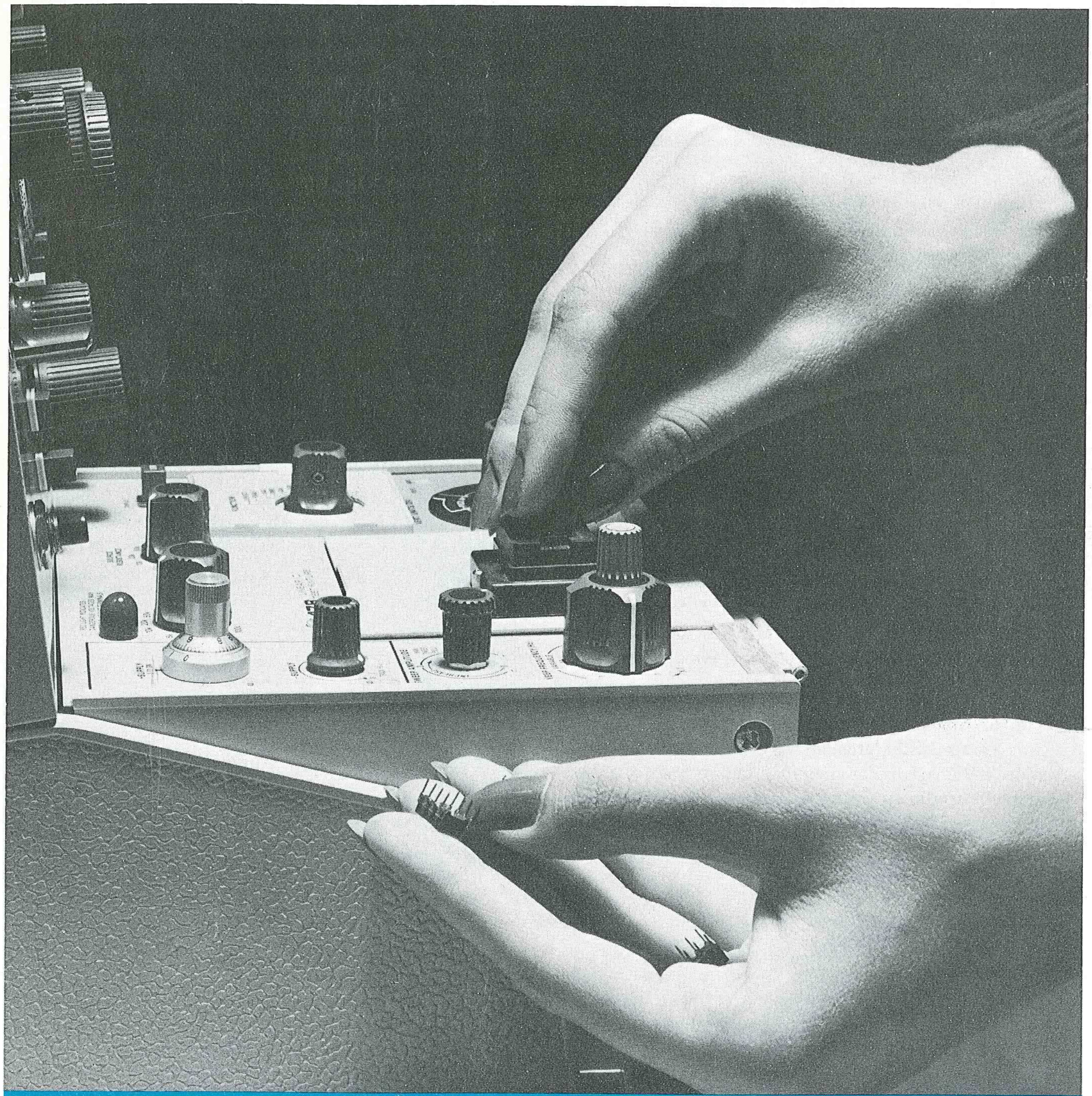
11/72

# TEK SCOPE

NOVEMBER 1972



# PROGRESS IN SEMICONDUCTOR TESTING

Jack Millay = Project Manager

*Providing advancements in component measurements, the new 577 Curve Tracer Measurement System combines display storage and linear IC testing capabilities in a new, inexpensive, easy to use instrument.*

A curve tracer is a special purpose oscilloscope used to display the performance characteristics of many different types of electrical components. The name "curve tracer" originated from the ability of these instruments to display the characteristic curves representing the capabilities of active devices. Their use today includes not only active devices but also relays, power supplies, small induction motors, light bulbs, connectors, capacitors, and other components.

Tektronix, Inc., long the leading manufacturer of curve tracers, now introduces the 577 Curve Tracer Measurement System. This new, low-cost system makes the majority of the measurements required to test semiconductors. In addition, it is a complete system for making extensive tests on linear integrated circuits.

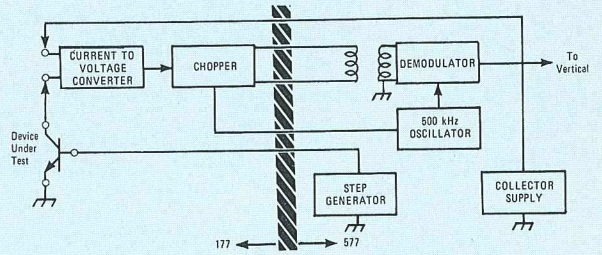
To provide the most versatile measurement system, modular construction techniques are used. The 577 Curve Tracer Measurement System consists of three major sections; display module, mainframe, and test fixture. Two display units are available; the D1 Storage, a split-screen bistable storage unit, and the D2, a large-screen non-storage display unit. These attach to the 577 Curve Tracer mainframe; the display units can be interchanged in a matter of minutes. The mainframe also accepts plug-in test fixtures. Presently available are the 177, a test fixture for displaying tests of two-, three-, and four-lead devices, and the 178, a test fixture specifically designed to display characteristics of linear integrated circuits such as operational amplifiers, differential amplifiers, and regulators. The plug-in test fixture concept also allows future expansion of the system.

**Cover**—*Pictured is the 178 Linear IC Test Fixture used with the new 577 Curve Tracer which offers display storage. Most linear IC tests can be performed with this low-cost bench top system.*

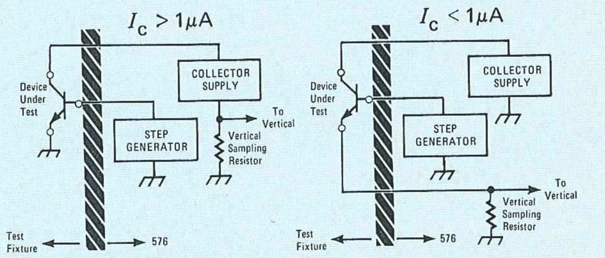
## The Mainframe

The 577 Curve Tracer mainframe contains the power supplies, horizontal amplifier, vertical amplifier, collector supply, and step generator. Controls for the collector supply, step generator, and horizontal volts/division are located on the 577 mainframe. Vertical deflection factor, however, is controlled from the test fixture, allowing selection of optimum ranges for the device being tested.

A new collector current measuring scheme for vertical deflection was developed for the 577. A comparison between this method and that used in previous curve tracers is shown in Fig. 1. Notice that in the 577/177 the collector current is sensed in the test fixture rather than in the mainframe as in previous instruments. This has two major advantages. First, the collector supply does not have to be isolated from ground as in previous designs, resulting in a considerable cost savings in the construction of the 577. Secondly, the test fixture can be easily designed to measure the current in any lead of the device under test as required, for example, in the 178 Linear IC Test Fixture.



(a) Method of collector current measurement in 577/177.



(b) Method of collector current measurement in 576.

**Fig. 1.** *Block diagrams of the collector current measuring circuitry in the 576 and 577.*

## The Display Modules

Each of the display modules uses a 6½-inch ceramic CRT with an 8 x 10 division (½ inch/div) internal graticule. The CRT, with 3.5 kV accelerating potential, has a bright, well-defined trace. Simplest of the display modules is the D2 display unit. It contains the CRT with its controls, the high-voltage supply, a beam finder, and the power switch. In addition to the normal display functions of the D2, the D1 display module provides storage on a split-screen, bistable CRT.

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## The Test Fixtures

The 178 Linear IC Test Fixture allows the display and measurement of linear IC characteristics such as gain, input current, common-mode rejection ratio, and power supply rejection ratio. Its operation will be covered in a separate article immediately following this discussion.

The 177 test fixture is designed to test two-, three- and four-lead devices. This test fixture provides many of the features found in previous curve tracers such as looping compensation, Kelvin sensing, and interlocked high-voltage collector supply (100, 400, and 1600 volt positions).

The 177 can measure collector currents at sensitivities as low as 200 pA/division. This is made possible in large part by the new collector current measuring scheme. The mode switch on the 177 includes a position which allows measurement of emitter-base leakage or breakdown characteristics. Also included on this test fixture is an independent −12 to +12 V bias supply which can be used to bias the substrates of devices having more than three terminals.

A new measurement possible with the 177 is comparative capacitance measurements to as low as 1 pF. The difference in current required to charge and discharge the capacitance from the collector terminal to ground is shown by a loop in the display. By comparing the displayed looping of several devices, comparative capacitance can be determined. Unknown capacitance values can be measured by using a reference capacitor to calibrate the display in terms of capacitance/division.

## Operating the 577 with the 177

Operator convenience has been designed into the 577/177 system to provide faster measurements and simpler operation. The front panel has been simplified by eliminating several unimportant controls, while at the same time retaining the operator conveniences pioneered by the TEKTRONIX 576 Curve Tracer.

A new feature in the 577 system is automatic shutdown of the collector sweep if more than 2½ screen diameters of vertical deflection result (on higher current ranges only). This will often prevent the device under test from being destroyed if it is subjected to more current than is expected.

To provide easier setup, the front-panel pushbuttons have been color-coded. When all of the dark grey buttons are pressed in, the system is ready for most normal measurements. Lights are used behind the skirts of the STEP OFFSET AMPL, HORIZ VOLTS/DIV, and VERTICAL SENSITIVITY knobs. This makes the selected measurement value readily visible. Another feature of the back-lit knobs is that the lights automatically change position when the magnifiers or X.1 controls are used so they always indicate the correct measurement value.

## For More Convenience, Add Storage

The D1 Storage display adds new operator convenience to semiconductor testing and makes possible measurements which previously were either very difficult or impossible to make. Comparison measurements where you want to directly compare the characteristics of one device with those of another are made easier with storage. An application of storage which uses the split-screen feature is storing the limits of device performance on one half of the screen and comparing it against the performance of another device displayed on the other half.

The changing characteristics of a device at different operating levels can be readily compared using storage. Fig. 2 shows the collector current of a transistor plotted against the base to emitter voltage. The curve at the left was plotted at a vertical sensitivity of 0.2 nA/div. Each successive curve is one order of magnitude greater and the last curve is at 20 mA/div. In this way, the performance of the transistor may be viewed and compared over nine orders of magnitude of collector current.

Storage can also be very useful to display the changes in characteristics of the device under test due to some external influence such as when heated or cooled. This is an easy way to find the zero temperature coefficient point of FET's and Zener diodes.

