteristics that do not go from point A to point B in the anticipated, ideal manner. These are not unusual amplifiers that were built especially to demonstrate a point, but commonly available integrated circuit operational amplifiers. The "unusual" response is the ideal curve in Figure 1. Most devices either do not produce an ideal DC transfer characteristics or their application (operating conditions) distorts the characteristic beyond recognition.

Interpreting the Information

A large number of applications make use of an operational amplifier's extremely high DC gain. Three such uses are transducer amplifiers, voltage regulator amplifiers and D to A converters. In these applications a high "gain" is usually relied upon to minimize errors and keep the circuit performance dependent mainly upon precise, passive components that make up a feedback network.

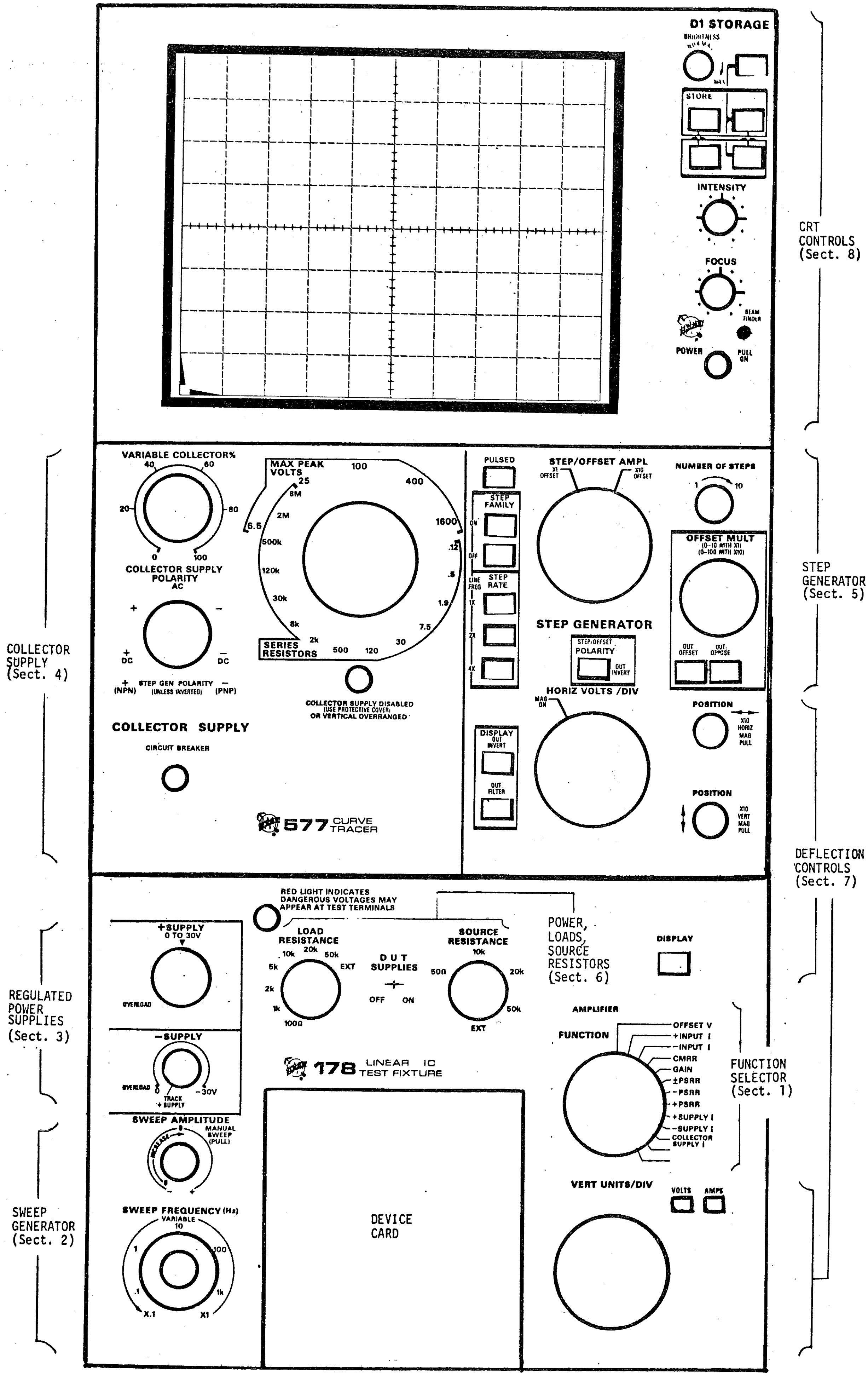
One way to evaluate how well an operational amplifier performs in such a DC application is to determine how much its differential input voltage changes during normal operating conditions. To minimize error this change should be small compared to the signal being amplified. Just how small depends upon how much is error admissible. However, an amplifier's input voltage is required to change in order for it to operate. Theoretically, an amplifier's "gain" determines how much its input must change to produce a given change in output: V(in) = V(out)/GAIN. In a world of ideal amplifiers, where all curves look like Figure 1, knowledge of an amplifier's gain is reasonably adequate for intelligent circuit design or component selection. As Figures 2 through 5 show, however, the real world is seldom ideal. Here, thermal effects often mask and completely overshadow changes due to "gain" alone. Higher "gain" amplifiers do not necessarily perform better or give less DC error than lower "gain" amplifiers in all applications.

