COVER:
A PROGRAMMABLE OSCILLOSCOPE FOR PRODUCTION TESTING, page 2

SEE ALSO:
A HIGH-STABILITY, HIGH-SENSITIVITY DC SCOPE PLUG-IN UNIT, page 16
SIMPLER TDR MEASUREMENTS pages 9, 10, 12
Fig. 1. Recording shows zero stability achieved by dc stabilizer in new Programmable Oscilloscope. Signal for recorder was derived at CRT deflection plates with scope set on 5 mV/cm deflection factor range and shows less than ½ mV zero level shift with extreme change of temperature. (Trace variations which appear as noise actually are stabilizer switching transients, normally blanked on CRT.) Instrument at room temperature was first turned on at left, and it stabilized in less than 3 minutes. At time ‘A’, recorder was stopped while instrument was cooled to 0°C before recorder was started again. At time ‘B’, recorder was stopped once more while instrument was warmed to 55°C and then restarted.  

AN ADVANCED NEW DC-25 MHz OSCILLOSCOPE FOR PROGRAMMED PRODUCTION TESTING  

A new oscilloscope has the special capability of maintaining its dc baseline without drift. This leads to higher dc accuracy and the important characteristic of being programmable.

Although cathode-ray oscilloscopes are widely used because of their versatile measurement capabilities, they are yet to find wide application in automatic test systems. Attempts in the past to provide an oscilloscope with programmable controls have met with less than complete success primarily because of the inherent drift of sensitive dc-coupled deflection amplifiers. Some means of taking drift into account must be incorporated if programmed displays of waveforms are to achieve a high degree of accuracy.

Now, in a major departure from established concepts, a new oscilloscope resolves the problem of drift by automatically rezeroing itself 3 times a second to correct for both long- and short-term drift in the vertical amplifier. In this oscilloscope, the dc stabilization maintains the baseline at any selected position, thus enabling accurate measurement of waveform levels without requiring the operator to constantly adjust dc levels. It is thus entirely practical to use this instrument in programmable systems, greatly simplifying operating procedures by making unnecessary the need for adjusting instrument controls during the course of a measurement sequence.

The functions of vertical sensitivity, positioning, input coupling, sweep time, trigger source, and trigger slope can all be programmed remotely through a rear input connector, eliminating the danger of measurement...
errors resulting from operator selection of the wrong range. Hence, in programmed systems where repeated sequences of tests are made, such as in production testing, this oscilloscope makes it possible for less-skilled personnel to use an oscilloscope with uniformly accurate results.

The stabilizing technique also permits the instrument to make reliable measurements of dc levels with analog voltmeter accuracy. In situations where several types of measurements are made, the new scope may be used in place of other instruments to measure dc levels, as well as waveforms, with complete confidence. The virtually complete absence of variations in the dc level of the vertical amplifier, even in the face of ambient temperature changes, is shown by the recording of Fig. 1.

In addition to enabling dc measurements ordinarily not attempted with an oscilloscope, the stabilized vertical amplifier allows accurate offset of the baseline in calibrated increments above or below the center of the CRT graticule. In view of this capability, the vertical deflection amplifier was designed with a wide dynamic range which, along with the wide offset range (±25 cm), allows expanded scale measurements to be made. With offset, small ac signals riding on a relatively large dc may be examined in detail even though dc coupling is retained. Waveforms may be expanded several times beyond full scale for detailed examination of any part of the waveform, as shown in Fig. 4.

**WIDE RANGE SCOPE**

Apart from its stable dc operation, the new oscilloscope (—hp— Model 155A) is capable of high performance in many other respects. It is basically a general purpose, wideband, single-channel oscilloscope with a high-frequency 3-dB point at 25 MHz (Y axis), a response figure that is referred to an 8-cm display rather than the 6-cm reference usually used for scopes with bandwidths higher than 10 MHz. Rise time is less than 15 nanoseconds for 8-cm deflection and less than 20 nanoseconds with pulses that have amplitudes expanded considerably beyond the 8-cm display area. Minimum deflection factor (maximum sensitivity) is 5 mV/cm. Unmagnified sweep times range down to 0.1 μs/cm and a ×5 magnifier is included for expanded sweeps. The scope is thus well-suited for critical laboratory applications as well as programmed testing, bringing the accuracy and convenience of drift-free performance to the lab bench.

**PUSHBUTTON OPERATION**

Only the most commonly-used controls of the new oscilloscope are visible to the user during normal programmed operation, but all other controls that are standard for a general-
purposely located behind a hinged door along the bottom of the front panel (Fig. 3). Concealing these controls reduces the danger of misadjustment by the semi-skilled operator but with the door lowered, the controls are readily available to the trained operator.

In the manual mode of operation, vertical sensitivity and sweep time are controlled by momentary-contact, illuminated pushbuttons for quick selection of ranges. Stepped vertical positioning is controlled by a front panel knob and the zero-voltage level is indicated on an illuminated front panel display (Fig. 9), an especially desirable arrangement for expanded scale measurements when the baseline may be positioned off the screen. All other functions are controlled by conventional knobs and switches.

PROGRAMMED OPERATION

In the programmed mode, all programming of the instrument is digital and is accomplished by contact closures to ground, thereby placing a minimum

ELIMINATING DC DRIFT

In the new oscilloscope described in the accompanying article, the dc level of the amplifier is stabilized approximately 3 times a second. During the stabilization interval, a sequence generator disconnects the input signal and the vertical positioning voltage from the amplifier, grounds the amplifier input, and samples any difference of potential that may be present at the vertical deflection plates. Normally, the deflection plates should be at some prescribed potential when the input is grounded, any other potential difference represents drift.

Charge representing the potential difference is stored in a capacitor and held there until the next sampling interval. Between samples, when the input signal is connected to one input of the differential amplifier, the signal at the opposite input is the sum of a correction signal, derived from the stored capacitor voltage, and the position signal introduced to offset the trace vertically. The correction voltage provides an offset that compensates for any drift.

The stabilizing system takes advantage of the dead time during flyback of the horizontal sweep. The stabilizer cycle is started by a signal from an AND gate that senses inputs from both the sweep gate and a delay multivibrator (see block diagram, Fig. 1). They control the correction feed to store 350 milliseconds since the last sample, as determined by the delay multivibrator, and that an ensuing sweep has been completed, as signified by the sweep gate. These are shown as waveforms A, B, and C in Fig. 2.

