TEKSCOPE

SEPTEMBER 1971

CLEAR

simple operation

$|x|^y$

$\sqrt{x^2+y^2}$

$+$

one key programming

$=$

no need for complex computer language

CLEAR

REMOTE

DEFINE

● $f(x)$ ●

- a programmable desktop calculator
- the R1340 data coupler
- the 7D14 counts current to minimize circuit loading
- regulated power supplies as operational amplifiers

Cover: The front cover bears a message —did you see it? It says, "Simple operation plus one key programming equals no need for complex computer language." It means it doesn't take an expert to use the Scientist 909.

the TEKTRONIX® Scientist 909:

a powerful, programmable desktop calculator

By Dave Takagishi, Electronics Engineer
Calculator Products Division

For the first time, it is unnecessary to learn a complicated machine language in order to operate a powerful desktop calculator. The TEKTRONIX Scientist 909 (and its companion, the Statistician 911) speaks the universal language of mathematics, substituting a simple keyboard language for complicated machine languages in scientific calculators.

This new calculator incorporates a powerful keyboard that is unmatched for simplicity of operation.

OPERATION BY MATHEMATICAL EXPRESSION

Mathematical expressions are entered directly as they would be written in equation form, using parenthesis if desired. For example, to solve the equation

$$(a - b)^{(c \times d)} \times \frac{(e + f)}{(g - h)} =$$

where a,b,c. . . .h are variables of the user's choosing.

Press:

$\boxed{\text{CLEAR}}$ $\boxed{(}$ a $\boxed{-}$ b $\boxed{)}$ $\boxed{|x|^y}$ $\boxed{(}$ c $\boxed{\times}$ d

$\boxed{)}$ $\boxed{\times}$ $\boxed{(}$ e $\boxed{+}$ f $\boxed{)}$ $\boxed{\div}$ $\boxed{(}$ g

$\boxed{-}$ h $\boxed{)}$ $\boxed{=}$ **answer**

ONE-VARIABLE FUNCTION KEYS

Trig, Log, x^2, $\frac{1}{x}$, $\sqrt{x}$, and other one-variable function keys operate directly on the number in the display. For example, to find:

$$\sinh \frac{1}{(\ln \cos a)^2} \qquad \text{for } a = 36.5°$$

Press:

$\boxed{\text{CLEAR}}$ $\boxed{\text{DEG} \bullet \; \bullet \text{RAD}}$ **36.5** $\boxed{\cos x}$ $\boxed{\ln x}$ $\boxed{x^2}$ $\boxed{\frac{1}{x}}$

$\boxed{\text{hyper}}$ $\boxed{\sin x}$

Read the answer, **+644839326.7**

TWO-VARIABLE FUNCTION KEYS

Two-variable function keys such as $\boxed{|x|^y}$ and $\boxed{\sqrt{x^2+y^2}}$ operate on the display as the first variable x, and on the next entry or expression as the variable y. For example, to find:

$$a^b + \sqrt{c^2 + d^2 + f^2}$$

Press:

$\boxed{\text{CLEAR}}$ a $\boxed{|x|^y}$ b+c $\boxed{\sqrt{x^2+y^2}}$ d $\boxed{\sqrt{x^2+y^2}}$ f