Consider Figure 2 for example. Measuring large-signal "gain" from points A and B tells nothing about how the input changes between these points. The large signal gain of 106 db (200,000) suggests that the total input voltage excursion over a ±10 volt operating range is 100 microvolts. However, the 577/178 display clearly shows that the actual excursion is 160 microvolts. More significant may be the input voltage excursion for small signals. The gain curve begins to approximate a straight line for small enough signals, making small-signal gain a more meaningful parameter for evaluating amplifier performance in some cases. Consider for example a small signal near zero volts output in Figure 2. The input voltage excursion is great for relatively small output voltage changes. The computed DC gain for these small signals is only 50,000, far worse than the large-signal "gain" of 200,000 measured from points A and B.

Though small-signal gain can be a meaningful parameter in some applications, it is not a staisfactory substitute for a complete GAIN curve. For example, to find where small-signal gain is best and where it is worst would require many measurements over an amplifier's entire range. By contrast, this information can be determined at a glance from the complete GAIN curve as normally traced on the 577/178 CRT. Another limitation of small-signal gain is measurement equipment. If the measurement is made at frequencies above the amplifier's first break point, which often occurs below 10 Hz., the measurement is inadequate for determining the amplifier's DC behavior. Where small-signal measurement is called for, however, the 577/178 can be adjusted to trace only a small portion of the GAIN curve at any frequency from 0.01 Hz. to 1 K Hz.

In summary, if all amplifiers had ideal gain curves there would be little need for a curve tracer. In fact, both large-signal and small-signal gain measurements made at near DC condition would both give equally valid results. However, real world condition produces an acute need to display amplifier behavior with curves. Curves are necessary if a designer is to intelligently predict a device's operation in a given circuit, and if an evaluation department or incoming Q/A group is to intelligently screen devices for a given application.

IDENTIFICATION OF CONTROLS



FUNCTION OF CONTROLS

1. Function Selector

The Function Selector does several jobs as it is rotated through its eleven positions. It selects the points to be monitored by the vertical and horizontal axes of the display and selects the point to be driven by the Sweep Generator. The specific operation of the function switch depends in part upon the Device Card being used in the 178 and not all of the eleven positions are used with every card. Separate interchangeable nomenclature panels show the function of each position that is useful for any particular Device Card. A detailed description of the functions are included with description and specifications of the cards.

2. Sweep Generator

The Sweep Generator provides a sinusoidal waveform to various control points to facilitate plotting characteristic curves of the device-under-test. The control points depend upon the particular Device Card selected and the setting of the Function Switch. In many test functions the Sweep Generator varies the output voltage of the device-under-test or its common mode input voltage. In test six through ten on the Function Selector, the Sweep Generator varies the voltage of the regulated supplies (+ supply and - supply).