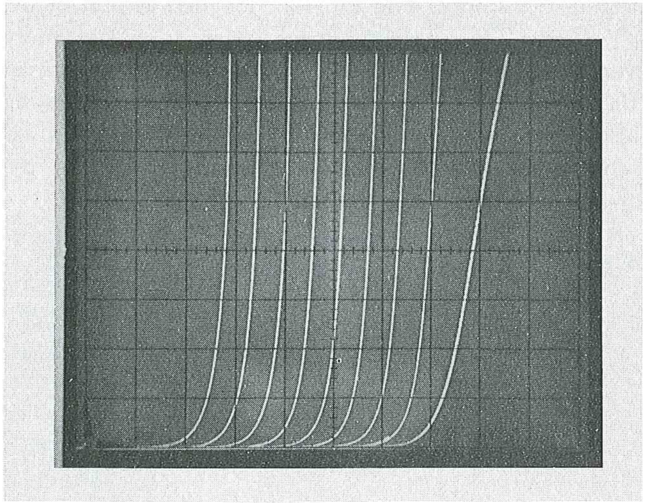


***Fig. 2.** Storage display of a series of single curves plotted at different vertical sensitivities.*

Checking the characteristics of a device which is operated near or even beyond its specified dissipation limits can be facilitated by storage. With the stored display, the device under test needs to be subjected to the potentially destructive conditions for only long enough to store the trace. For tests where it is desired to intentionally cause the device to fail, the stored display allows close examination of the conditions present at the time of failure.

Storage also allows more convenient plotting of the characteristics of devices when using the pulsed or DC collector sweep modes. These characteristics are normally displayed as dots on the screen. Storage allows the dots to be stored as the collector voltage is varied, thus tracing out the complete curves.

Some very unusual tests can be made using storage. One example is checking relays for pull-in and drop-out voltage and current. With the collector supply operated in the DC mode, the relay coil is connected between the collector and emitter terminals. Then the collector supply voltage is varied manually. When the relay armature moves, it induces a voltage change into the coil which can be seen on the display.

Taking photographs of the display is greatly simplified with storage also, particularly when using the pulsed or DC sweep modes. Storage allows the complete display to be presented at a uniform intensity and unwanted displays can be erased as many times as necessary before the correct display is obtained, thereby saving film.

# LINEAR IC TESTING COMES TO THE CURVE TRACER

Om Agrawal—Project Engineer

Until now, testing of linear ICs has been an expensive, complex job. Most of the IC testers previously available either required special test cards which could test only one specific type of IC, were computer controlled, or needed external equipment to make the measurement. This limited the use of IC testers to only the most critical or important test areas such as manufacturing or incoming inspection. As a result, linear IC testing was not available in many locations where it could be very beneficial.

With the introduction of the new 577/177/178/D1/D2 Curve Tracer Measurement System, Tektronix, Inc. now makes testing linear ICs as easy and convenient as testing transistors. The 178 was designed as part of the 577 Curve Tracer Measurement System to make it more versatile and less expensive. In addition, since many of the same areas that require discrete component testing also require IC testing, this arrangement provides extended test capabilities in a convenient, easy to use system which requires a minimum of bench space.

## System Design

The 178 plugs into the 577 Curve Tracer Measurement System. The D1 Storage display is recommended for use with the 178 since it provides the best display of the very low sweep rate which must be used to display many linear IC characteristics. In combination with these units, the 178 provides the complete capabilities to measure and display the various parameters of linear ICs. The 178 includes a sweep generator, positive and negative supplies, vertical measurement system, feedback loop for the device under test, and switching capabilities to facilitate testing of the many varying parameters under diverse conditions.

Plug-in test cards define the type of IC that can be tested. Presently, two test cards are available; a card for testing IC amplifiers, and a card for testing IC regulators. These test cards can be easily interchanged to test either type of device. The pin configuration for specific devices is determined by jumper leads on the test card. The card can be quickly set up to test most of the linear ICs presently available.

## Testing IC Amplifiers

The basic circuit configuration of the 178 with the Amplifier test card installed is shown in Fig. 3. This configuration makes it possible to test operational amplifiers under open loop conditions and allows the test conditions to be set up as specified by the manufacturer. The Feedback Amplifier permits measurement of AC differential input voltage without loading the inputs. The Sample and Hold Amplifier nullifies the effect of DC offset voltage while allowing this voltage to be measured without loading the inputs. The source resistors and load resistors can be easily selected by front-panel switches. The FUNCTION switch provides the necessary switching of the generators and amplifiers for the different tests. Test conditions can also be changed by varying the amplitude and frequency of the + and — voltages to the Device Under Test.

Specifications given by the IC manufacturer are at typical operating levels. However, if you are designing a circuit which requires the IC to operate at different levels than those specified (e.g., different output voltage levels, load, frequency, etc) performance could be completely different. The 178 allows you to check operation of the amplifier IC under the specific conditions at which it will be operating. Typical characteristics which can be checked on a linear IC amplifier are open-loop DC gain, common-mode rejection ratio, power supply rejection ratio, input and supply current, phase shift, effect of thermal feedback, and check of popcorn and random noise. Some of these tests on a typical linear IC are shown in Figs. 4 through 10.

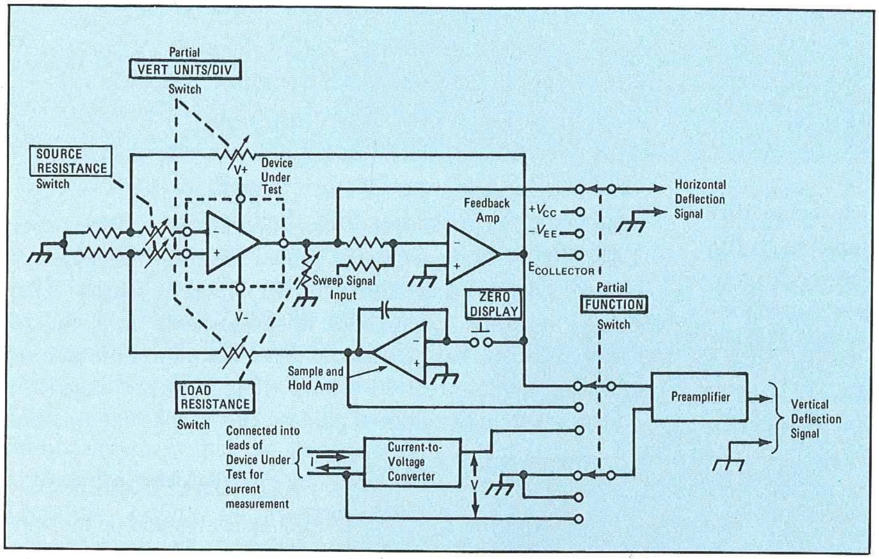


**Fig. 3.** *Block diagram of the 178 configured for testing operational amplifiers.*

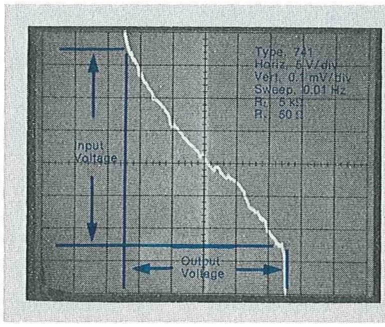


**Fig. 4.** *Plot of open loop gain with bandwidth limited to eliminate noise. Small aberrations in trace indicate popcorn noise. Calculating overall gain:*

$$GAIN = \frac{\text{output voltage swing}}{\text{input voltage swing}} =$$

$$\frac{5 \text{ div} \times 5\,\text{V/div}}{6 \text{ div} \times 0.1\,\text{mV/div}} = 41{,}700$$

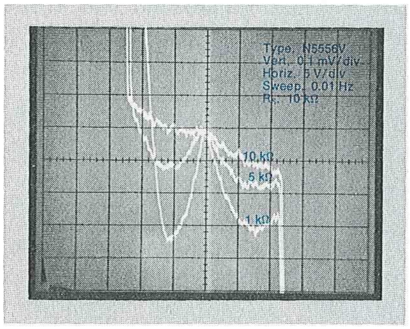


**Fig. 5.** *Open loop gain changes resulting from change in load. When the output is loaded, the power dissipation in the output stage raises the temperature of the whole chip. This change in temperature causes a change in input offset voltage that changes low-frequency gain.*

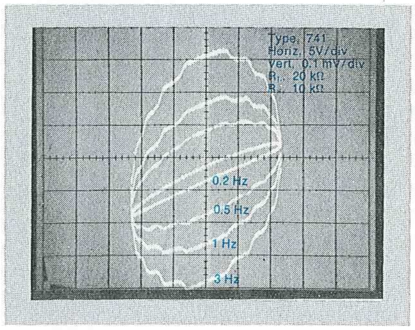


**Fig. 6.** *Shows the phase shift associated with gain at several different sweep frequencies.*

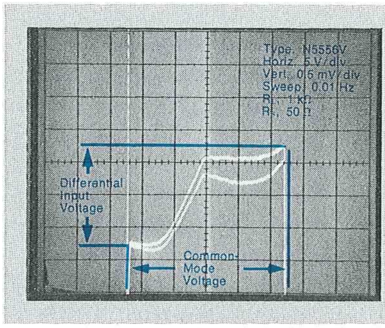


**Fig. 7.** *Plot of common-mode rejection ratio (CMRR). Notice that the CMRR is changing from point to point. Overall CMRR can be calculated as follows:*

$$CMRR = \frac{\text{common-mode voltage}}{\text{differential input voltage}} =$$

$$\frac{5 \text{ div} \times 5\,\text{V/div}}{3 \text{ div} \times 0.5\,\text{mV/div}} =$$

$$16{,}700 = 20 \log_{10} (16{,}700) = 84 \text{ dB}$$

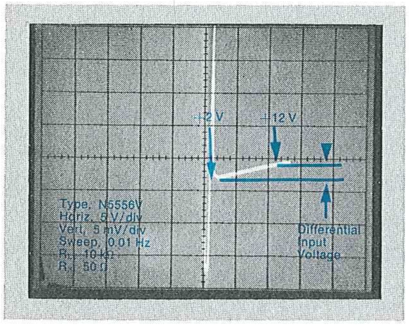


**Fig. 8.** *Power-supply rejection ratio (PSRR) with both + and — supplies varied out of phase. Horizontal axis shows change in supply voltage while vertical axis shows differential input voltage. Calculating PSRR from +2 volts to +12 volts:*

$$PSRR = \frac{\text{supply voltage variation}}{\text{differential input voltage}} =$$

$$\frac{2.0 \text{ div} \times 5\,\text{V/div}}{0.5 \text{ div} \times 5\,\text{mV/div}} =$$

$$4{,}000 = 20 \log_{10} (4000) = 72 \text{ dB}$$

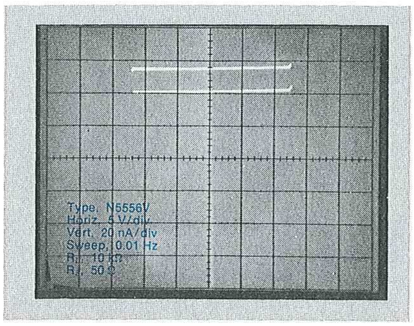


**Fig. 9.** *Checking input bias current and input offset current. Top line shows positive input bias current of about 56 nA. Bottom line shows negative input bias current of about 42 nA. Difference between positive and negative input bias current is the offset current of about 14 nA.*

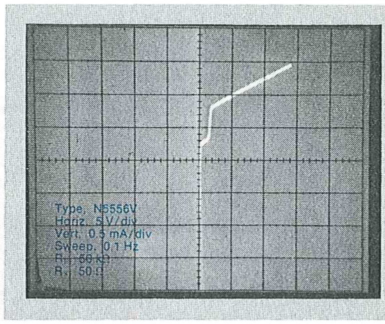


**Fig. 10.** *Positive supply current plotted against positive supply voltage.*

## Testing IC Voltage Regulators

IC regulators have come into common usage in low-voltage power supplies. The 178 can display the parameters of these devices when the Regulator test card is installed.

Fig. 11 shows the basic circuit configuration when this card is installed. The Sample and Hold Amplifier nullifies effects of DC output voltage on the Device Under Test. The output of the Feedback Amplifier is proportional to the AC changes at the output of the Device Under Test.

Just as for amplifier ICs, the 178 allows IC regulators to be tested under conditions approximating those of the actual circuit. Some of the tests which can be made are measurement of output voltage, line regulation, load regulation, and measurement of input current.