The switching functions are controlled by the sequence generator, a monostable multivibrator that is triggered by the signal from the AND gate. The sequence generator has three outputs with three distinct 'on' times. The 2-millisecond output controls the sampler reed switch which closes the correction feedback loop (waveform D). The 3-millisecond output drives the reed switches that disconnect the input and positioning signals and that reference the amplifier input to ground (waveform E). These switches are held closed 3 milliseconds to insure that the correction loop is opened again before anything is done that might disturb the reference to which the amplifier is stabilized. The 5-millisecond output inhibits the sweep generator, the additional 2 milliseconds allowing time for the amplifier to recover from any switching transients before the display is again presented on screen (waveform F).

The output of the amplifier that senses drift is coupled through an emitter-follower to the storage capacitor in the stretcher or zero order zero hold. The emitter-follower serves as a low-impedance driver for charging the capacitor.

The output from the zero order hold is then fed through a cathode-follower to an attenuator and mixing circuit and then into the normally undriven input of the main vertical differential amplifier.

The forward gain of the vertical amplifier with the correction loop open is about 2000 at maximum amplifier sensitivity. During the time the loop is closed, the gain is reduced to 100 by the return ratio of 200. The net result is that the correction reduces any drift by the return ratio. With correction, the vertical amplifier, with its minimum deflection factor of 5 mV/cm, has a drift characteristic that compares with an uncorrected amplifier having but 1 V/cm deflection factor. The stabilized amplifier maintains a zero offset baseline within plus or minus 0.1 centimeter of center screen, after less than a three-minute warmup, and it is virtually unaffected by environmental tem-
number of requirements on the programming device. The oscilloscope can be programmed by a wide variety of digital devices such as computers, punched cards, and stepping switches.

A total of 35 program lines provide full programming capability. A maximum of 9 contact closures are required at one time for each program, depending on the functions to be programmed. Vertical deflection factor and sweep time require two each. Vertical offset requires two closures, with one determining the amount of offset and the other determining polarity, and vertical input coupling (ac or dc) requires a single closure. Trigger source signal selection requires a single closure to select internal, external, or line. Trigger slope needs one closure to select the positive or negative slope of the signal for initiating triggering.

Each open program line has a —12-V potential on it and any switching device capable of sinking at least 20 milliampere to ground can be used for programming (power for programming is supplied by the scope main frame). An isolated ground line is supplied to the program input connector so that a front panel switch may be used to disable all program inputs should this requirement arise.

PROGRAMMER

A companion instrument, the hp-Model 1550A Programmer, provides the means for storage and selection of programs for the oscilloscope controls. The Programmer (Fig. 6) allows each preset program to be selected in any order either manually by one of the pushbuttons on the Programmer, or remotely by a single contact closure. The Programmer thus may serve as a storage buffer for system programmers.

Switching to a new program requires about 10 milliseconds. The selected program is indicated by a light in the appropriate pushbutton on the Programmer and lights in the oscilloscope pushbuttons indicate the ranges being programmed.

Programs are established by diode pins that plug into a matrix on a circuit board in the Programmer (Fig. 7). Up to 18 complete preselected programs may be stored and selected by one Programmer and Programmers may be cascaded to increase the number of programs by multiples of 18.

The Programmer has one auxiliary programming line that normally is not used for any of the scope functions. This line, useful for additional programming instructions, may be programmed 'off' or 'on' by appropriate insertion of a diode pin connector.

As shown by the circuit diagram of Fig. 8 the Programmer uses external power and it may be used as a controller for other equipment that is compatible with the Programmer's logic level and power requirements.

TRANSFER OF CONTROL

While the instrument is being operated from programmed instructions, any of the pushbuttons may be operated manually to override the program when the need arises to search for a signal or otherwise deviate from a standard program sequence. This is important in production testing or system checkout if a manual search for the signal is required at times when the waveform to be measured does not appear on the scope display because of a malfunction or misalignment of the equipment under test. To restore programmed operation, resetting the previous program or switching to a new one is all that is required.

To facilitate transfer of control between programmed and manual operation, the vertical deflection factor and sweep time control inputs, either manual or programmed, are stored in a memory in the oscilloscope. The memories consist of multistable multivibrator...
Fig. 7. Oscilloscope junctions are quickly set up in Programmer by insertion of diode pin connectors in appropriate holes. Each column represents one program. Legends at left and right indicate functions selected by corresponding levels in column.

generated noise pulses is necessary since any noise that might be coupled into programming lines could cause erroneous ranges to be set up. Instead of using the input from the programming device to generate the programming signal directly, each input is buffered by a reed relay. The Program input then energizes the reed relay which in turn generates the switching signal. Noise impulses of sufficient energy to close a relay are not usually encountered.

For applications not requiring programmability, the oscilloscope can be operated without the circuit cards required by external inputs. These cards and associated cabling may be added at any later time should a requirement for programmability arise.

**VERTICAL OFFSET**

The new oscilloscope allows either discrete-step or continuous control of vertical positioning. Calibrated step control, coupled with dc stabilization, is necessary for programmed operation to insure accurate and repeatable measurements of waveforms. The step control permits offset of the baseline in 1-centimeter steps up to plus or minus 5 centimeters, and then in 5-centimeter steps up to plus or minus 25 centimeters. The dividers in which these voltages are derived have resistors of \( \frac{1}{4\%} \) accuracy to insure that the offset signal is accurate to better than \( 2\% \). The steps may be selected manually by the front panel control as well as remotely in the programmed mode of operation.

A manually-operated vernier behind the hinged cover allows continuous control of positioning to approximately 3 centimeters above and below any digital setting.

Control of the offset then remains in the manual mode until either the previous program is reset or a new program is selected.

**VERTICAL AMPLIFIER**

The vertical amplifier, exclusive of the dc stabilization circuits, is differential throughout. The circuitry is solid-state except for Nuvistors in the input stage, which provide the high impedance and low-leakage characteristics required for a 1-megohm input resistance. The input attenuator uses specially shielded reed relays and tight tolerance resistors to provide good high frequency response and an accuracy of \( \pm 0.2\% \). Input capacitance is held constant at approximately 50 pF.

The low-level stages of the amplifier are designed for linear operation with signal amplitudes that would cause deflection of greater than \( \pm 50 \) centimeters. The output stage and driver have fast diode clamping circuits that prevent large signals from saturating the transistors, thus enabling expanded scale displays without creating distortion in the visible part of the display.

Fig. 8. Each pushbutton in Programmer controls relay that grounds all program lines for relays on corresponding program lines in oscilloscope (diodes decouple lines from programs other than that being activated). Single external closure to ground also activates all program lines in corresponding program.
Delay lines in the amplifier retard the signal 200 ns to permit display of the leading edge of fast rising waveforms while the same waveform is used to trigger the sweep.