$\boxed{=}$ **ans.**

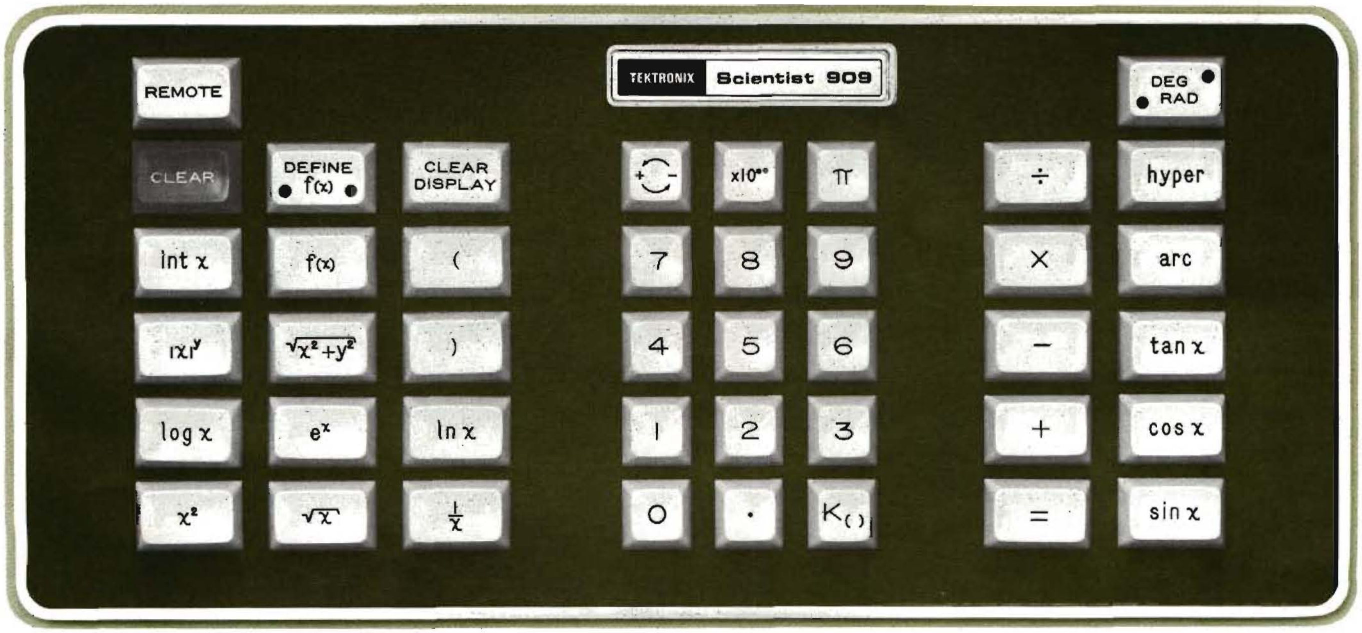
MEMORY STORAGE

The TEKTRONIX Scientist 909 has memory storage and recall that is extremely easy to operate. Any number in the display can be stored and identified with a two digit constant by pressing $\boxed{=}$ $\boxed{K_{()}}$ followed by the two subscript digits, 00 through 25.

For example, to display 17 and store it in register number 21

Press:

$\boxed{\text{CLEAR}}$ **17** $\boxed{=}$ $\boxed{K_{()}}$ **21**



The powerful Scientist 909 keyboard provides access to more mathematical functions than any other machine with fewer total keys.

The stored number (17 in the above case) can be recalled to the display again and again at any later time by pressing $\boxed{\text{K()}}$ and the two subscript digits (21 in the above case). These recalled numbers can be used in all keyboard operations just as new digit entries are used.

Example:

$$\left[(3 \times \mathbf{K}_{00} + \mathbf{K}_{01}{}^2) \times 7 + \sin \mathbf{K}_{\dot{0}0}\right] \times \mathbf{K}_{02} = \mathbf{K}_{03}$$

Indirect subscript addressing allows the Scientist to automatically sequence and operate on all stored constants. The number in the display is stored and identified with indirectly addressed subscripts by pressing $\boxed{=}$ $\boxed{\text{K()}}$ $\boxed{\text{K()}}$ followed by two digits.

Example: Let $\pi =$ constant indirectly addressed as K_{17}. Pressing $\boxed{\pi}$ $\boxed{=}$ $\boxed{\text{K()}}$ $\boxed{\text{K()}}$ 21

will label $K_{17} = 3.141592654$ if $K_{21} = 17$ (from previous example). Subsequently whenever pressing $\boxed{\text{K()}}$ $\boxed{\text{K()}}$ 21, π will appear in the display.