## Summary

The 577/177/178 Curve Tracer system joins many other TEKTRONIX instruments which help the engineer to better understand the discipline in which he works. This system expands component measurements and makes them easier for better product specification by the manufacturer, more effective circuit design by the engineer, and quicker instrument repair by the service technician.

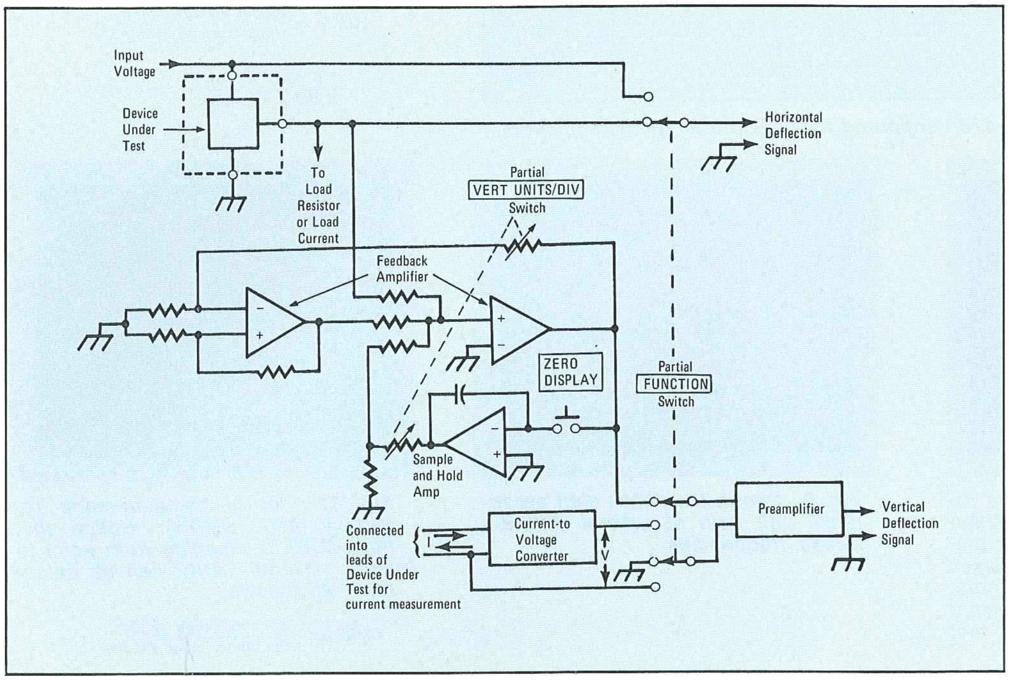
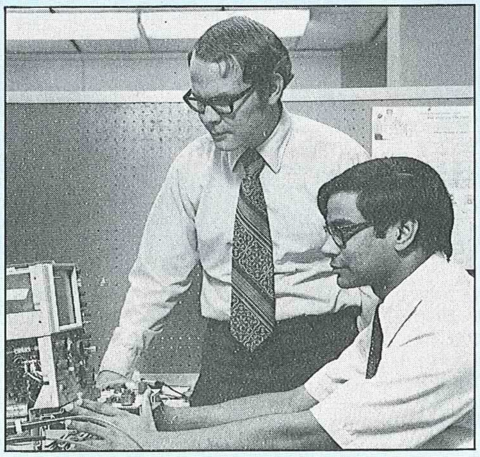


*Fig. 11.* *Block diagram of the 178 configured for testing IC regulators.*

### ACKNOWLEDGMENTS

Jack Millay headed up the very able team which designed the 577 Curve Tracer Measurement System. Working on the electrical design were Jim Knapton, Bob Herb, Bob Verrinder, Om Agrawal, Dave Rule, and Gary Davis. Tom Saucy did the mechanical design while Darrell Barrett and Gil Stephens provided evaluation support. Lena McIntosh and Iona MacKay built the prototype instruments. And there were many others who helped in both large and small ways to make this project a success.

### OUR AUTHORS



**Jack Millay**

Jack attended Multnomah College before joining TEK in 1958. As manager of the Curve Tracer Engineering Group, he has been involved in most of the recent advancements in this area and has authored several previous articles for TEKSCOPE.

Jack is married and has two children. When not working with curve tracers, he enjoys flying, bee keeping, and antique cars.

**Om Agrawal**

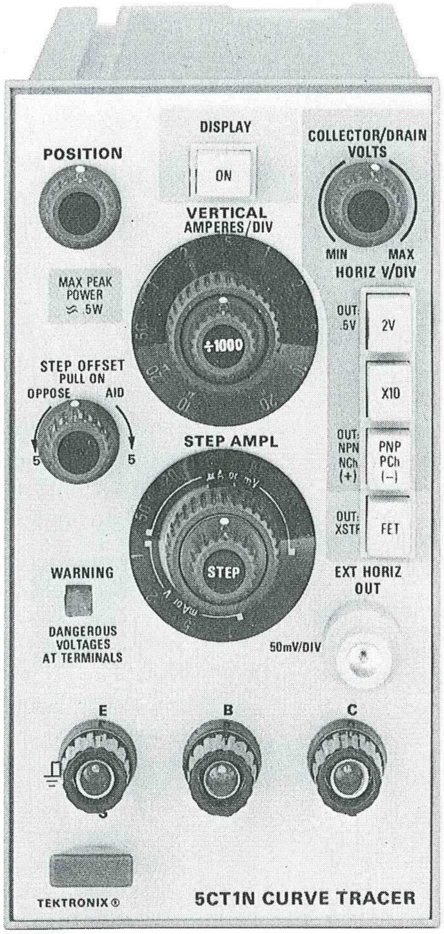
Om is a native of India and received his Bachelors of Technology in Electrical Engineering at the Indian Institute of Technology, Kanpur, India. After coming to the U.S., he attended the Case Institute of Technology, receiving an M.S.E.E. He is presently attending the University of Portland where he plans to receive an M.B.A. degree in December.

Since starting at TEK in 1970, Om has worked on the 172 as well as the current 577/177/178 project. When not working or studying, he enjoys swimming and roller skating.

# OSCILLOSCOPE TO CURVE TRACER WITH ONE PLUG-IN

*Matt Zimmerman* — Instrument Engineering

The need for some form of tester becomes obvious to anyone who works with semiconductor devices. By measuring parameters of interest, a tester provides operating information about a device. A simple go no-go (static) tester provides a limited amount of data, and usually only about a specific operating point. Such things as breakdown, leakage, or non-linearity may go undetected, and device matching is very difficult. Dynamic testers in general, and curve tracers in particular, quickly provide information which is difficult if not impossible to obtain with a static tester.



Tektronix makes a variety of curve tracers, and each has its particular advantages. Two recent entries into the TEKTRONIX Curve Tracer line are plug-in curve tracers—the 5CT1N and 7CT1N. The 5CT1N is designed for use with the TEKTRONIX 5000-Series and the 7CT1N for the 7000-Series Oscilloscopes. The primary advantage of the plug-in curve tracer is that it is now possible to have both a laboratory oscilloscope and a moderate range curve tracer in one package. As handy as this is for bench use, it is even more useful for on-site repairs. Other advantages are low cost and ease of operation.

These units have been designed to make the usual tests quickly, but even extensive tests can be done with a minimum of difficulty. Power available at the test terminals is limited to 0.5 watt. While this may seem insufficient at first, most small signal devices can be adequately tested with this power level. Also, because of this limited power, it is unlikely that a device will be accidentally destroyed and errors caused by device heating are almost eliminated. Now let's look at some of the tests that can be made with this curve tracer.

## Testing Signal and Power Diodes

Set up controls and connect diode as shown in part A of the Basic Measurement Reference Chart. For a functional check, turn COLLECTOR/DRAIN VOLTS clockwise. A trace similar to the one shown should appear if the diode is good. Horizontal displacement is forward voltage ($V_F$), and vertical displacement is forward current ($I_F$).

Forward current up to 160 milliamps can be measured. By pressing the NPN-PNP switch, reverse polarity voltage is applied to the diode and reverse current or leakage ($I_R$) as low as 10 microamps can be measured. By changing the .5 V - 2 V and X10 buttons, reverse voltages ($V_R$) up to 200 volts may be applied to the device.

If it is desired to look at an $I_R$ of less than 10 microamps, return COLLECTOR/DRAIN VOLTS to zero and release the ÷ 1000 button. This increases the sensitivity of the VERTICAL AMPERES/DIV by a factor of 1000 and puts the plug-in into a DC sweep mode. The normal display becomes a dot. Position the dot to the upper right hand corner of the CRT and increase COLLECTOR/DRAIN VOLTS. $I_R$ as low as 10 nanoamps can now be measured.

## Testing Zener Diodes

When testing Zeners, usually only the reverse or breakdown characteristics are important. Make initial set up and connections as shown in part B with the .5 V - 2 V and X10 buttons set to the appropriate range for the Zener being used. Advance COLLECTOR/DRAIN VOLTS until diode breakdown occurs. Zener voltage ($V_Z$) is measured horizontally, and Zener current ($I_Z$) is measured vertically. Zeners up to 200 volts can be tested in this manner, but the available power is limited to 0.5 watts peak. Pressing the NPN-PNP switch displays the Zener's forward characteristics.

## Testing Tunnel Diodes

The important characteristics of a tunnel diode—peak current ($I_P$), peak voltage ($V_P$), valley current ($I_V$), and valley voltage ($V_V$)—ocur in the forward direction, normally with less than one volt across the device. Set up as noted in part C with diode connections as shown. Advance COLLECTOR/DRAIN VOLTS until tunnel action occurs. Any diode having an $I_P$ less than 160 milliamps can be checked. The display will be adequate for functional checks. If a more detailed analysis is required, the horizontal scan can be expanded by connecting the external output to an Amplifier plug-in. By setting the amplifier deflection factor below 50 mV/div (100 mV/div for the 7CT1N), the horizontal voltage can be expanded as desired.

## Testing Silicon-Controlled Rectifiers & Silicon-Controlled Switches

These devices may be functionally tested only if their gate firing current is less than 15 mA. Set up and connections are shown in part D. Adjust COLLECTOR/DRAIN VOLTS for full scale deflection and advance STEP control until SCR or SCS conducts. If this does not supply enough current to switch the device, pull out the STEP OFFSET control and adjust aiding offset for about 5 more milliamps. Forward voltage at any current up to 160 milliamps can now be measured. The reverse characteristics of an SCS can be tested by pressing the NPN-PNP switch.

To measure forward blocking voltage up to 200 volts, connect the gate terminal to the cathode terminal directly or through a fixed resistor. Advance COLLECTOR/DRAIN VOLTS until the device starts to conduct as in diode breakdown. When a current level above the holding current is reached, the device will switch to the ON state, and forward voltage will drop to a low level. Pressing the NPN-PNP switch allows measurement of reverse blocking voltage.

## Testing NPN-PNP Transistors

The 5CT1N/7CT1N are designed to give functional, $\beta$ or $h_{fe}$, and $V_{CE}(sat)$ measurements easily. Other tests that can be made are $BV_{CEO}$ and $I_{CEO}$, $BV_{CER}$ and $I_{CER}$, $BV_{CBO}$ and $BV_{EBO}$. Since the maximum peak power delivered to the device is only 0.5 watt, most transistors are safe from accidental damage due to excess power.

For a functional test, set up as in part E. Set COLLECTOR/DRAIN VOLTS for full screen display (less if transistor exhibits breakdown). Turn STEP control clockwise to increase number of steps until a family of curves is displayed. Small signal $\beta$ or $h_{fe}$ is $\Delta I_C/\Delta I_B$ and can be calculated from the display as follows: set collector current ($I_C$) to desired level using STEP AMPL, STEP, and VERTICAL AMPERES/DIV controls. Divide VERTICAL AMPERES/DIV setting by STEP AMPL setting to obtain $\beta$/div. Measure the vertical distance between two curves near the desired $I_C$ level and multiply by $\beta$/div to obtain $\beta$ for the device under test. Positioning or offset may be used to set the desired curve at a convenient reference point.