**TRIGGERING**

The trigger signal is derived at a point between the vertical input attenuator and the amplifier input and it is applied to a separate, high-performance ac-coupled differential amplifier. No trigger amplification takes place in the vertical deflection amplifier itself because of the switching transients generated during the stabilization cycle, which would affect synchronization adversely.

In the absence of an input signal, the time base trigger system automatically generates triggers at about 30 Hz thus assuring a continuous display of the base line. This is especially convenient when the oscilloscope is used as a voltmeter to measure dc levels. When the triggering control is switched to 'Auto', the trigger level is preset for optimum triggering on most waveforms. However, trigger level may be adjusted manually by a front panel control located on the front panel outside and just above the enclosed panel where it is readily available to the user if needed.

**CRT AND Z-AXIS**

The CRT used in the new oscilloscope provides a bright display on an 8 x 10 centimeter area and it has an internal graticule which eliminates parallax error in the reading of waveform amplitudes. The tube is a post-accelerator type using a mesh electrode and an overall accelerating potential of 7.5 kV. The vertical deflection factor of the tube is 7.5 volts/cm, and the horizontal deflection factor is 12.5 volts/cm making the tube compatible with solid-state amplifiers. The longer persistence provided by P2 phosphor is used to suppress stabilization flicker.

The Z-axis or intensity modulation amplifier is a direct-coupled operational amplifier. Z-axis input signals from dc to rise times faster than 60 ns may be displayed on the CRT.

**ACKNOWLEDGMENTS**

Electrical design of the Model 155A/1550A Oscilloscope was by Roy Wheeler and Charles House; product design was by Norman Overacker. Thomas Schroath, and Philip Foster. The author wishes to extend a note of gratitude to Norman Schrock of the -hp- Oscilloscope Division for his support and encouragement during the project.

— John Strathman
Project Leader

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**DESIGN LEADERS**

Chuck House joined -hp- in 1962 after earning his BSEE degree from the California Institute of Technology. Two years later he earned his MSEE degree from Stanford University in the -hp- Honors Cooperative Program. At -hp-, Chuck initially worked as a development engineer on the 140A Oscilloscope and then on the design of the vertical amplifier in the Model 155A Oscilloscope. Norm Overacker started with -hp- in 1957 on a part-time basis while participating in a cooperative work-study program at San Jose State College. Initially, he worked as a mechanical assembler, a production-line test technician, and as a service department repair technician. After earning his BSEE degree in 1962, Norm joined -hp- full time as a service engineer but transferred to the -hp- Oscilloscope Division in 1963 where he has been a product design engineer on the 155A/1550A Programmable Oscilloscope project. Norm also taught courses in basic electronics and electronic circuits at the College of Mateo, California. John Strathman joined -hp- in 1957 as a development engineer. Initially, he participated in the development of the Model 120A Low Frequency Oscilloscope and was then project leader for development of the Model 122A Dual Trace Oscilloscope and the 130C Sensitive Oscilloscope. He was also project leader on several plug-ins for the 160B/170A Militarized Oscilloscopes, including the 166C Display Scanner, the 165D High Gain Amplifier, and the 162F Wide Band Amplifier. John presently is manager of low frequency and special purpose oscilloscope development in the -hp- Colorado Springs laboratory. John received his BSEE degree from the University of Illinois in 1955 and his MSEE degree from Stanford University in 1960 in the -hp- Honors Cooperative program. He is a member of IEEE, Tau Beta Pi, Theta Kappa Nu, Sigma Tau, and Pi Mu Epsilon.

Roy Wheeler worked for seven years in product design prior to obtaining a BSEE degree from the University of Illinois in 1963. He then joined -hp- as a development engineer doing circuit design for various sections of the 155A/1550A Programmable Oscilloscope. Roy, who is a member of Beta Kappa Nu, has done graduate work at the University of Colorado.
**SPECIFICATIONS**

**MODEL 155A OSCILLOSCOPE**

**VERTICAL DEFLECTION SYSTEM**

- **DEFLECTION FACTOR (SENSITIVITY):** 12 calibrated ranges from 5 mV/cm to 20 V/cm in 1, 2, 5, 10 sequence. Vernier allows continuous adjustment between calibrated ranges and extends deflection factor to at least 50 V/cm.

- **ATTENUATOR ACCURACY:** ±2%.

- **BANDWIDTH (referred to 8-cm signal at 1 MHz from 250 source):** DC coupled: DC to greater than 25 MHz at 3 dB down. AC coupled: 2 Hz to greater than 25 MHz at 3 dB down.

- **RISE TIME:** Less than 15 ns at 8 cm reference signal. Less than 20 ns at 25 cm reference signal. (With 250 source having rise time <3 ns.)

- **POSITION:** Base line can be offset ±25 cm from center screen of CRT in calibrated 1-cm steps from 0 to 5 cm and 5 cm steps from 5 to 25 cm. Accuracy of steps is ±2%, when amplifier gain is calibrated. Vernier allows continuous ±3 cm adjustment about setting of step offset.

- **DC STABILITY:** Zero-setting dc stabilization maintains zero offset base line within ±0.1 cm of center screen on CRT over entire sensitivity range after 3-minute warm-up. Zero setting occurs approximately 3 times per second.

- **SIGNAL DELAY:** Signal is delayed so that leading edge of fast rise signal is visible at start of sweep.

- **INPUT IMPEDANCE:** 1 megohm shunted by approximately 20 pF.

- **MAXIMUM INPUT VOLTAGE:** 400 volts (dc ± peak ac).

- **REAR INPUT:** Rear panel BNC input connector is selectable by front panel switch. Input impedance is 1 meegohm shunted by approximately 80 pF. Bandwidth is greater than 20 MHz, rise time less than 18 ns for 8 cm step.

- **REAR OUTPUT:** Rear-panel BNC connector provides low-impedance dc-coupled vertical signal output corresponding to on-screen display. With stabilizer operating, output signal is dc-stabilized and contains 5 ms stabilizer switching transient at ± 3 Hz.

- **HORIZONTAL DEFLECTION SYSTEM**

  - **INTERNAL SWEET:** 18 calibrated ranges from 0.1 μs/cm to 50 ms/cm in 1, 2, 5, 10 sequence. Accuracy is typically within 1%, always within 3%. Vernier allows continuous adjustment between calibrated ranges and extends slowest sweep to at least 0.125 s/cm.