PROGRAMMING

A "learn program" key is included on the Scientist 909 keyboard. While this key, $\boxed{\text{DEFINE} \bullet f(x) \bullet}$, is activated, the calculator is in a learn mode in which every key stroke (up to 256 steps) is memorized. These memorized key depressions may be automatically repeated at any time by pressing the key called $\boxed{f(x)}$ (thereby eliminating repetitive keying sequences). This feature may be used to define your own special function key. For example, to define your own special inverse Gudermannian function key where

$$f(x) = \ln \tan \left(\frac{x}{2} + \frac{\pi}{4}\right)$$

Press:

$\boxed{\text{DEFINE} \bullet f(x) \bullet}$ $\boxed{\div}$ 2 $\boxed{+}$ $\boxed{\pi}$ $\boxed{\div}$ 4 $\boxed{=}$

$\boxed{\tan x}$ $\boxed{\ln X}$ $\boxed{\text{DEFINE} \bullet f(x) \bullet}$

Now use the $\boxed{f(x)}$ key like any other function key operating on one variable.

In addition to the above type of programming, which is essentially linear (no branching or looping) the TEKTRONIX calculator family includes an "add on" programmer, the 926.

This programmer unit provides the branching and looping features of a small computer and will store 512 program steps in its internal MOS storage. The contents of this storage can be transferred to a tape cartridge which installs in the Programmer. Each cartridge holds up to 10 blocks of these 512 step programs. The Programmer 926 combined with a TEKTRONIX Scientist 909 or Statistician 911 Calculator can accomplish most tasks a scientific computer can, with the exception of those tasks requiring very large data storage.

APPLICATIONS OF THE SCIENTIST 909

Applications for the TEKTRONIX Scientist 909 span virtually every discipline and profession where mathematics is used. Scientists, engineers, educators, statisticians, surveyors, metallurgists, astronomers, bankers, merchants, designers — all can be freed from the confusion of machine language and the tedium of paper and pencil arithmetic to spend their valuable time on more creative processes.

ANALYTICAL INSTRUMENTATION SYSTEMS

Application requiring control and readout of analytical instruments may frequently be handled by a modern programmable calculator instead of a high cost mini-computer. The laboratory may already own (or plan to buy) a scientific calculator for individual desk use, and would like to avoid the purchase of a larger, faster machine unless the application really requires it.

A good example of an application that can be handled by a programmable calculator is the Gas Chromatograph/Mass Spectrometer (GC/MS). This type of instrumentation system has been successfully controlled and monitored by a mini-computer, is relatively low speed, and therefore well suited to calculator control.

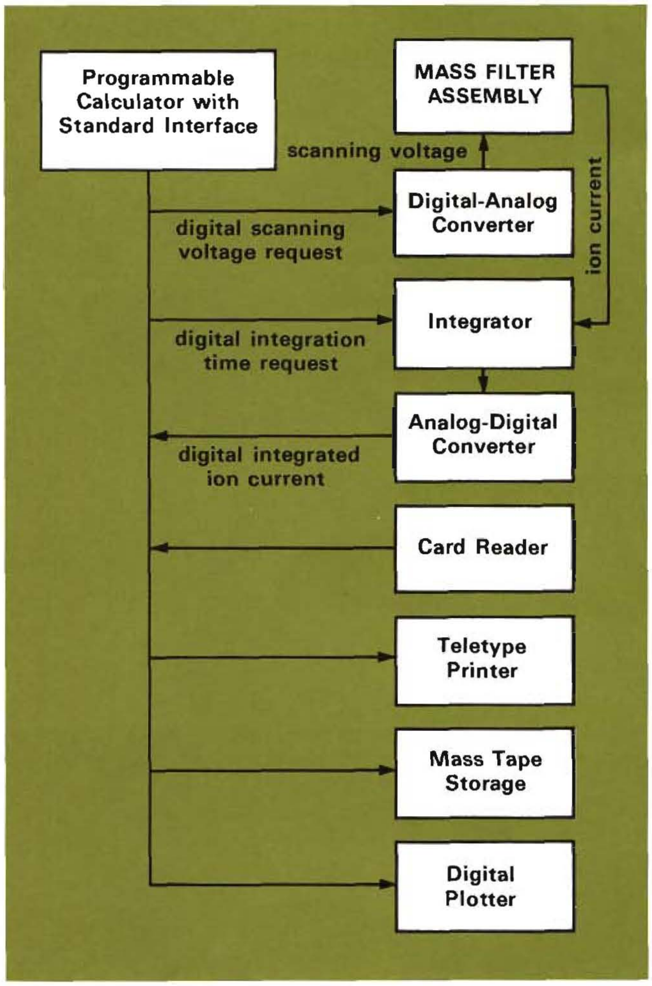
The heart of the GC/MS is a mass filter assembly. Gas samples for mass analysis are inserted into the ionizing chamber and forced through the filter by accelerating electrodes.