$V_{CE}(sat)$ is the collector to emitter voltage at a point near or below the knee of the displayed curve. $V_{CE}(sat)$ is dependent upon base drive and collector current, so these factors must be considered if $V_{CE}(sat)$ is being measured to verify a specification.

To measure $BV_{CEO}$ and $I_{CEO}$, open the transistor base-lead by removing it from the test adapter or B/D jack. Adjust COLLECTOR/DRAIN VOLTS and change .5 V - 2 V and X10 buttons until specified $I_{CEO}$ is obtained vertically. Read $BV_{CEO}$ horizontally. $I_{CEO}$ less than 10 microamps may be tested by using the ÷1000 button. $BV_{CES}$ and $I_{CES}$ are measured the same way, except that the base lead is shorted to the emitter lead. To measure $BV_{CER}$ and $I_{CER}$, the base lead is connected to the emitter lead through an external resistor.

$BV_{EBO}$ is the reverse voltage necessary to break down the emitter base junction. The easiest way to measure it is to connect the base lead to the emitter terminal and the emitter lead to the collector terminal, leaving the collector lead open. Adjust COLLECTOR/DRAIN VOLTS until breakdown occurs, which is usually at less than 20 volts.

## Testing Field-Effect Transistors

Most FET's can be checked with the 5CT1N and 7CT1N. Functional, $I_{DSS}$, $g_m$, and $V_P$ are the most common operational checks. Placing the XSTR-FET button in the FET position sets the plug-in to measure FET's in the depletion region. The same test adapter can be used, since the XSTR-FET button changes the internal lead connections, and changes the transistor base current drive to opposite polarity FET voltage drive. However, proper device basing configurations as specified by the FET manufacturer must be observed.

For a functional check, set up as in part F. Turn COLLECTOR/DRAIN VOLTS to obtain full screen deflection and adjust the STEP AMPL and STEPS controls to display a family of curves. $I_{DSS}$ is measured by turning the STEP control fully counterclockwise. This applies zero bias to the FET, and the single curve that remains is the $I_{DSS}$ curve.

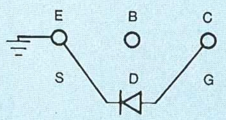
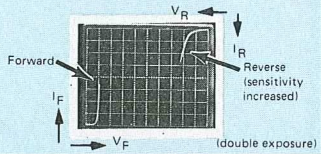
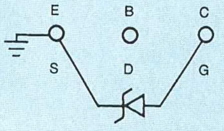
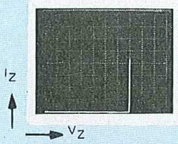
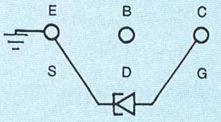
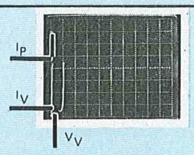
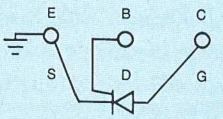
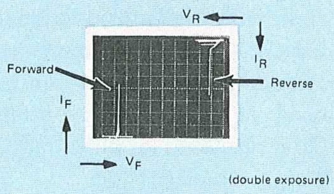
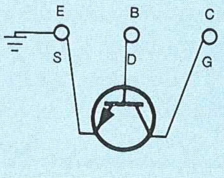
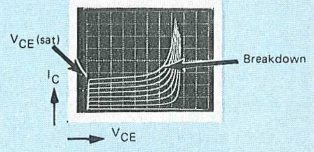
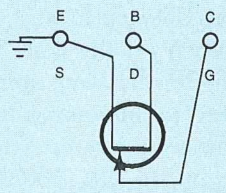
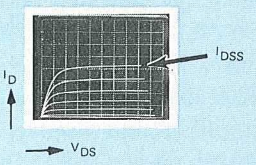
Small signal transconductance ($g_m$) is $\Delta I_D/\Delta V_{GS}$. To measure $g_m$, obtain a display of $I_D$ as described for a functional check. Use STEP AMPL, STEPS, and VERTICAL AMPERES/DIV to obtain desired $I_D$. Calculate $g_m$/div by dividing the VERTICAL AMPERES/DIV setting by the STEP AMPL setting. Measure vertical distance between two curves and multiply by calculated $g_m$/div. If it is desired to look at an FET in the enhancement region, pull out the STEP OFFSET knob and adjust up to 5 steps of opposing offset. Since the offset is uncalibrated, the zero bias ($I_{DSS}$) point must be marked in some manner.

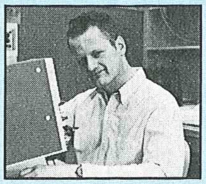
Pinch off voltage $V_P$ is measured by increasing the STEP AMPL and STEP controls until a specified pinch off current is reached. $V_P$ is the step amplitude multiplied by the number of steps required to reach pinch off.

## Summary

The 5CT1N and 7CT1N are designed to give a rapid check of device characteristics. Only a few of the checks which can be made have been discussed here. For more detailed information or for further tests, see either the Tektronix Measurement Concepts Book "Semiconductor Device Measurements" (P/N 062-1009-00) or the instruction manual for the particular plug-in.

### 5CT1N/7CT1N
### BASIC MEASUREMENT REFERENCE CHART

| DEVICE | CONTROL SETTINGS | | CONNECTIONS | TYPICAL WAVEFORM |
|---|---|---|---|---|
| A. Signal & Power Diodes | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>NPN-PNP<br>XSTR-FET | MIN<br>Out (.5 V)<br>Out (X1)<br>1 mA/DIV<br>In (÷1)<br>Out (NPN)<br>Out (XSTR) |  |  |
| B. Zener Diodes | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>NPN-PNP<br>XSTR-FET | MIN<br>As needed<br>As needed<br>1 mA/DIV<br>In (÷1)<br>Out (NPN)<br>Out (XSTR) |  |  |
| C. Tunnel Diodes | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>NPN-PNP<br>XSTR-FET | MIN<br>Out (.5 V)<br>Out (X1)<br>1 mA/DIV<br>In (÷1)<br>Out (NPN)<br>Out (XSTR) |  |  |
| D. SCR & SCS | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>STEP OFFSET<br>STEP AMPL<br>STEP<br>NPN-PNP<br>XSTR-FET | MIN<br>Out (.5 V)<br>Out (X1)<br>10 mA/DIV<br>In (÷1)<br>In (off)<br>1 mA/step<br>ccw<br>Out (NPN)<br>Out (XSTR) |  |  |
| E. NPN - PNP Transistors | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>STEP OFFSET<br>STEP AMPL<br>STEP<br>NPN-NPN<br>XSTR-FET | MIN<br>In (2 V)<br>Out (X1)<br>1 mA/DIV<br>In (÷1)<br>In (off)<br>5 μA/step<br>ccw<br>Match Transistor<br>Out (XSTR) |  |  |
| F. Field Effect Transistors | COLLECTOR/DRAIN VOLTS<br>.5 V - 2 V<br>X10<br>VERTICAL<br>÷1000<br>STEP OFFSET<br>STEP AMPL<br>STEP<br>NCh(+)-PCh(—)<br>XSTR-FET | MIN<br>In (2 V)<br>Out (X1)<br>.5 mA/DIV<br>In (÷1)<br>In (off)<br>.2 V/step<br>ccw<br>Match FET<br>In (FET) |  |  |



**Matt Zimmerman**—Matt began his electronics training while in the U.S. Navy and continued his studies to receive an Associate Degree in Electronics from Long Beach City College. In his six years at TEK, Matt has worked in the Standards Lab, CRT Support, and now as Design Technician in the 5100-Series group. Among the products he has worked on here are the 5CT1N/7CT1N, 5100 Series, and TM 500 Series.

Matt is married and has two children. In his spare time, he is building a new house for his family.

# DELAYING SWEEP GOES DIGITAL

Bob Beville = Design Leader

Delayed sweep in the oscilloscope takes on a new face with the introduction of the 7D11 Digital Delay Unit. As a new complement to the Tektronix 7000 Series of products, the 7D11 can assist the oscilloscope user in need of accurate, low-jitter sweep delays, or having delay-by-count applications.

## Before Digital Delay

Until now, sweep delays and differential time interval measurements have been made with the analog ramp—pickoff method. The function of the delaying sweep is to: accept the desired trigger, initiate its sweep—a calibrated ramp, run out to the desired delay time as determined by the pickoff comparator circuit and generate the delay gate that notifies the delayed sweep to start or arm for triggering. The delayed sweep usually is set to run a decade or more faster than the delaying ramp. The delayed ramp is then applied to the horizontal amplifier and displays the waveforms of interest with added resolution.[1-2] Intensification on the CRT by the delayed sweep gate helps in setting the start of the delayed sweep to the point desired.

The analog ramp type delay has been, and still is, doing an effective job. Some users, however, have applications that now exceed its capabilities in the areas of jitter, accuracy and linearity. Out of need to overcome some of these limitations, the 7D11 evolved.

## Digital Delay By Time

The 7D11 has two basic modes of operation. The first is the Delay by Time mode—where a highly accurate internal clock is the time base from which delays are derived. Its function is still to notify the delayed sweep when to run. Its uses, such as measuring the width of a given pulse or determining the stability of an astable multi, are similar to analog ramp delay methods in that both deal in calibrated absolute time.

The selected delay time is set by the number that is placed into a digital counter. Each count is related to one period of the crystal controlled clock. The ambiguity of one full clock period in starting the count is ever present in methods using gated clocks. This is overcome by actually using a high frequency oscillator which is phase locked to the clock crystal. The HF oscillator is switched into a frequency divider at the time that delay counting is to begin. This method yields a trigger-coherent clock that has a gate ambiguity of only one cycle of the HF frequency. Once this trigger-coherent clock gets started, the accuracy of the count is maintained by the stability of the crystal oscillator. The temperature-controlled crystal oscillator in the 7D11 has 0.5 ppm stability, suitable for most measurements. If more is desired, the front panel external 1 MHz input may be driven from an in-house timing standard.

### CRT Readout of Delay

The selected delay, by time or events, is displayed on the CRT READOUT of the 7000-Series mainframes. Seven and one-half digits are displayed. For example, in the time mode, for a delay time of 1 second, the CRT reads 1000.0000+ in the upper readout channel; the legend "ms" is displayed in the lower channel. The least significant digit, then, is 100 ns, as the 7D11's internal clock is 10 MHz. The "+" symbol reminds the operator to include the setting of the Fine Delay (ns) control on the 7D11 front panel. This control is a 0 ns to at least 100 ns analog delay in series with the digital time delay. It is provided to allow delay time adjustment through a complete digital increment and obtain all possible values of delay between. Where the helidial of the analog sweep delay was in control of the three most significant digits, the Fine Delay (ns) is only concerned with the two least significant digits of the measurement. Readings of the digital delay significant digits displayed on the CRT are unambiguous and with the Fine Delay (ns) control, resolution to one nanosecond is possible.

### Forward-Reverse and Throttle

A novel control is used to set the time delay or number of events desired. A spring-loaded potentiometer is suspended in mechanical as well as electrical center. The absolute value of wiper voltage is applied to a voltage-to-frequency converter to increment (or decrement) the display counter. The wiper is also compared to ground to steer the direction rail of the display counter. In one control the decision to count forwards or backwards is made, and the rate of change of the count is set by the magnitude of the rotation of the knob. For example, a large count can be quickly set by rotating the control completely clockwise and backing off as the desired count is approached.

## SOME APPLICATIONS

### Measuring Propagation Time

The application of a 7D11 measuring the propagation time through a cable, network, or device under test is depicted in Fig. 1. A pulse generator is driving the device under test (d.u.t.) as well as initiating the digital time delay. The front panel delayed trigger output and the d.u.t. output are observed using a dual-trace vertical in the Alternate mode. The reference trigger for the Alternate mode is the d.u.t. output. The 7D11 output and d.u.t. output are then alternately viewed while the 7D11 digital delay is incremented, and lastly, the Fine Delay (ns) is varied until the two waveforms coincide on screen. When they coincide, as in Fig. 1, the two delay times are equal. The digital reading plus the Fine Delay reading is the delay through the device under test.