- **MAGNIFICATION:** x5 expansion on all ranges extends fastest sweep to 20 ns/cm. Accuracy is typically within 3%, always within 5%.

- **SLOW SWEEPS:** 10 slow sweeps, 10 and 50 ms/cm sweeps to 0.1, 0.2, and 0.5 s/cm, respectively. Accuracy is typically within 3%, always within 5%.

**TRIGGERING:**

- **AUTOMATIC:** Base line displayed in absence of input signal. Internal: 40 Hz to greater than 25 MHz from signals causing 0.5 cm deflection or more from 50 mV/cm to 20 V/cm and from signals causing 20 cm deflection or more from 5 mV/cm to 20 mV/cm deflection factor, also from line voltage. External: 40 Hz to greater than 25 MHz from signals 0.5 volt to 10 volts peak-to-peak. Input impedance: 100 k shunted by approximately 20 pF.

- **AMPLITUDE SELECTION:**
  - **INTERNAL:** Same as Automatic Internal except lower cutoff frequency extends to 10 Hz.
  - **EXTERNAL:** Same as Automatic External except lower cutoff frequency extends to 10 Hz.

- **TRIGGER POINT AND SLOPE:** Internally from any point on displayed waveform; externally from any point between ±5 volts, positive or negative slope.

- **SINGLE SWEET:** Front panel switch select single sweep operation.

**REMOTE PROGRAMMING**

Programmability is accomplished by contact closures to isolated common line. Control lines are offset, 12 volt-amperes, and include means for selecting any of the preset programs.

**TRIGGER SLOPE:** Plus or minus. Two control lines, one used per program.

- **INTERNAL:** 40 Hz to greater than 25 MHz or more from 50 mV/cm to 20 V/cm and from signals causing 0.5 cm deflection or more from 5 mV/cm to 20 mV/cm deflection factor, also from line voltage.

**ACCESSORIES FURNISHED:**

- **MODEL 10001A 10:1 Connecting Cable to Model 155A Oscilloscope,** plus an auxiliary single line function, and includes means for selecting any of the preset programs.

**PROGRAM STORAGE:**

Up to 18 different programs may be stored. Additional output connector for control lines is provided on rear panel to permit cascading of programmers for additional program storage if desired.

**PROGRAM SELECTION:**

Front panel switch permits selection of three operating modes: manual, remote, and off.

**MANUAL PROGRAMMING**

Preset programs are selected in any order by momentary contact, illuminated pushbuttons on Programmer front panel.

**REMOTE PROGRAMMING**

Programs may be selected externally by a single contact closure to isolated common line. Control lines must provide 10 ms before programs can be switched. Program control lines are available at rear panel connector. External contact closures and contacts must switch maximum of 300 mA. Program control lines are available at rear panel connector. External contact closures and contacts must switch maximum of 300 mA.

**PROGRAMMING PINS:**

Programs are selected by inserting diode pins in 15 in. 10 in. pin board. Extra diode pins included for one auxiliary function per program.

**POWER REQUIREMENTS:**

- **Model 155A:** Power supplied by Model 155A Oscilloscope. Minus 10 volts for auxiliary function is supplied at rear panel; current for auxiliary function is limited to 50 mA.

**DIMENSIONS:**

- **15% in. wide, 31/2 in. high, 18% in. deep (426 x 89 x 466 mm).**

**WEIGHT:**

- **Net, 12 lbs.**

**ACCESSORIES FURNISHED: Model 10129A Input Con- nection Cable to Model 155A Oscilloscope,** 3 ft. long. Mating connector for remote programming connector.

**ACCESSORIES AVAILABLE: Model 10130A Inter- connecting Cable to Model 155A Oscilloscope,** 10 ft. long. Special length interconnecting cables available upon request.

**PRICE:**

- **$600.00**

- Prices f.o.b. factory

Data subject to change without notice.

**SPECIFICATIONS**

**MODEL 1550A PROGRAMMER**

Programmer provides means for programming vertical sensitivity, vertical positioning, vertical input coupling, sweep time, trigger source, and trigger slope in Model 155A Programmable Oscilloscope, plus an auxiliary single line function, and includes means for selecting any of the preset programs.

**PROGRAM STORAGE:**

Up to 18 different programs may be stored. Additional output connector for control lines is provided on rear panel to permit cascading of programmers for additional program storage if desired.

**PROGRAM SELECTION:**

Front panel switch permits selection of three operating modes: manual, remote, and off.

**MANUAL PROGRAMMING**

Preset programs are selected in any order by momentary contact, illuminated pushbuttons on Programmer front panel.

**REMOTE PROGRAMMING**

Programs may be selected externally by making a single contact closure to isolated common line. Control lines must provide 10 ms before contact closures and contacts must switch maximum of 300 mA. Program control lines are available at rear panel connector. External contact closures and contacts must switch maximum of 300 mA.

**PROGRAMMING PINS:** Programs are selected by inserting diode pins in 15 in. 10 in. pin board. Extra diode pins include one auxiliary function per program.

**POWER REQUIREMENTS:**

- **Model 1550A:** Power required by Model 1550A is supplied by Model 155A Oscilloscope. Minus 12 volts for auxiliary function is supplied at rear panel; current for auxiliary function is limited to 50 mA.

**DIMENSIONS:**

- **15% in. wide, 31/2 in. high, 18% in. deep (426 x 89 x 466 mm).**

**WEIGHT:**

- **Net, 12 lbs.**

**ACCESSORIES FURNISHED: Model 10210A In- terconnecting Cable to Model 155A Oscillo- scope,** 3 ft. long. Mating connector for remote programming connector.

**ACCESSORIES AVAILABLE: Model 10130A Inter- connecting Cable to Model 155A Oscilloscope,** 10 ft. long. Special length interconnecting cables available upon request.

**PRICE:**

- **$600.00**

- Prices f.o.b. factory

Data subject to change without notice.

TIME DOMAIN REFLECTOMETRY IN 75-OHM SYSTEMS

THE -hp- TDR system has a characteristic impedance of 50 ohms because this is the most common impedance for cables and microwave systems. There are, however, other common impedances, and in the communication industries, in television broadcasting, and in community-antenna television systems, 75 ohms is widely used.

Calibration and interpretation of the TDR display are simplest when the characteristic impedance of the TDR system is the same as the characteristic impedance of the system being tested. The reason for this is that, when these impedances are matched, energy reflected from the system being tested is terminated in the proper impedance, and no re-reflections occur at the source.