Adjusting the Frequency - The SWEEP FREQUENCY control adjusts the Sweep Generator frequency from 0.01Hz to 1kHz. Five calibrated frequency steps of 0.1, 1, 10, 100 and 1kHz are provided. The VARIABLE control provides continuous adjustment from 0.1 times to 1 times the selected decade value.

Adjusting the Amplitude - The SWEEP AMPLITUDE control continuously adjusts the Sweep Generator's amplitude from zero volts to its maximum value which depends upon the function being swept by the generator. Amplifier output voltages and common mode voltages can be swept up to a ± 30 volt range or the limits of the device under test, whichever is less. The Regulated Power Supplies can be swept from zero volts to the voltage selected by the Power Supply controls.

Manual Control - To manually control the Sweep Generator's output, pull the AMPLITUDE control. The output may be set anywhere within the voltage range described under amplitude adjustment above. The FREQUENCY control is inoperative in this mode.

3. Regulated Power Supplies

Two regulated, adjustable power supplies are located in the 178, one positive and one negative. Their adjustment range is 0 to 30 volts and have 150mA current capability. Adjustable current limiting for these supplies is provided on the Device Card. Overload lights in the supply control area indicate when the current limit is reached.

Adjusting the Voltage - The supply voltages may be adjusted independently or from a single control. When the -SUPPLY control is put in the TRACK + SUPPLY position, the voltage of both supplies is controlled by + SUPPLY control, a 3-turn, calibrated dial. The accuracy of adjustment is 2% ±100mV. When not in this track mode, the -Supply is independently adjustable by -SUPPLY control. In certain positions of the Function Selector, tests six through ten, the supply voltages are also under control of the Sweep Generator.

4. Collector Supply

The Collector Supply is located in the 577 mainframe. Only two voltage ranges are available when the 178 is plugged into the mainframe, MAX PEAK VOLTS of 25 or 100 volts. The Collector Supply is not used for most 178 functions. When the Collector Supply is not in use, select the 25 volt range and select either + DC or -DC position on the COLLECTOR SUPPLY POLARITY control.

Safety Interlock - A safety interlock helps to protect the operator from dangerous voltages. The push-button on the 178 front-end panel must be depressed to turn-on the Collector Supply when the 100V range is selected.

Function of Controls - The function of the Collector Supply controls is included in the 577-177-D1-D2 Operators Manual.

5. Step Generator

The Step Generator is located in the 577 mainframe. It is a regulated voltage or current supply and has two main modes of operation. In the stepping mode it provides discrete steps of voltage or current synchronized with the Collector Supply. In the offset mode it provides continuously variable DC voltage or current. These two modes may be selected independently. When they are operated together their outputs are additive. The Step Generator is not used for most 178 functions. Press SINGLE button (in STEP FAMILY area) to turn off stepping function when Step Generator is unused.

Function of Controls - The function of the Step Generator controls is included in the 577-177-D1-D2 Operators Manual.

6. Power, Loads and Source Resistors

Disconnecting DUT Power Supplies - The DUT SUPPLIES switch disconnects all DUT power sources in its OFF position, including the + SUPPLY, the - SUPPLY, the Collector Supply and the Step Generator.

Adjusting the Source Resistance - The SOURCE RESISTANCE control selects one of four input resistor pairs: 50Ω (500Ω when vertical deflection factor is in the range 1mV to 50mV/div), 10kΩ, 20kΩ or 50kΩ. External resistances may be selected in EXT position. These external resistors mount on the Device Card and are in series with 50Ω (500Ω when vertical deflection factor is in the range 1mV to 50mV/div) which is the minimum available resistance. All input voltage measurements are made on the source side of the input resistance.

The Source Resistors are not available to every Device Card. Device Card specifications indicate whenever Source Resistance Switch is inoperative.