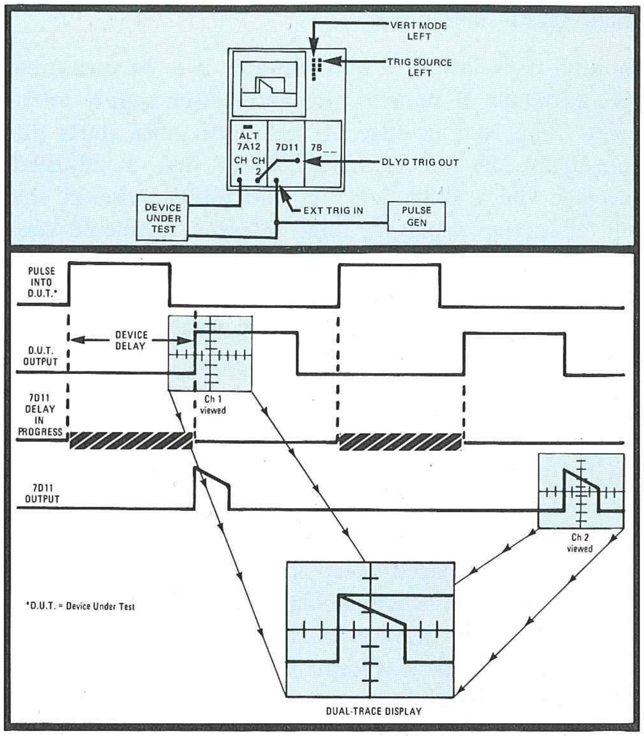


*Fig. 1. The 7D11 measuring device propagation delay.*

### Measuring Delays <100 ns

The fact that the 7D11 minimum time delay is 100 ns, doesn't prevent measurement of delays less than 100 ns. The setup for that is depicted in Fig. 2. The waveforms below show that the second pulse in and out of the d.u.t. are measured and the difference reading $T_2 - T_1$ is the device delay.

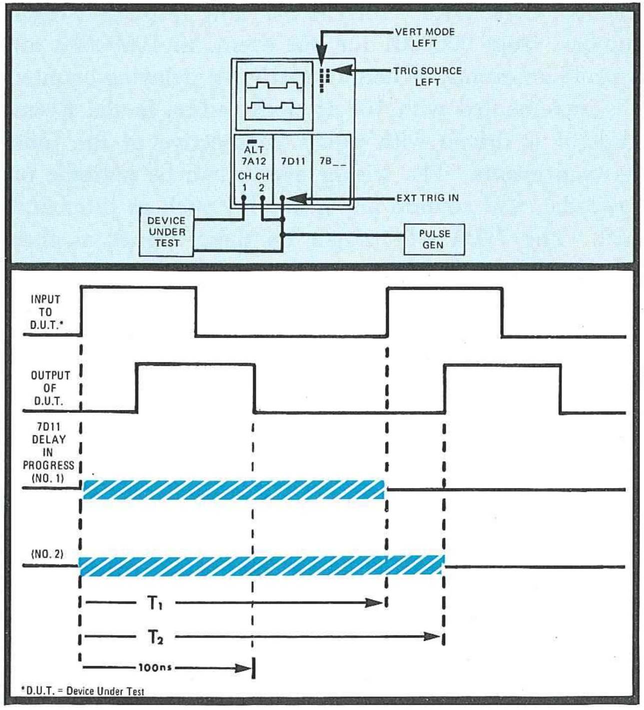


*Fig. 2. Measuring device delays of less than 100 ns.*

### Pulse Width Variations

Suppose the width of a multivibrator is to be measured over extremes of temperature and power supply tolerances. The leading edge of the multi pulse starts the time delay. Digital, plus Fine Delay (ns), is adjusted to place the trailing edge of the multi pulse in the delayed sweep display at some reference graticule line. The circuit under test is subjected to the voltage and temperature extremes and the 7D11 delay is adjusted to bring the trailing edge back to the reference graticule line.

### Measuring Jitter

The stability of an oscillator or other astable circuit can be measured (up to 0.5 ppm) with the 7D11 triggering the delayed sweep. The 7D11 accepts one of the oscillator cycles to trigger on and starts a relatively long time delay. A delayed sweep speed is used that displays approximately one whole oscillator cycle across the CRT screen. The time delay is found which exhibits a distribution of jumbled waveforms but doesn't exceed a full cycle. The time excursion of the jumbled waveforms is measured and the contribution to jitter of the 7D11 (2.2 ns or delay time x $10^{-7}$, whichever is greater) is subtracted. Then the adjusted time excursion over the 7D11 delay time is computed.

### Delay by Count or Events

The Delay by Events mode of operation counts arbitrary trigger events, and delivers an output (notifies the delayed sweep) when the preselected number of events is reached. The CRT READOUT now displays integer numbers from 0000001 for one event, to 10000000 for ten million events. Where formerly the delaying counter was incremented with 100 ns clock pulses, in the Event mode it is driven with pulses irrespective of the time between events. The trigger events can be periodic or aperiodic, and contain any instability such as jitter and drift. The 7D11 will trigger on these events, as they occur, up to a 50 MHz rate.

To determine when to start counting the selected number of events, the Events Start Trigger input must be provided with a related synchronization pulse of some kind. In TV line selector applications, the start trigger would be furnished by the vertical sync pulse, and the horizontal sync pulses become the events counted. In a like manner, the origin pulse of a disc memory becomes the start trigger, while the disc clock will be counted until the storage location to be observed is reached.

Delay by Event provides a significant improvement over using absolute time for sweep delay when observing events whose repetition rate is an arbitrary or irrational value, and contains cycle to cycle variations like flutter, wow, line surges, or underdamped servo response.

### A Synchronization Frame Generator

If a rotational or cyclic piece of equipment is being observed, the 7D11 can become a synchronized frame generator in step with it if the equipment clock is the event start trigger as well as the trigger events to be counted. This is accomplished by setting the events delay equal to the number of clock periods in the cycle. For example, suppose a 127-bit pseudo-random-bit sequence generator is built, and a sequence-frame pulse to establish the "beginning" of the sequence is needed. The clock is counted with $n = 127$ events. A scope, triggered every 127th clock, keeps the sequence in step and stationary for viewing. The frame can be advanced or retarded by changing "n" to 128, or 126, for a moment and then back to 127. The whole sequence may be made to "pass in review" a bit at a time if large multiples of the sequence length, like $n = 12700$ are used and "n" is shifted to 12701 or 12699.

### Range Calibration of Radars

An example where delay by time or delay by events are about equally desirable is the range calibration of a radar set. Time delay using 6.167 $\mu$s per nautical mile could be used. However, handling multiples of this number may soon become tedious. Consider then a gated delay line oscillator built to run at 16.215 MHz.[3] When turned on by the range gate (also turning on the Events Start Trigger) the events triggered are counted at the rate of 100 per nautical mile, a much easier number to interpret.

For radar and TDR type applications the one-way propagation time is often the more useful piece of information. A mode switch called NORM-ECHO is contained inside the 7D11. ECHO divides the time clock by two. The readout isn't altered, so the one-way-trip time is displayed directly while the time clock is doing the "out and back" computation for you.

### Front Panel & Interface Outputs

As another customer benefit, the delaying interval—that time from the start of triggered counting until the time of the output delayed pulse—is applied to several places. This waveform is available at a front panel connector. With the exception of approximately 30 ns, the interval output is equal to the digital time delay read on the CRT. With the aid of the Fine Delay (ns) control, the $\approx$30 ns may be added to its width making the delaying interval useful as a precision width generator.

As long as the 30 ns delay is reckoned with by using the Fine Delay, any arbitrary width interval from 100 ns on, can be found. In the Events mode, the delay interval has the same turn-off lag as it did when it turned on. When "n" periodic events are counted, the delaying interval generates a width of n-1 periods.

## Delaying Interval Viewing

The delaying interval is also made available to the mainframe. In the case where the 7D11 is used in a vertical compartment, a 'delaying pedestal" is generated on its vertical analog channel.[4-5] When the vertical mode button for this channel is pressed on, and the time base and 7D11 are triggered in parallel, the pedestal display will show the start of delay at start of sweep—out to the selected delay time.

As is customary with vertical plug-ins, provision is made in the mainframe to supply the time bases with an internal trigger. When a 7D11 is used in a vertical compartment, it too provides a trigger to the interface path for time base triggers. Some of the examples in this article depict the 7D11 in 3-hole mainframes using this path.

Used in the "A" horizontal compartment of a 4-hole, 7000 Mainframe, the 7D11 functions as a replacement for the delaying time base. The pedestal-like interval now is applied to the Z-axis by internal switch, to blank the B sweep. This is to create the useful "A intensified by B" display for locating the point in a waveform where delayed sweep is desired. As in sweep delaying plug-ins and monolithic scopes, a front panel switch permits you to select "B starts after delay" (BSAD), "B triggerable after delay" (BTAD), or INDEPENDENT operation.

INDEPENDENT or stand alone uses of the 7D11, when suitably triggered from an external generator, include precision pulse width generator, synchronous divide by N generator, TDR fault locator, and long term electronic timer. Using Line trigger as the source of events, and the Events mode maximum capacity of 10 million, nearly 46.3 hours of delay can be obtained.

## Summary

Digital Delay can be used in the casual delayed sweep applications obtaining an accuracy, linearity, and low jitter never before achieved. Delay by Events gives jitterless displays that track with the clock jitter, drift and instabilities of the apparatus being observed. These and many other measurements are now available to oscilloscope users through the new capabilities and flexibility of the 7D11 Digital Delay Unit.

### Acknowledgments

Credits for the 7D11 effort go to Carlo Infante, project manager; Bob Beville, design leader; Bruce Hofer, design engineer; Dick Trost, technical aide; Phil Lloyd, mechanical design; Jim Gerakos, industrial design; Lois Davis, prototype support; Donna Fricker, Mike Hughbank and Norma Peterson, EC board design. Many others were in supportng roles, and to them too— a hearty thank you.

1. Understanding Delaying Sweep, TEKTRONIX SERVICE SCOPE, June, 1968.
2. Operation instructions: Delay Sweep Time Measurement, Delayed Sweep Magnification, Section 2 of any TEKTRONIX Manual on Delaying Sweep plug-in or portable oscilloscopes.
3. Gated Delay Line Oscillator, P. E. Dingwell, EEE, Sept., 1968.
4. 7D14 Trigger View. TEKSCOPE, Jan., 1971.
5. 7D15 Counter Signals Displayed, TEKSCOPE, Sept., 1972.