The -hp- TDR system can now be converted easily for testing 75-ohm systems by means of new 50-to-75-ohm adapters recently developed by the -hp- Colorado Springs Division (Fig. 1).

The adapters are 25-ohm resistors with connectors which are compatible with the -hp- TDR system and with common 75-ohm systems. Fig. 2 is a schematic diagram of a typical TDR setup for testing a 75-ohm cable. Energy returning to the TDR system from the cable is properly terminated in 75 ohms by the series combination of the 25-ohm adapter and the 50-ohm TDR system, thereby eliminating source re-reflections.

Fig. 3 is a photograph of the TDR display for the setup of Fig. 2 with an open circuit at the end of the 75-ohm cable (Z_L = ∞). The display shows an initial mismatch at point 'A' which is the result of the 50-ohm TDR system's being terminated in the 100-ohm series combination of the adapter and the 75-ohm cable. This mismatch does not hinder operation, however. Level 'B' is now the 75-ohm reference level (reflection coefficient $\rho = 0$) and level 'C' is now the open-circuit level ($\rho = 1$). The system can be calibrated to read reflection coefficient directly for 75-ohm operation by adjusting the step control of the TDR plug-in (screwdriver adjustment) so that the difference between levels 'B' and 'C' is ten centimeters on the display when the reflection coefficient control is in the $\rho/cm = 0.1$' position. The reflection coefficient control is then calibrated for 75-ohm systems instead of for 50-ohm systems.

When the -hp- TDR system is operated with a 50-to-75-ohm adapter, the system rise time increases to about 170 picoseconds (instead of 150 ps) and the internal noise level is increased by a factor of 1.5. Other specifications of the TDR system are unchanged. A set of 75-ohm impedance overlays is included with each adapter.

The 50-to-75-ohm adapters may also be used with any signal generator which has a 50-ohm source impedance. The adapter converts the generator into a 75-ohm source so that it can be used in 75-ohm systems without reflections from the source and without any loss of pulse amplitude. If the generator has a calibrated pulse amplitude control, this control retains its calibration when the adapter is used.

Charles A. Donaldson

Charles A. Donaldson graduated from the University of Colorado in 1962 with a BS degree in electrical engineering and business. After graduation, he spent three years in the evaluation and design of pulse generators and oscil-loscope circuitry. Chuck joined -hp- in 1965 as an applications engineer, and since then he has been working with the sampling and pulse-generator design groups of the -hp- Oscilloscope Division in Colorado Springs.

RISE TIME CONVERTERS FOR
SIMPLER TDR TESTING OF BAND-LIMITED SYSTEMS

Time domain reflectometry (TDR) is a simple and accurate way to locate and analyze discontinuities in coaxial cables and microwave transmission systems. The time domain reflectometer applies a fast voltage step to the cable or system under test; some of this energy is reflected by discontinuities or changes in the characteristic impedance of the system; then both incident and reflected waves are displayed on an oscilloscope. Because of the finite velocity of electromagnetic waves, discontinuities at different distances from the step generator appear as individual responses on the display, and their locations can be determined easily. The shape and magnitude of each reflection tell what kind of discontinuity is present: resistive, inductive, or capacitive, series or shunt.

The rise time of the incident voltage step in a TDR system is made as short as possible to permit the system to resolve closely spaced echoes and to measure accurately very small reactive discontinuities. In the Hewlett-Packard Time Domain Reflectometer, which consists of the -hp- Model 1415A Plug-in with the -hp- Model 140A Oscilloscope, the rise time of the incident step is less than 120 picoseconds and the overall rise time of the system is less than 150 picoseconds, equivalent to an upper frequency limit of more than 2.3 GHz.

In some cases, however, such as in testing systems which will be operated only in a limited frequency range, a slower rise time can be useful because it provides test conditions which are closer to the actual operating conditions. A common example is a pulse-transmission system for which the pulse rise time is never faster than a given value, say 5 nanoseconds. If the cable is tested using the fast TDR steps ($t = 0.15$ ns), reflections from many reactive discontinuities can appear which would not be of concern in a system designed for a 5 ns rise time. This extra information then makes it more difficult than necessary to clean up the system. If the rise time of the TDR step is slowed to 5 ns, the cable responds in the same way as in actual use, and only discontinuities which affect the operation of the system appear on the TDR display.

**RISE TIME CONVERTERS**

With a new series of Rise Time Converters (Fig. 1), the fast rise time of the normal TDR voltage step can be slowed to any of five values between 0.5 nanoseconds and 10 nanoseconds.

The converters are low-pass filters which have been designed for minimum departure of the output step from a Gaussian leading edge and for minimum deviation from a 50-ohm output impedance. The Gaussian leading edge makes the TDR test signal a good compromise in shape and frequency components for the range of signals found in actual operating systems. The 50-ohm output impedance is the same as the output impedance of the reflectometer, which means that unwanted re-reflections are eliminated. Stripline mounting has been used to reduce parasitic effects.

Fig. 1. New rise time converters, -hp- Models 10452A to 10456A, slow the rise time of the voltage step in the -hp- TDR system to 0.5, 1.0, 2.0, 5.0, or 10.0 nanoseconds to simplify testing of band-limited systems. Rise time of -hp- system without converters is 0.15 ns. Shown is 5 ns converter, Model 10455A.

Fig. 2. Rise time converter is placed between STEP OUTPUT and SIGNAL IN connectors of -hp- TDR system, which consists of Model 1415A TDR Plug-in for Model 140A Oscilloscope.

NEW TDR APPLICATION NOTE

A new application note, 'Selected Articles on Time Domain Reflectometry Applications,' has just been published. This note contains reprints of five articles on uses of TDR which originally appeared as technical reports, papers, and magazine articles. Titles of the articles are:

1. Time Domain Reflectometry — Theory and Applications
2. Transmission Line Pulse Reflectometry
3. Mechanical Scaling Enhances Time Domain Reflectometry Use
4. Some Uses of Time Domain Reflectometry in the Design of Broadband UHF Components
5. Thermocouple Fault Location by Time Domain Reflectometry.

Copies of the note may be obtained by requesting Application Note No. 75 from the nearest -hp- Field Office or by writing:

Hewlett-Packard
Colorado Springs Division
1900 Garden of the Gods Road
Colorado Springs, Colorado 80907

The converters are inserted between the step output and signal in connectors of the -hp- reflectometer (Fig. 2). Fig. 3a shows a TDR display for a typical cable with the 5-ns converter in place. The discontinuities that appear are only those that might affect the actual operation of the cable. Once these have been identified, the converter can be removed to make the full resolution of the reflectometer available for accurately locating the troublesome discontinuities (Fig. 3b).