Adjusting the Load Resistance - The LOAD RESISTANCE control selects one of six load resistors: 100Ω, 1kΩ, 2kΩ, 5kΩ, 10kΩ, 20kΩ or 50kΩ. External resistance may be selected in EXT position. The external resistor mounts on the Device Card and is in parallel with 50kΩ which is the maximum available resistance.

The Load Resistors are not available for every Device Card. Device Card description indicates whenever Load Resistance Switch is inoperative.

7. Deflection Controls

All deflection controls are located on the 577 mainframe except the controls for vertical deflection factor and for display zeroing. These are located on the 178 test fixture.

Positioning - The POSITION controls (labeled with a vertical arrow or horizontal arrow) adjust the location of the display or spot on the CRT. If no trace or spot is displayed it may be off-screen or the intensity may be too low. See "CRT Controls" for use of the BEAM FINDER and INTENSITY controls.

A X10 MAG is activated on either or both axes by pulling out on the appropriate position control knob. The X10 MAG changes the deflection factor by ten.

Adjusting the Vertical Deflection Factor - VERT UNITS/DIV control on the 178 selects the vertical deflection factor. The deflection factor is either voltage or current per division depending upon the Function Switch position - an indicator lamp shows either VOLTS or AMPS. A sector of the VERT UNITS/DIV control is devoted to low current deflection factors only. If this current only sector is selected when the VOLTS indicator lamp is on, the deflection factor illumination (the lamp behind the knob skirt) automatically turns off.

The voltage measurement range is 10μV/div to 50mV/div (from 1μV/div with X10 vertical magnifier). The current measurement range is 50pA/div to 50mA/div (from 5pA/div with X10 vertical magnifier). The entire current range is not useful on all current measuring positions selectable by the Function Switch. See functional description for the particular Device Card being used.

When the vertical magnifier is selected the corresponding deflection factor change takes place on the VERT UNITS/DIV control.

Adjusting the Horizontal Deflection Factor - The HORIZ VOLTS/DIV control on the 577 mainframe selects the horizontal deflection factor. Most measurements require the HORIZ VOLTS/DIV control to be in the Collector Volts segment of its range unless otherwise stated by the functional description for the Device Card being used.

The voltage measurement range is 50mV/Div to 200V/Div (from 5mV/Div with X10 horizontal magnifier) although the highest voltage positions are not useful with the 178 test fixture.

When the horizontal magnifier is selected the corresponding deflection factor change takes place on the HORIZ VOLTS/DIV control.

Inverting the Display - Releasing the upper NORM button in the DISPLAY area of the 577 mainframe inverts the polarity of both the vertical and horizontal display.

Filtering the Vertical CRT Deflection - Releasing the lower NORM button in the DISPLAY area of the 577 mainframe adds a low pass filter to the vertical deflection signal to remove unwanted noise. The pass band of the filter is very low and can add phase shift of its own to the display unless the test frequency approaches DC. Care should be exercized when using the filter.

8. CRT Controls

The CRT controls are located on the D1 Display Module.

Adjusting the Intensity and Focus - The INTENSITY and FOCUS controls adjust the brightness and spot size of the display. Adjust for best display.

Finding Off-Screen Displays - Pressing the BEAM FINDER button compresses the display so that any signal is shown on screen. (If no trace or spot is present, try turning up the intensity in addition to pressing the BEAM FINDER). The compressed display shows in which direction a trace is off-screen and permits easy positioning into the viewing area.

Controlling Storage - Pressing the left-most buttons labeled UPPER and LOWER in the STORE area selects the storage mode for the upper and lower half of the CRT respectfully. Pressing the right-most buttons in this area selects that half of the CRT to be erased; both may be pressed together to allow erasing the entire screen. To erase a stored display press the ERASE button.

The brightness of a stored display is controlled by the BRIGHTNESS control. For extended retention once a display has been stored, reduce the brightness to a minimum and turn up only for viewing. For normal operation and retention times, however, keep BRIGHTNESS control at MAX. Note, this control only operates when the collector sweep is either turned down with the VARIABLE COLLECTOR % control or disabled as indicated by the yellow lamp.