## 7D11 SPECIFICATIONS

### TRIGGERING

| EXTERNAL TRIGGER | | | | |
|---|---|---|---|---|
| SOURCE | Int, Line, Ext, Ext ÷ 10 | | | |
| COUPLING | DC, AC, AC LF Rej, AC HF Rej | | | |
| MAX INPUT VOLTAGE | 150 V DC + Peak AC | | | |
| LEVEL RANGE | ±3.5 V in Ext<br>±35 V in Ext ÷ 10 | | | |
| INPUT R and C | 1 MΩ ±5%, 20 pF ±2 pF | | | |
| SENSITIVITY | COUPLING | FREQUENCY RANGE | MIN SIGNAL REQUIRED | |
| | | | INT | EXT |
| | AC | 30 kHz - 10 MHz<br>10 MHz - 50 MHz | 0.3 div<br>1.0 div | 150 mV<br>750 mV |
| | AC LF REJ* | 30 kHz - 10 MHz<br>150 kHz - 10 MHz<br>10 MHz - 50 MHz | 0.3 div<br>—<br>1.0 div | —<br>150 mV<br>750 mV |
| | AC HF REJ | 30 Hz - 50 kHz | 0.3 div | 150 mV |
| | DC | DC - 10 MHz<br>10 MHz - 50 MHz | 0.3 div<br>1.0 div | 150 mV<br>750 mV |

| EVENTS START TRIGGER | |
|---|---|
| SOURCE | External Only |
| COUPLING | DC Only |
| MAX INPUT VOLTAGE | 150 V DC + Peak AC |
| LEVEL RANGE | ±3 V |
| INPUT R and C | 1 MΩ within 5%, 20 pF ± 2 pF |
| SENSITIVITY | 40 mV minimum, 30 Hz to 4 MHz; increasing to 100 mV, 4 MHz to 20 MHz; increasing to 250 mV, 20 MHz to 50 MHz. |

### EVENTS DELAY

**Events Delay Range**—One to $10^7$ events.

**Delay Increments**—One event.

**Insertion Delay**— 35 ns ±5 ns.

**Recycle Time**—Less than 500 ns.

**Maximum Event Frequency**—At least 50 MHz.

### TIME DELAY

**Digital Delay Range**—Normal Mode: 100 ns to 1 s in 100 ns increments. Echo Mode: 200 ns to 2 s in 200 ns increments.

**Analog Delay**—Continuously variable from 0 to at least 100 ns, accuracy within 2 ns of indicated delay.

**Jitter With Internal Clock**— 2.2 ns or (delay time X $10^{-7}$) whichever is greater.

**Insertion Delay**—Zero within 2 ns.

**Recycle Time**—Less than 575 ns.

**Time Base**— 500 MHz oscillator phase locked to internal or external clock.

**Internal Clock**— 5 MHz Crystal oscillator. Accuracy is 0.5 ppm.

**External Clock**— 1 MHz within 2%, AC coupled, 50 Ω.

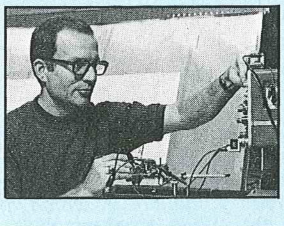
### OUTPUTS

**Delayed Trigger Out**—Amplitude: 2 V or greater into open circuit, 1 V or greater into 50 Ω. Risetime into 50 Ω Load: 2 ns or less. Falltime into 50 Ω Load: 5 ns or less. Pulse width 200 to 250 ns.

**Delay Interval Out**—Amplitude: 2 V or greater into open circuit, 1 V or greater into 50 Ω. Risetime and Falltime: 5 ns or less. Accuracy: Equal to Delay Interval less 20 to 30 ns.

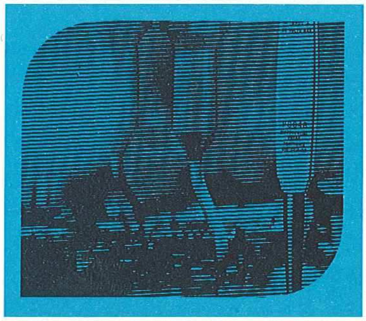
### READOUT

**Display**— 7½ digit with leading zero suppression. ms legend in Time Delay Mode. Plus (+) symbol reminds the operator to add on the FINE DELAY (ns) setting.



**Bob Beville**—Bob received his B.S.E.E. in 1961 and M.S. in 1963 from the Univ. of Florida. Before joining Tek in 1964 he worked as a mission conductor of refractometer experiments at Patrick AFB. After serving as a Field Engineer in our Syracuse and Poughkeepsie Field Offices, he transferred to Electrical Evaluation. Here his varied duties included design work on the trigger circuitry for the 11B2A Delayed Sweep Time Base, responsibility for design of calibration fixtures and CRT READOUT test and evaluation. After joining the Laboratory Oscilloscope Group, he was assigned the 7D11 project. Bob also teaches logic design in the Tek Education Program, and with his family enjoys camping, metal detecting and treasure hunting.

# TEKNIQUE



*Fred Beckett* = Engineer

## A PRACTICAL APPROACH TO
## DIFFERENTIAL AMPLIFIERS AND MEASUREMENTS

In Part I of this series we examined the basic concepts of the differential amplifier and the common-mode rejection ratio (CMRR). We noted that the main benefit attributed to the differential amplifier was its ability to reject the common-mode signal thereby allowing us to measure the desired signal in its true form. We also discussed sources of measurement error such as probes and source impedance differences. We will now address ourselves to the correct methods of making a differential measurement.

### MAKING THE DIFFERENTIAL MEASUREMENT

### *PART II*

There are two basic forms of differential measurements possible with an oscilloscope. The first is the conventional form of differential measurement between two electrical sources. The second is a differential comparator measurement. This latter technique is a difference measurement which compares an electrical potential against a reference voltage thereby deliberately introducing a "common-mode" condition. It is normally referred to as the "slide back" form of measurement and is a form of the null balance technique commonly found in some types of electronic measuring equipment.

### The Conventional Differential Measurement

Oscilloscope manufacturers provide two means of making differential measurements by conventional methods:

(1) a differential amplifier, either as a plug-in or non plug-in with a dual beam or dual-trace display.

(2) a dual-trace instrument, either plug-in or non plug-in with the differential measurement capability when the instrument is used in the ADDED display mode.

Fig. 1 shows these two forms. The table in Fig. 2 shows the features of these two types of differential measuring instruments. The table also shows the limitations of the ADDED mode technique. The ADDED mode technique should not be disregarded as an acceptable method for a differential measurement. Clearly its limitations lie in relatively poor CMR. It should be pointed out that many differential measurements do not require the exacting capabilities offered by a differential amplifier. For example, the cancellation of the ripple component from an unregulated power supply can quite adequately be performed by the ADDED display mode. However, when measuring a small signal such as you might expect from some types of thermocouples or bridge configurations, large common-mode signals can be a problem due to the limited CMR capability of the ADDED mode.

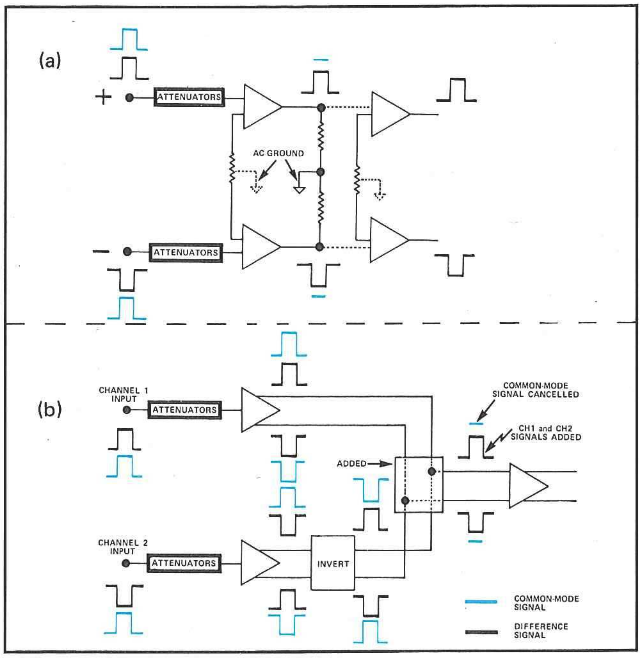


***Fig. 1.** Figure 1(a) shows a block diagram of the conventional differential amplifier. Figure 1(b) is a block diagram of the "ADDED" mode technique in which the outputs of CH 1 and CH 2 are added algebraically.*

| FEATURES | DIFFERENTIAL | ADDED MODE | COMMENTS |
|---|---|---|---|
| Typical CMRR | Typically between 10,000:1 to 100,000:1 from DC to 100 kHz | 100:1 or greater at 50 kHz (422 Spec) | Using the "ADDED" mode, CMR can be optimized by connecting Channels 1 & 2 inputs to a common source (calibrator) and adjusting Channel 1 or 2 GAIN for minimum CM display. |
| Probes CMRR Compensatable or matched for CMRR | YES | NO | |
| Balanced Input Circuits | YES | NO | With the "ADDED" mode, input RC input TC may vary within ±2% between channels. |
| Input Amplifiers Phase Corrected | YES | NO | |
| High Sensitivity | YES | NO | Typical for "ADDED" 5 mV/div (453A)<br>Typical for differential 10 $\mu$V/div (7A22) |
| High Input Impedance | YES<br>See Comments | NO<br>Nominal 1 megohm input impedance | This feature is either switchable (W unit) or by strap removal, (7A22, 5A22N) |

*Fig. 2. Table showing the relative merits of a true differential amplifier and one using the "ADDED" mode technique.*

## The Differential Comparator

You will recall in Part 1 of this series we stated that the differential amplifier appears in two basic forms: namely, the paraphase type and the push-pull. The only difference between the two is that the paraphase has one input referenced to a fixed potential—this is the basic form of the differential comparator. To make it useful, the fixed potential is replaced by a calibrated variable DC supply which is called the comparison voltage ($V_c$).

Fig. 3 shows a functional block diagram of a typical differential comparator system. Notice that we can operate this unit as a conventional differential amplifier by simply switching to the A—B mode with the DISPLAY switch.

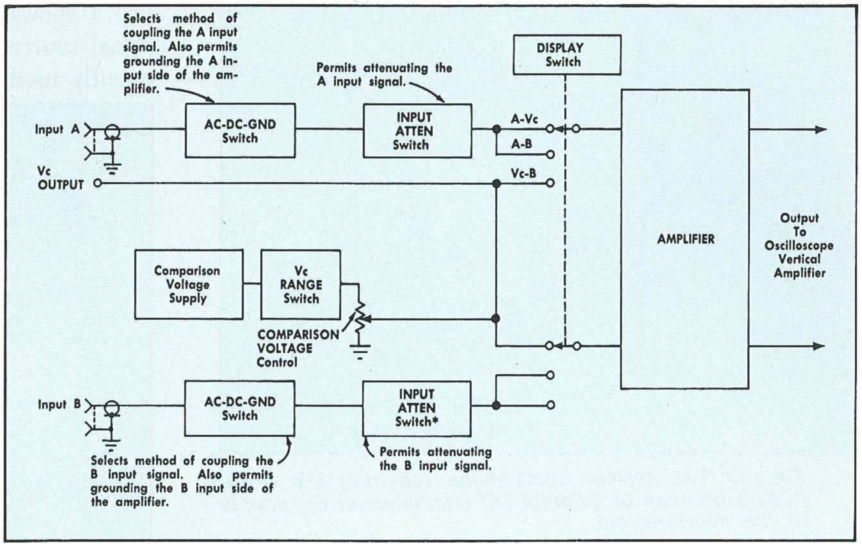


*Fig. 3. A block diagram of a typical differential comparator. Notice when the DISPLAY mode switch is in the A—B position the unit becomes a conventional amplifier.*

Let's see how we go about making a differential comparator measurement. First, we establish a reference position on our display by grounding both inputs. Then, selecting the appropriate input (positive voltage source to the + INPUT, negative voltage source to the − INPUT), we switch the other input to the comparison voltage ($V_c$). Next, the comparison voltage is adjusted until the trace "slides back" to the reference position. What have we accomplished? Using the "difference" principle we have introduced a "common-mode" condition in the form of the comparison voltage; that is, the comparison input voltage now equals the signal input. We see that we now have the ability to measure any potential whether it be DC, complex in nature, or a combination of both—such as a complex wave superimposed on a DC potential. Thus, we have an extremely versatile measuring tool. Notice, however, it does not have the mechanism to reject any interfering signal.

From the practical point of view, we must recognize some limitation when making comparator measurements. In order to measure a large potential or a waveform which is superimposed on a large potential, it may be necessary to attenuate the input signal to within acceptable limits to prevent damage to the input circuits. The first thing we must recognize is that the probes and/or attenuators, plus the comparison voltage circuits, will introduce an error by the amount they deviate from their true value. Simply stated, a resistance divider with a tolerance of ±0.1% will introduce that same error to our final reading. You must be aware of these limitations when making an absolute measurement with a differential comparator. These errors may differ from instrument to instrument so it is advisable to check your instrument manual for these details.