The mass of any ions that successfully pass through the filter is directly proportional to the applied scanning voltage. Ions passing through are detected by a photo-multiplier whose output current is fed to an integrator.

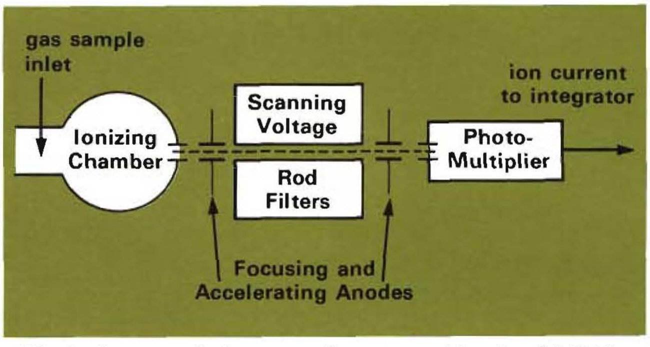
GC/MS operation begins with a calibration cycle program. A reference compound with a few known mass spectrum lines is placed in the inlet. The mass of these known lines can be entered from the keyboard or by punched card. The scanning voltage is then incremented, and at each step the ion current is determined. Signal to noise can be optimized by programming the integration time as a function of signal strength, since the integrated current is divided by the integration time to obtain the actual current.

The scanning voltage of each ion current peak is combined with the known mass of each peak and interpolated to produce a calibration curve which is stored for later use.

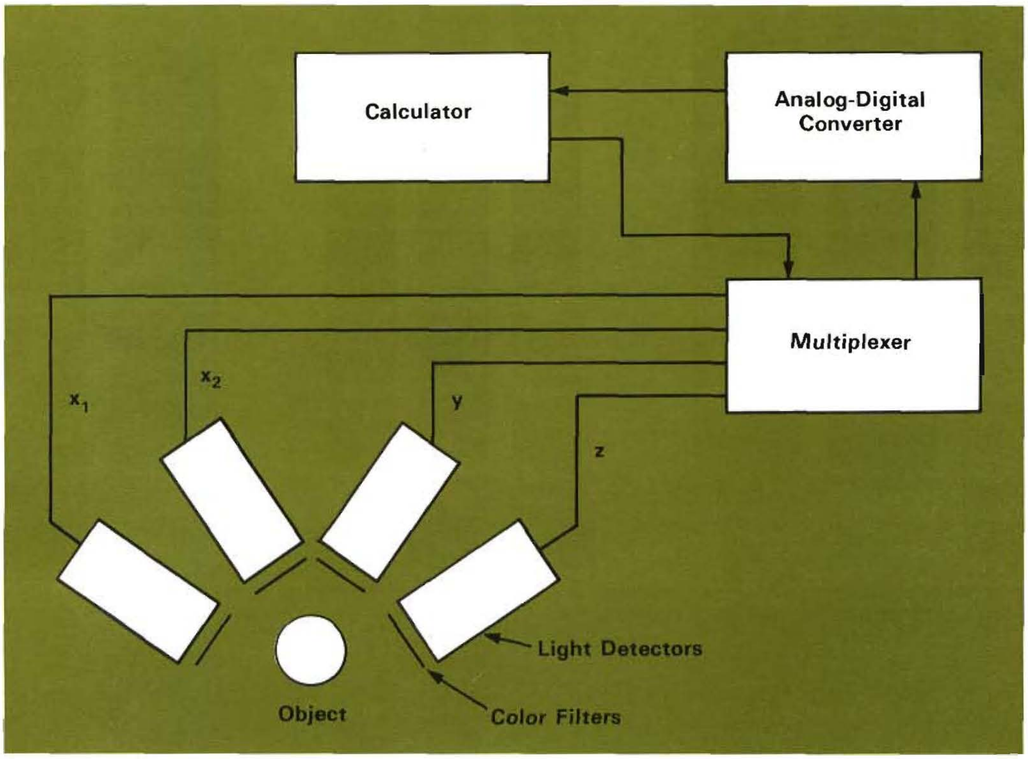
After calibration, the unknown sample is placed in the inlet. The scanning voltage is stepped from the lowest to the highest value required, stopping at each step while the calculator adjusts the integration time for best signal to noise. The resolution (separation of voltage steps) can be constant, or variable, within a scan. Each voltage step is corrected by the calibration curve referred to earlier. The integrated current divided by the integration time gives the amplitude of the mass corresponding to each voltage step. A plotter records the resulting spectrum as it is produced and stored on tape for future use. The voltage and amplitude of each peak can be found mathematically and printed out on a teletype or printer.