For testing low-pass or band-pass systems, the converters can be used as low-pass filters to attenuate the frequency components of the TDR step which are above the highest frequency of interest. The converters are not designed as filters, so their frequency responses are not specified. However, their bandwidths B are related to their nominal rise times t, approximately by the relationship t,B = 0.35.

The new rise time converters can also be used with any fast-rise-time pulse generator with a 50-ohm output impedance in order to increase the rise and fall times of the output pulse without changing its amplitude or impedance level. The output rise time will be given approximately by

\[ t_{r,\text{out}} = \sqrt{t_{r,\text{in}}^2 + t_{r,\text{gen}}^2} - 0.014 \]

where \( t_{r,\text{out}} \) is output rise time (nanoseconds), \( t_{r,\text{in}} \) is nominal output rise time of converter (ns), \( t_{r,\text{gen}} \) is risetime of generator step (ns).

ACKNOWLEDGMENTS

Design of the Rise Time Converters was carried out at the -hp- Colorado Springs Division by a team consisting of Gene A. Ware, who did much of the electrical design, George H. Blinn, Jr. and Daniel A. Paxton, Jr., who designed the packaging, and the undersigned.

—Lee R. Moffitt

SPECIFICATIONS

-hp-
MODELS 10452A - 10456A
RISE TIME CONVERTERS

OPERATION:
These Converters produce a known rise time step when driven by a fast rise time 50-ohm source. The leading edge of the output wave is approximately Gaussian.

RISE TIMES: (10-90% points as measured in 150 ps rise time system) 10454A: 2.0 ns 10452A: 0.5 ns 10455A: 5.0 ns 10453A: 1.0 ns 10456A: 10.0 ns

RISE TIME ACCURACY: ±5% or better

OVERSHOOT: Less than ±3%

OUTPUT IMPEDANCE (dc): 50 ohms when used with 50-ohm generator.

OUTPUT MISMATCH: Less than ±5% reflection of step voltage with rise time equal to nominal rise time of converter.

ALLOWABLE INPUT VOLTAGE: Up to 50 volts, open circuit, from 50-ohm source.

CONNECTORS: GR Type 874

WEIGHT: Net, 8 oz. (227 g)

DIMENSIONS: 4.5 in. long, 2 in. wide, 1.5 in. high (114.3 x 50.8 x 38.1 mm); 10 in. (254 mm) cable attached.

PRICE: -hp- 10452A-10456A Rise Time Converters: $75.00 each.

Prices f.o.b. factory
Data subject to change without notice
A CALIBRATED SUSCEPTRANCE FOR TDR MEASUREMENTS OF SMALL REACTIVE DISCONTINUITIES

TIME DOMAIN REFLECTOMETRY (TDR), which is described briefly in another article in this issue, uses a pulse-echo technique to locate and characterize impedance discontinuities in cables and microwave devices. TDR offers many advantages over single-frequency or swept-frequency techniques, including its ability to locate reflections accurately and its ability to make accurate measurements of characteristic impedance $Z_0$ (provided that a known reference is available for comparison).

One important class of discontinuities consists of those which act like small reactances, either series inductances or shunt capacitances, on a transmission system of otherwise constant characteristic impedance. Fig. 1 is a photograph of a typical TDR display, showing the test step and a reflection from a capacitive discontinuity of about 1.5 pF.

Many common reactive discontinuities have capacitances of less than a picofarad or inductances of less than a nanohenry. In such cases the reflection produced by the basic TDR system is non-ideal, because these small reactances respond only slightly to the non-zero rise time of the test step ($t_r$ for the basic -hp- TDR system is 0.15 ns). Inductance, capacitance, reflection coefficient, and standing wave ratio for these small reactive discontinuities have in the past been measured either by means of approximate TDR techniques or by means of conventional frequency-domain devices like the slotted line. Both of these methods are somewhat tedious and inaccurate.

It is now no longer necessary to resort either to frequency-domain techniques or to approximations when small reactive discontinuities are encountered. The accuracy of TDR measurements of reactive discontinuities can be greatly enhanced by using a calibrated reactance as a comparison standard, and a new calibrated susceptance (Fig. 2) has recently been developed for this purpose. A standard reactive reflection is realized by placing a calibrated variable shunt capacitance in a section of precision air-dielectric coaxial line. The capacitance between center conductor and probe is indicated by a hairline on a dual scale, which is calibrated by a high-resolution bridge technique to read either capacitance or inductance. The calibrated susceptance has a capacitance range of 0 to 1 picofarad, and an inductance range of 0 to 2.5 nanohenries; most reactive discontinuities are in these ranges.

CAPACITANCE AND INDUCTANCE MEASUREMENTS

A measurement of an unknown reactance is made by placing the calibrated susceptance and the unknown in tandem in a conventional TDR setup (Fig. 3). If the unknown reflection is capacitive, the calibrated susceptance is adjusted until it causes an equal negative-going deflection on the display (Fig. 4). The unknown capacitance is then read directly on the capacitance scale of the calibrated susceptance. If the unknown reflection is
inductive, the calibrated susceptance is adjusted to give an equal but opposite deflection, and the unknown inductance is read on the inductance scale. Since the measurement is comparative, the inductance or capacitance of the discontinuity can be measured accurately even if the TDR system has a relatively slow rise time, and even if the rise time changes because of losses in connection lines and cables.

**Reflection Coefficient Calculations**

Reactive discontinuities generally act like lumped inductances or capacitances which do not vary with frequency. In such cases, the reflection coefficient \(\rho\) and the standing wave ratio SWR can be calculated over a wide range of frequencies on the basis of a single measurement of \(L\) or \(C\) made with the calibrated susceptance.

The complex reflection coefficient as a function of the complex frequency \(s\) is:

\[
\rho(s) = \frac{s}{s + \frac{2Z_0}{L}}
\]

where \(s = j2\pi f\) for real frequencies \(f\). The standing wave ratio is:

\[
SWR = \frac{1 + |\rho(s)|}{1 - |\rho(s)|}
\]

The value of the characteristic impedance \(Z_0\), to be used in these formulas can also be determined by a comparison measurement with the calibrated susceptance, which has a characteristic impedance of 50 ohms ±0.1 ohm. Thus all of the important information about reactive discontinuities can be obtained, with an accuracy previously impossible, by adding to the TDR system a single inexpensive device.