## DC OFFSET

When making a differential measurement with a conventional differential amplifier, we are often confronted with a situation whereby we have different DC conditions at the source of the measurement. Fig. 4 shows two typical cases, one involving a biomedical measurement, the other an electronic circuit measurement. In these cases we must "offset" one DC potential against the other and at the same time provide symmetrical input conditions to the differential amplifier. This is the purpose of the offset feature. Offset may be described as another form of "slide back" whereby we "cancel out" the effect of DC unbalance, allowing true differential measurement with the benefits of common-mode rejection.

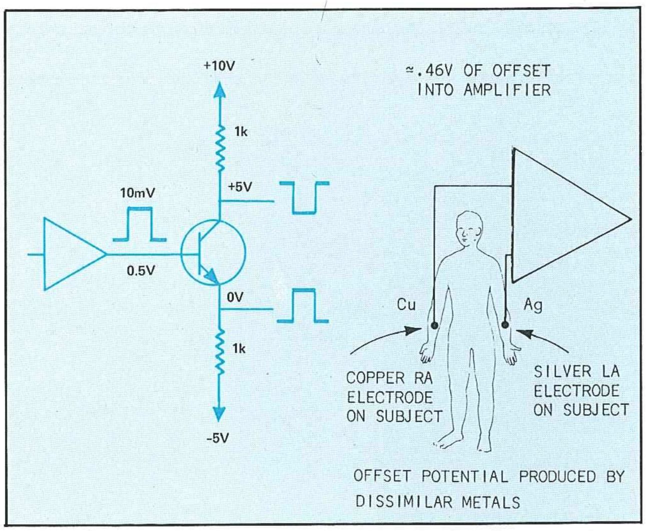


***Fig. 4.*** *Two typical applications requiring the offset feature because of different DC conditions at the source of the measurement.*

## Making the Differential Measurement

Now let's look at some basic procedures to observe when making differential measurements.

1) Check the gain of the amplifier using a known calibration source. When using a dual-trace amplifier in the "ADDED" mode you will need to check the gain of both vertical channels. Make sure both step attenuators are set to the same deflection factor and the VARIABLE controls are in the calibrated position.

2) If the measurement requires the use of probes, the following points should be observed:
   a) Use only the probes recommended for the instrument.
   b) Make sure the probes are properly compensated.
   c) If the probes are CMR compensatable such as the TEKTRONIX P6055, connect both probes to a common source (scope CALIBRATOR) and adjust them for minimum common-mode deflection.

3) If the measurement requires the use of interconnecting cables between the signal source and the amplifier, the following rules should be observed:
   a) Make the cables as short as practical.
   b) Make both cables the same length and strive for symmetry in all respects.
   c) Connect the cable shields as shown in Fig. 5(a).
   d) Avoid running the cables past known sources of interference such as electrical switchboards and the like.

In a severe common-mode environment, the method you use to connect the signal source to the measuring instrument may be the limiting factor between an accurate measurement and one you have to compromise. Improper use of ground leads may introduce common-mode loops or EMI into your measuring system. Figure 5 shows the correct method of connecting to the signal source and some incorrect methods that are frequently used.

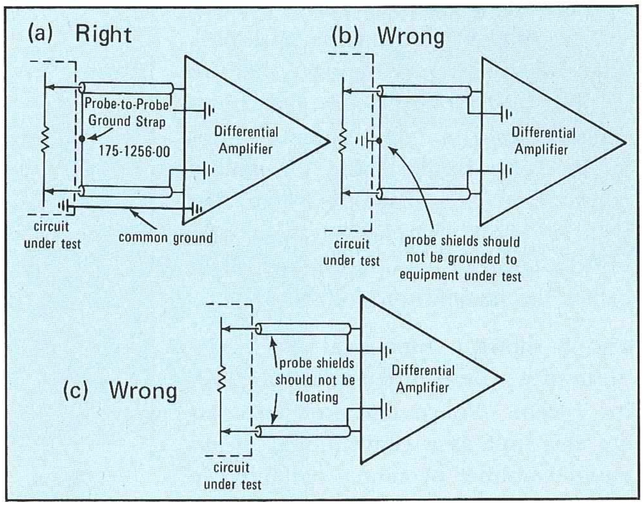


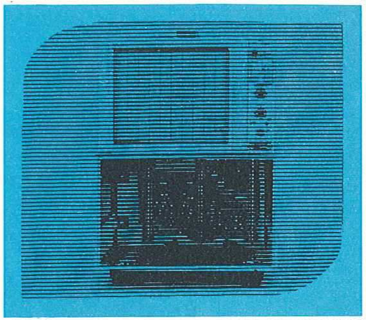
***Fig. 5.*** *Figure 5(a) shows the correct method of connecting the differential amplifier to the signal source. Figures 5(b) and (c) show the incorrect methods of connection often used.*

## Summary

Differential amplifiers vary in type and capability. Some are designed as true differential amplifiers from the input connectors to the output terminals. Some, such as the dual-trace unit operated in the ADDED mode, offer limited differential capability. Others provide a calibrated DC voltage source for highly accurate comparison measurements. All are designed to let you make measurements that are difficult, if not impossible, with single-input instruments. Selecting the appropriate differential amplifier and using proper techniques to connect the signal source are of equal importance in achieving accurate differential measurements.

In the concluding article in this series we will discuss "guarded" measurements and other techniques that further enhance our measurement capability.

# SERVICE SCOPE



## SERVICING 5100-SERIES DISPLAY UNITS

*Ken Kinman* — Service Support Coordinator

There are five display units currently available for the 5100-Series Oscilloscopes. These include single and dual beam units with conventional CRT's and their counterparts with storage CRT's. Much of the circuitry is common to all of the units so we will limit our discussion to the D11 Single Beam Storage Display unit in the interest of brevity.

The display units contain the CRT and its associated controls, the high voltage and Z-axis circuitry, calibrator, horizontal and vertical amplifiers, and in storage units, the storage circuitry and controls.

The modular type construction used in the 5100-Series Oscilloscope system is a boon to the service technician as it provides a quick means of isolating problems to major components. For example, if you suspect trouble in the indicator unit, it can be quickly checked by operating the oscilloscope without the plug-in units installed. Under these conditions a defocused spot at or near the center of the CRT should be obtainable if the unit is working properly. The intensity of the spot should be adjustable with the INTENSITY control.

If, upon turning up the INTENSITY control, no spot is visible, press the BEAM FINDER button. If the problem is in the deflection amplifiers, the spot should appear somewhere on screen. Its position should point you directly to the vertical amplifier, horizontal amplifier or both.

Let's consider a situation in which the spot appears to the left of center screen when the BEAM FINDER is pressed. It would be helpful at this point to install an amplifier plug-in in both the vertical and horizontal compartments of the scope. If an amplifier is not available for the horizontal compartment, a time base will do. Now press the BEAM FINDER button and note that the position of the spot is still to the left of center screen. Place a shorting lead between the bottom leads of R123 and R133 (refer to the Deflection Amplifier/High Voltage Board Parts Location Grid in the manual). If this produces no change in the spot position, interchange Q124 and Q134. If the spot position reverses, Q134 should be suspected of being open. If there is no change, interchange Q126 and Q136. This should reverse the spot position. If so, Q136 is probably open.

Should these procedures fail to locate the problem, it will be necessary to investigate the passive components associated with the active devices just discussed.

Problems in the vertical amplifier can be located using the same technique.

### The High Voltage Supply

The circuitry for the high voltage supply is shown in the CRT circuit diagram in the manual. The high voltage oscillator consists of Q252 and the primary windings of T240. The lower primary winding provides the necessary feedback for the oscillator. The drive to the oscillator is regulated by Q262, Q264, Q278 and their associated components.

You will notice that the CRT grid supply is referenced to the Z-axis amplifier consisting of Q222, Q226 and Q234. Therefore, the Z-axis amplifier must be working properly if we expect to control beam current properly.

High voltage malfunctions are readily apparent at the CRT faceplate and usually result in one of two conditions:

1) No intensity.
2) Maximum intensity, unaffected by the INTENSITY control or Intensity Range control.

Let's troubleshoot the high voltage circuit assuming we have the first condition, no intensity. Caution should be observed when troubleshooting this area as dangerously high potentials may exist in the CRT circuitry.

Measure the CRT cathode supply (—3400 V) at the H.V. Test Point. If it is not present, the gate of Q278 will rise, pulling the source with it until CR264 conducts. The source of Q278 should measure about 0.6 V. This condition will cut off Q264, which in turn cuts off Q262. CR262 will be reverse biased. This condition should provide maximum drive to the base of the high voltage oscillator Q252. If you can verify these conditions within the regulator circuit, you can assume it is functioning normally.

The next step is to check the voltages supplying the high voltage oscillator. You may find the collector voltage of Q252 is at —38 V. This would indicate a blown fuse in the +40 V supply. The fuse is located in the 5103N mainframe.

### The Z-Axis Amplifier

If the CRT cathode supply is normal and you have no intensity or intensity control, check the voltage at the CRT control grid. That voltage should be about —3450 V. Watch the CRT faceplate while measuring the control grid voltage. If the beam appears but the intensity is not adjustable, the reference for the control grid supply is incorrect and you are providing a source through your voltmeter.

Next, check the voltage at the collector of Q226. It should be about +65 V with the INTENSITY control clockwise. If the voltage at that point is negligible, check the current source transistor, Q234. If the voltage at the collector of Q226 is high (+65 V or more), the beam current will be at maximum and not adjustable. You should suspect Q226 or Q222 or their associated circuitry as being defective.

## The Storage Circuitry

Now let's take a look at the storage circuitry. Storage tube characteristics have a tendency to change with age. What appears to be a defective unit may only require calibration to restore it to normal operation. Here is a quick and easy procedure for setting up the storage controls.

With the power off, insert an amplifier plug-in and time base plug-in in their respective compartments in the mainframe. Remove the right side cover and locate the storage circuit board near the front of the instrument. Now perform the following steps:

1. Pull the POWER switch to on.
2. Obtain a trace using a 1-ms/div sweep speed. The trace should be sharply focused.
3. Rotate INTENSITY full ccw. If the writing beam cannot be fully extinguished, push the BEAM FINDER switch and adjust the Int Range control (R245) until the trace is just visible. Releasing the switch should result in no visible trace.
4. Push the STORE buttons to the in position. Push both ERASE buttons at the same time to the in position.
5. Measure the voltage at TP2. (See Fig. 4-1 in the D11/D15 manual.) You should read +370 V. R387 should swing that voltage about ±5 V. If this cannot be accomplished, turn the instrument off. Now check the insulated heat sink jackets (black) on Q362, Q364, Q372, Q392 and Q396. Access to these is accomplished by removing the large heat sink plate at the rear of the instrument. Apply power to the instrument and check to see if any voltage is present on the top portion of the black heat sink jackets. Those showing any voltage reading should be replaced as they will improperly load the +370-V supply. Reinstall the large heat sink plate.

   If the +370-V supply is still abnormal, measure the drop across CR387. This is a protection diode and should not be conducting during normal operation. If the diode is in its zener mode (about 34 V), Q386 is probably defective.
6. With the +370-V supply operating properly, slowly increase the trace intensity and write the entire screen positive by slewing the trace vertically several times. If the trace cannot be stored, rotate the Store Level control cw until storage is possible. If storage still cannot be accomplished, check the voltage at TP1. It should be about +125 V. If it is abnormally high, check Q356 and Q358. If that point is unusually low, check Q362 and Q364. The STORE LEVEL control R350 should swing the voltage at TP1 from about +20 V to +290 V DC.