DEVICE CARDS

A selection of Device Cards provide test configurations most suited to several classes of devices. The Standard Operational Amplifier Card is an included accessory with the 178.

Device Cards provide a means of making electrical connection to the DUT (device-under-test). The Standard Op Amp Card as well as many other Device Cards include the Barnes Corporation's interconnection system and come with a 16-pin in-line socket. A number of other sockets are available from the TEKTRONIX catalog or from the Barnes Corporation.

Most classes of linear IC devices do not have standard pin configurations. For this reason and for greatest flexibility, most

Device Cards employ jumper wires to connect inputs, output, supplies and other DUT terminals to the appropriate 178 functions. In addition, provision is made on the cards for inserting external components and for adjusting the +SUPPLY and -SUPPLY current limiting.

The operation of the FUNCTION selector on the 178 front panel depends upon the device card used and the description of each card includes operation of the FUNCTION selector. An interchangable nomenclature subpanel permits individual labelling of the FUNCTION selector for different Device Cards.

Standard Op Amp Card

The Standard Op Amp is a class of amplifier devices that require two power supplies (plus and minus), have two (differential) high impedance inputs and have a single output. The output voltages of these devices depends mainly upon their differential input voltage and is relatively insensitive to the input common mode voltage (the voltage common to both inputs). The range of permitted common mode voltage is usually large.

Offset Voltage is the differential input voltage required to maintain output voltage at zero. The maximum permitted offset voltage with the Standard Op Amp Card is 25 mV to operation at all vertical deflection factors.

Gain is the change in op amp output voltage divided by the corresponding change in differential input voltage. For an output voltage swing of ±10 volts the measurable range of gain with the Standard Op Amp Card is approximately 34 db (50) to over 126 db (2 million). Lower gains may be measured at less output voltage change.

CMRR (Common Mode Rejection Ratio) is the change in differential input voltage divided by the change in common mode voltage while the output voltage is maintained at zero. The measurable range of CMRR is the same as the range for GAIN with the Standard Op Amp Card.

Whenever the CMRR of an op amp greatly exceeds its GAIN a significant error can exist in the CMRR measurement.

<u>PSRR</u> (Power Supply Rejection Ratio) is the change in differential input voltage divided by the change in power supply voltage while the output is maintained at zero. For a power supply swing of 5 volts the measurable range of PSRR with the Standard Op Amp Card is approximately 22 db (12.5) to over 114 db (500,000).

<u>The FUNCTION Selector</u> has the following eleven functions when using the Standard Op Amp Card.

Function	Vertical Display	Useful Vertical Range	Horizontal Display and Sweep Generator Controlling Point
OFFSET V	Differential Input Volts	10µV (1µV Mag) to 50 mV/div	Output Volts
+ INPUT I	+ Input Current	50 pA (5 pA Mag) to ~~0.2~~ 0.5 mA/div	COMMON MODE INPUT ~~Output~~ Volts
- INPUT I	- Input Current	50 pA (5 pA Mag) to ~~0.2~~ 0.5 mA/div	COMMON MODE INPUT ~~Output~~ Volts
CMRR	Differential Input ΔV	10 µV (1 µV Mag) to 50 mV/div	Common Mode Volts
GAIN	Differential Input ΔV	10 µV (1 µV Mag) to 50 mV/div	Output Volts
+ PSRR	Differential Input ΔV	10 µV (1 µV Mag) to 50 mV/div	+ Supply Volts
- PSRR	Differential Input ΔV	10 µV (1 µV Mag) to 50 mV/div	- Supply Volts
± PSRR	Differential Input ΔV	10 µV (1 µV Mag) to 50 mV/div	+ Supply Volts
+ SUPPLY I	+ Supply Current	0.1 µA (10 µA Mag) to 50 mA/div	+ Supply Volts
- SUPPLY I	- Supply Current	0.1 µA (10 nA Mag) to 50 mA/div	- Supply Volts
Collector Supply I	Collector Supply Current	1 nA (0.1 nA Mag) to 50 mA/div	Collector Supply Volts