**Accuracy**

Capacitance measurements made with the calibrated susceptance are accurate within ±0.005 picofarads or 5% \(C\), whichever is greater, for values of \(C\) between 0 and 0.5 pF. Useful range is 0 to 1 pF but the scale is roughly logarithmic, becoming more compressed at the high end. Thus for values of \(C\) above 0.5 pF, the width of the hairline limits the accuracy with which the scale can be read. However, nearly all of the capacitive discontinuities usually encountered lie between 0.01 and 0.15 pF.

Inductance measurements are accurate within ±0.013 nanohenries or 5% \(L\), whichever is greater, for values of \(L\) between 0 and 1.3 nH. Useful range is 0 to 2.5 nH.

---

**Specifications**

- **hp-874A Calibrated Susceptance**
  - **Capacitance Range:** 0 to 1 pF
  - **Accuracy:** ±0.005 pF or 5% \(C\), whichever is greater, \(0 < C < 0.5\) pF
  - **Inductance Range:** 0 to 2.5 nH
  - **Accuracy:** ±0.013 nH or 5% \(L\), whichever is greater, \(0 < L < 1.3\) nH
  - **Characteristic Impedance:** 50 ohms ±0.1 ohm
  - **Connectors:** GR874
  - **Line Length:** 17.4 cm
  - **Weight:** Net, 1 lb. (0.45 kg); Shipping, 2 lb. (0.9 kg)
  - **Dimensions:** (Maximum envelope): 7⅛ in. long, 2⅛ in. wide, 2⅛ in. high (191 x 73 x 64 mm)
  - **Price:** $250.00

Prices f.o.b. factory

Data subject to change without notice
STABILIZED PLUG-IN UNIT
(continued from back cover)

scale measurements. In addition, the plug-in amplifier was designed with a wide dynamic range (+50 cm) allowing detailed examination of any part of a waveform with high magnification, as shown in the photos of Fig. 6.

WIDE RANGE OFFSET

A separate Offset control on the plug-in enables input dc levels to be bucked out. It is thus possible to retain dc coupling while the waveform is magnified for high sensitivity. For example, small mechanical movements sensed by strain gages can be examined on the oscilloscope, using the offset to buck out any dc unbalance component of the signal, the high sensitivity to provide detail in the waveform, and the dc stability to provide confidence in the results. Or, it is possible to make such measurements as the determination of both the ac and dc components of small base currents in transistor circuits (using the series resistor current-measuring technique).

The Offset control enables the zero voltage level to be displaced as much as ±200 screen diameters (±2000 cm) from center screen on the most sensitive range and by at least ±50 cm on less sensitive ranges. The offset voltage is stable within 20 μV/hr and changes less than ±100 μV in a temperature change of 0 to 55°C.

DIFFERENTIAL INPUT

Other measures were taken in the design of the new plug-in to enhance the usefulness of the 50-μV/cm sensitivity. For example, the input is differential. The plug-in thus can be driven by balanced sources and it has excellent rejection of common-mode signals, 80 dB from dc to 60 Hz for instance. The common ground at the input may be disconnected from the internal circuit ground so that it can be driven by a common-mode voltage from a low source impedance to increase the common-mode input impedance, thus reducing the effects of unbalance source impedance. A front-panel control enables optimization of amplifier gain balance for best common-mode rejection.

Common-mode signals up to ±7.5 V have no effect on the wide dynamic range of the plug-in. Common-mode signals higher than that affect dynamic range by driving the amplifier towards a non-linear operating point but the plug-in is still capable of dynamic ranges greater than the ±20 cm of conventional oscilloscopes. For example, a dynamic range of typically ±34 cm is possible with a CM voltage of ±10 V.

To permit the use of a differential input, the offset and drift correction voltages are applied to the amplifier independently of the input. The offset may thus be used in differential measurements. (Transients at the input during the stabilization interval have been minimized by the use of a high-quality chopper relay, with good isolation from the drive signal, to decouple the input during stabilization).

Fig. 3. Strip chart recording shows insensitivity of plug-in stabilized dc level to variations in temperature. At start of recording scope was in environmental chamber at 55°C. Chamber temperature was reduced to −10°C over period of 1 hour and then held at that temperature for remaining ½ hour of test. Trace deviates less than ±20 μV during test.

Fig. 4. Bandwidth filter improves resolution of low-level, low-frequency waveforms. Photo of 500-Hz sine wave at top was made on 50-μV/cm range with full bandwidth (300 kHz at 50 μV/cm). Lower photo is of same waveform with bandwidth cut off at 5 kHz.

DESIGN LEADERS

PETTIT

Jim Pettit joined -hp- in 1962 following graduation as a BSEE from Utah State University. Two years later, he earned his MSEE degree from Stanford University in the -hp- Honors Cooperative Program. At -hp-, Jim initiated the development engineer on the 1754A Four-Channel Amplifier for the Model 175A Oscilloscope. Since that time, he has been associated with 140A/141A Oscilloscope program. He is at present a project leader in that group.

SCHROATH

Tom Schroath spent four years in the U.S. Air Force and two years as an air-conditioning engineer before earning his BSEE degree from Brigham Young University in 1963. Following graduation, he worked with an aircraft company and then joined -hp- in 1965 as a product designer on the 155A/1550A Programmable Oscilloscope. At present, he is a product designer in low frequency Oscilloscopes.
plug-in by limiting the passband to no more than that required by the signal. The filter has four positions, cutting off at 400 kHz (300 kHz on the 50 μV/cm range), 100, 25, and 5 kHz. Using the filter to reduce noise in the display improves the resolution of the measurement (Fig. 4).

STABILIZER OPERATION
The dc stabilizer in the new plug-in is similar in concept to the stabilizer in the -HP- Model 155A Programmable Oscilloscope, described on page 4. Normally, the stabilizer corrects for drift 3 times per second but with slow sweeps or in the absence of sweep operation, the stabilizer is self-triggering at a rate of 1/2 times per second (the trace is blanked during the stabilization interval). The plug-in may therefore be used independently of a time base. Stabilized X-Y displays are thus possible using a pair of these plug-ins to drive both the horizontal and vertical channels of a scope.

Automatic stabilization in the absence of a sweep also enables single-sweep measurements, with full confidence that no errors will creep into the measurement because of vertical amplifier drift during the waiting time before the sweep is triggered (there is only a 1% probability that the stabilizer and concurrent sweep hold-off will be cycling at the instant of triggering).