   Now turn the BRIGHTNESS control clockwise. Once the CRT screen is fully written, adjust R390 (CE1) fully ccw. The display should resemble that in Fig. 1. Note that at the point where the screen fills completely, the corners will begin to darken. The final setting of R390 should be at a point between full screen and the appearance of dark corners. See Fig. 2.

   If a display similar to Fig. 2 cannot be achieved, check the voltage at TP3. It should swing from 0 to +200 V when R390 is rotated through its range. Ideally the voltage should read +50 V, ±5 V.

   Another point to check is the waveform present at pin 1 (►) of P389. This should be a 120-Hz sawtooth about 15 V in amplitude. Any irregularity in the waveshape would indicate a defective bridge, CR329.
7. Adjust Non-Store Level (R395). Write the entire screen positive. Release UPPER STORE switch and note that the upper screen background glow disappears quickly (less than 1 sec). Adjust Non-Store (R395) to insure proper upper screen background fade rate. Half-screen storage should resemble Fig. 3.

   If proper storage fade rate cannot be accomplished, measure pin #6 of the harmonica connector at the upper right hand corner of storage board. This should be 140 V ±1.4 V. If Q396 is defective (i.e., open) the display will appear as in Fig. 4.

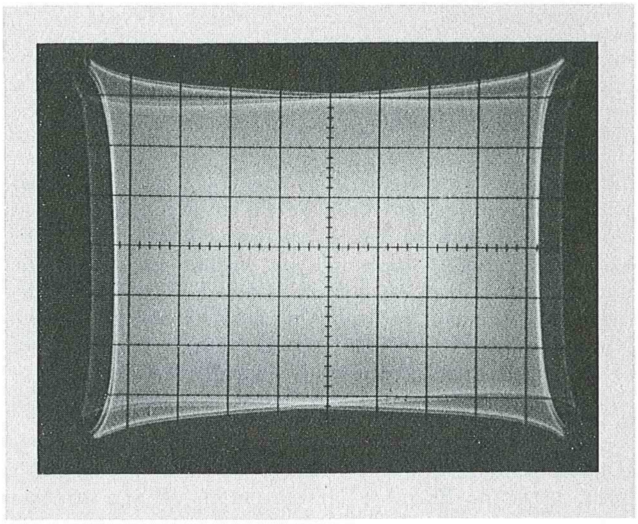


***Fig. 1.*** *Typical stored display with R390, CE1 set full counterclockwise.*

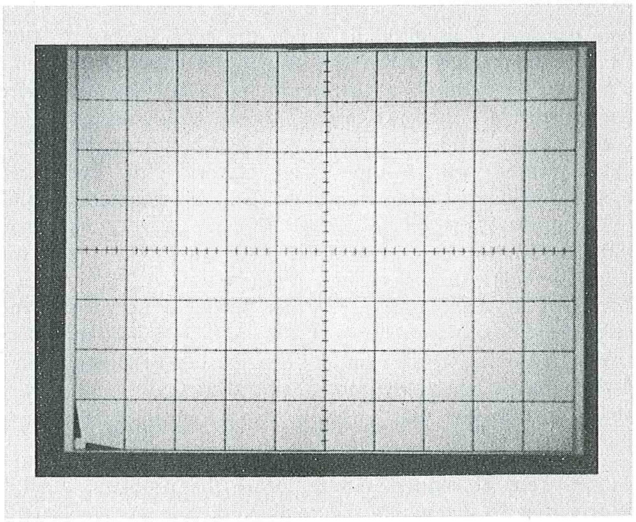


***Fig. 2.*** *Typical stored display with R390, collimation electrode control properly adjusted.*

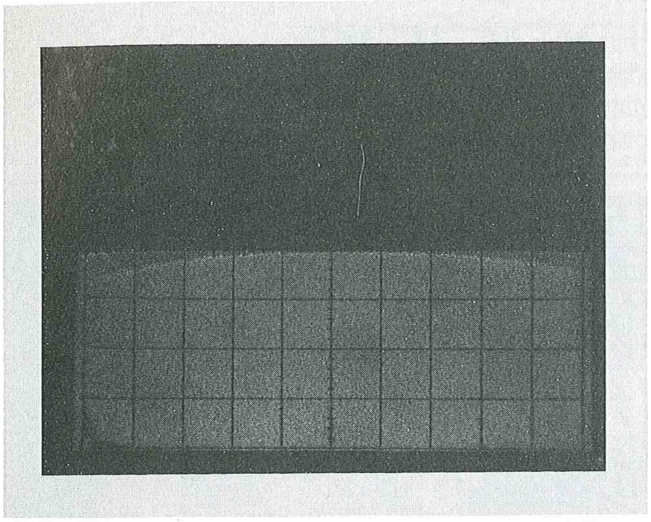


*Fig. 3. Typical half-screen stored display.*

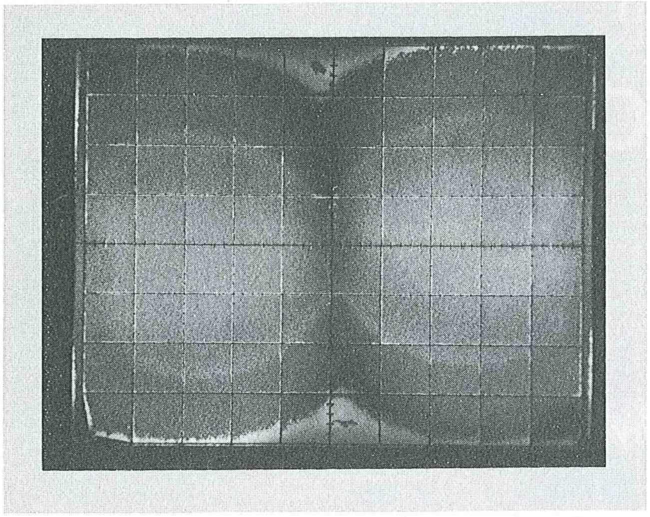


*Fig. 4. Stored display resulting from improper flood gun anode voltage due to open Q396.*

8. Adjust Store Level R350. Push store switches to "out" (non-store). Set TIME/DIV to 0.2 msec. Feed a 1.5-kHz sine wave signal into the vertical input and set the amplitude for 3.2 div of deflection. Trigger the sweep and adjust INTENSITY to a point where the trace just starts to defocus. Readjust the focus for a sharp trace.

   Set the time base Sweep Mode to Single Sweep and erase the stored display. Alternately store and erase single sweeps while increasing the sine-wave generator frequency in small increments. Allow about five seconds after each erasure before writing another display. Adjust the frequency to the highest rate that will permit the vertical transitions of the sine wave display to store anywhere on the center 6 x 8-division area of the screens, with no more than a 50% loss in luminance, or with the breaks in the trace not exceeding 0.025 inch. This is the maximum writing speed of the CRT.

   Maximum writing speed is calculated as follows:

   Writing speed (in divisions/second $= \frac{2\pi \text{ F } V_{p\,p}}{2}$ )

   substituting the display amplitude of 3.2 divisions for $V_{p\,p}$, the expression is reduced to

   Writing Speed $\approx$ 10 X F.

   Thus, for example, if the sine wave generator frequency is two kilohertz or greater, the maximum writing speed of the CRT is 20 divisions/millisecond (20,000 divisions/second) or greater.

   The writing speed should be $\geq$20 divisions/millisecond for the D11, $\geq$200 divisions/millisecond for the D15.

   Note: It may be necessary to repeat this step with a slightly higher trace intensity or store level.

   As the storage tube ages, its ability to store diminishes. This effect is first apparent in the center screen area.

9. Store Balance (R370). Measure the DC voltage at TP1. Probe TP4 and adjust Store Balance (R370) to a voltage identical to that at TP1.

   Inability to adjust R370 properly could be caused by Q372 being defective or possibly the 110-V zener diode VR370 failing. A quick check of store balance would be to check background level differences between erase "in" and "out" positions.

10. Sensitivity Correction (R385). Obtain a display of exactly 6 div of sine wave at 1 kHz (non-store). Switch to Single Sweep and push in both STORE buttons. Store a trace and check for exactly six divisions of signal. If the amplitude of the stored display differs from the non-stored display, adjust R385 while displaying the sine wave alternately in store and non-store.

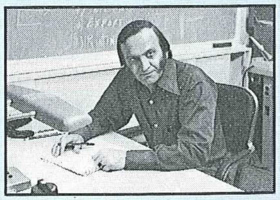
## Summary

This information pretty well covers the majority of possible trouble spots related to the 5100-Series display units.

Even though the situations were hypothetical, an attempt was made to familiarize the technician with the circuitry, and offer quick uncomplicated checks which in the long run reduce down time.

Most technicians will agree that the best troubleshooting aid is a good circuit description.

### ABOUT OUR AUTHOR



**Ken Kinman**—During his 13 years at Tek, Ken has served in many areas of Marketing. Following a stint as Product Service Technician he moved to a technical writing group where he authored the "Sweep Generator Circuits" concept book. Ken then moved into Field Engineering and worked out of the Huntsville, AL. Field Office for a year and a half. Returning to Beaverton he joined the Product Service Support Staff.

Ken is a graduate of DeVry Technical Institute of Chicago. His hobbies include photography, motocross cycle competition and music a la Neil Diamond.

# TEKSCOPE

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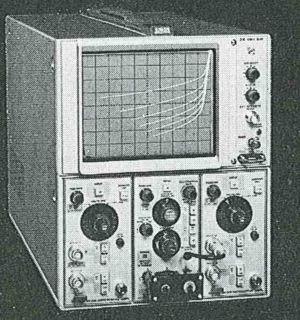

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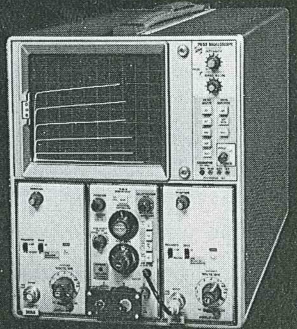

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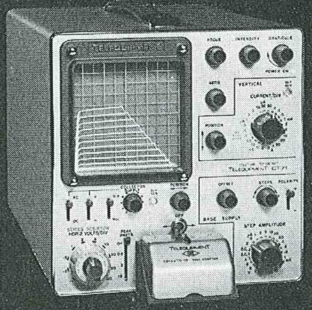

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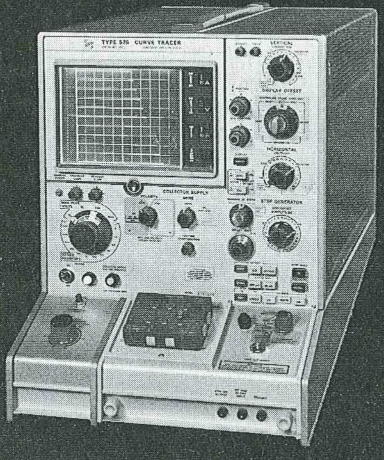

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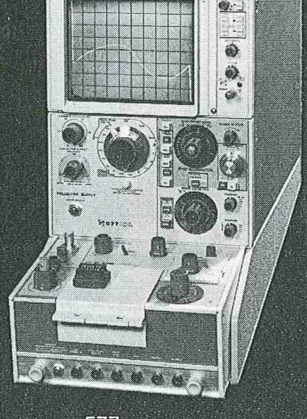

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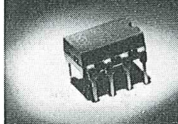

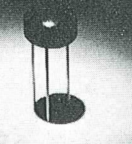

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1L5 & 132 w/sweep freq. converter. Bruce Hatch, Sound Genesis, 445 Bryant St., San Francisco, CA 94107. (415) 391-8776.

Type T Plug-In. Mr. Sawyer, Electronics Dept. Winona Area Vocational-Technical School, 1250 Homer Rd., Winona, Mn. 55987.

Type 82 Plug-In, any cond., T. E. Prescott, 1798 Rocky Creek Rd., Macon, Ga. 31206.

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