AMPLIFIER OUTPUT
A front-panel output connector is provided so that the plug-in may also serve as a sensitive stabilized preamplifier for other equipment. Maximum gain from the input to the front panel jack is 20,000. The signal at the output jack is periodically interrupted by the stabilization switching signals that ground and rezero the amplifier but these vary with the amplifier sensitivity.

SPECIFICATIONS

-HP-
MODEL 1407A
DIFFERENTIAL AMPLIFIER

DEFLECTION FACTOR (SENSITIVITY): 50 μV/cm to 20V/cm in 1, 2, 5 sequence. Vernier provides continuous adjustment between ranges and extends deflection factor to at least 50 V/cm. Attenuator accuracy is ±3%.

AMPLIFIER OUTPUT: Approximately 1 V/cm, dc-coupled, single-ended; dc level approximately 0 V, dynamic range is ±5 V. Output impedance less than 100 ohms. With stabilizer operating, output signal is dc-stabilized and contains 5-ms transients at stabilizer repetition rate.

BANDWIDTH:
Maximum Upper Limit: 20 V/cm to 200 μV/cm ranges — 400 kHz, (0.9 μs risetime) 50 μV/cm range — 300 kHz. Upper limits of 100, 25, and 5 kHz selectable with front panel switch on all sensitivities. Lower Limit: dc with input ac coupled; 2 Hz with input ac coupled.

DRIFT:
Long-term drift: Less than ±0.2 cm or less than ±50 μV, whichever is greater, per 200 hrs.

Temperature drift: Less than ±0.2 cm or less than ±50 μV, whichever is greater, over temperature range of 0°C to 55°C. Drift correction occurs at 3 Hz for 50 ms/cm sweeps and faster, and 1.5 Hz on 0.1 s/cm sweeps and slower.

RANGE TO RANGE SHIFTS: dc stabilization maintains fixed baseline reference within ±1 cm on CRT over entire range of sensitivity after 3-minute warmup.

POSITIONING: Baseline can be positioned to ±10 cm by continuous positioning or in calibrated steps of 0, ±5 cm, and ±10 cm. Calibrated positioning accuracy is ±3%.

DC OFFSET: Uncalibrated dc offset is provided in both single-ended and differential operation. Maximum amount of offset obtainable, referenced to input, varies with sensitivity approximately as follows: ±0.1 V at 50 μV/cm, increasing to ±0.5 V at 10 mV/cm, to ±5 V at 100 mV/cm, to ±50 V at 1 V/cm, and to ±600 V at 20 V/cm. Offset dc drift is less than ±20 μV/hr at constant ambient temperature or less than ±100 μV for ambient temperature change of 0°C to ±55°C.

DIFFERENTIAL INPUT: May be selected on all attenuation ranges; offset capability is maintained in differential operation.

COMMON MODE REJECTION: ±5 V peak input, 50 μV/cm to 50 mV/cm ranges dc-coupled: dc to 60 Hz — 90 dB, 60 Hz to 10 kHz — 60 dB.

Maximum Common-mode plus Signal Input (without overload): 50 μV/cm to 20 mV/cm — ±10 V peak, 50 mV/cm to 2 V/cm — ±100 V peak, 5 V/cm to 20 V/cm — ±600 V peak.

DYNAMIC RANGE: Dynamic signals up to ±50 cm of deflection can be displayed without distortion.

INPUT IMPEDANCE: 1 megohm shunted by 90 pF, constant on all attenuator ranges.

MAXIMUM INPUT: 600 volts (dc ± peak ac).

X-Y OPERATION: Two 1407A's can be used to give stabilized X-Y presentations. Internal 'X-Y NORMAL' switch enables plug-ins to synchronize stabilizing cycles.

TIME BASE COMPATIBILITY: Model 1407A can be used directly with Models 1422A and 1423A Time Bases; 1420A's below serial 441-01326 and 1421A's below serial 545-00651 must be modified for use with 1407A (use kit 01420-69502 for 1420A and kit 01421-69501 for 1421A).

WEIGHT: Net, 5 lbs. (2.3 kg). Shipping, 7 lbs. (3.2 kg).

PRICE: $625.00.
Price f.o.b. factory.
Data subject to change without notice.

A DC-STABILIZED OSCILLOSCOPE PLUG-IN
WITH 50-μV/CM SENSITIVITY

Freedom from dc drift overcomes one of the most troublesome effects in making oscilloscope measurements of transducer output and other small signals.

Many important waveform measurements, such as transducer measurements, require accurate retention and display of dc levels. Because of the inherent drift of dc-coupled amplifiers, oscilloscope measurements concerned with dc levels have often been inaccurate, or at least difficult. For this reason, the sensitivity of dc-coupled oscilloscopes has been limited, the state-of-the-art permitting a typical deflection factor of 100 μV/cm.¹

Drift has now been reduced to negligible levels by a dc stabilizer in a new 100-kHz vertical channel plug-in for two of the -hp- Oscilloscopes (Models 140A and 141A). Because of the reduction of drift, it was practical to make the minimum deflection factor of the plug-in 50 μV/cm, a sensitivity well-suited for transducer monitoring and for other low-level measurements that require retention of a dc reference level.

With drift practically eliminated, the trace stays in the desired screen position indefinitely. Sensitive oscilloscope measurements of dc levels therefore can be made with confidence with the new plug-in (-hp- Model 1407A).

DC STABILITY
Long term stability of the new plug-in is illustrated by the photos of Fig. 2, made while the plug-in was operated with a deflection factor of 50 μV/cm in the dc-stabilized mode. The photos were taken 65 hours apart and show no detectable drift during this time interval. The new plug-in operated in the 140A/141A Oscilloscopes has a long-term drift of less than ±20 μV or ±0.2 cm, whichever is greater, per 200 hours of operation. This is equivalent to only 0.1 μV/hr.

The plug-in has low sensitivity to temperature variations. The recording of Fig. 3 was made with a typical instrument during an ambient change from +55°C to -10°C in a 1½ hour time interval and indicates a drift of less than ±20 μV, once more showing that measurement uncertainties resulting from drift in low-level measurements are practically eliminated by this plug-in. Ambient temperature variations throughout a range from 0 to 55°C cause dc drift of less than ±50 μV or ±0.2 cm, whichever is greater.

CALIBRATED POSITIONING
The stabilized dc performance of the plug-in makes it feasible to use calibrated vertical positioning. The positioning circuit was designed to permit either continuous or stepped control, stepped control permitting the zero level to be displaced from center screen by ±5 or ±10 cm with an accuracy of 30% for more convenience in expanded measurements.

(continued inside on page 14)