Simplified block diagram of a Gas Chromatograph/Mass Spectrometer.



Block diagram of the mass filter assembly of a GC/MS.



Simplified block diagram of a colorimetry system.

COLORIMETRY

Programmable calculators have been successfully applied to the measurement of color. A typical system is illustrated at right. Light from the object being measured passes through color filters which divide it into basic colors. These are measured with photo detectors whose outputs are scanned by a multiplexed analog-to-digital converter and sent to the calculator. The calculator performs the following calculations:

$$x = (x_1 + x_2) \qquad \frac{y}{x+y+z} = K_{00}$$

$$\frac{x}{x+y+z} = K_{01} \qquad \frac{z}{x+y+z} = K_{02}$$

This computes and stores three numbers that uniquely identify the color.

The system referred to has been used to color match mink fur for repair of coats, replacing an experienced "mink matcher" with a calculator and a less experienced technician.

This system could be applied to color matching in process control. More multiplexer stations could be added to monitor the color of material and dyes going into a process, the color of material coming out, and a desired color sample. Using the information and a programmed knowledge of color mixing, the calculator could interface with valves controlling the dye inputs to match the output with the sample.

OTHER CALCULATOR PERIPHERALS

The utility of TEKTRONIX Calculators is enhanced with a family of peripherals including a digital strip printer, X-Y plotter, punched card reader and magnetic tape storage devices.

Dave Takagishi is one of the original 10 people responsible for development of the Scientist 909. He has been involved with design and implementation of the calculator from pre-breadboard through its production phase.

Dave is a graduate of San Jose City College and worked four years with Fairchild Semiconductor before joining Cintra in 1968. He became a Tek man in May, 1971, when Tektronix bought the Cintra assets.

Dave is 31 years old and married. His interests outside of calculators include golf and photography.

the R1340 Data Coupler

Complete testing of today's complex integrated circuits, printed circuit boards and other such products is a formidable task. To accomplish it, an equally formidable array of signal sources, power supplies, test fixtures and measuring devices are brought together to form automatic measurement systems. Some of the more sophisticated systems also include a computer.

How well we accomplish the testing task depends, to a large extent, on the ease with which the various elements of the system "communicate" with each other and with the computer.

The new TEKTRONIX R1340 Data Coupler could be called a "systems communication expert". The coupler is designed to multiplex data inputs and outputs of various system components to a common TTL data bus. This data bus can, in turn, be interfaced to a computer, data receiver, or data source. Using optional interface circuit cards, nearly any form and format of data can be applied to, or acquired from, the R1340. The unit can perform such functions as input/output level conversion, serial-to-parallel and parallel-to-serial format conversion and temporary storage of data in latching registers.

The unit is designed primarily for use with TEKTRONIX Automated Measurement Systems. However, it can serve just as well as an important building block in your system. Here are some of the chores it can perform:

- Provide the interface to bring your system under computer control.
- Couple the system to data-logging equipment.
- Interface the computer to registers, DVMs, test fixtures and other programmable instruments in the system.
- Digitize high-speed waveforms for computer analysis.

The R1340 consists of a rackmount cabinet with power supply, space for twelve plug-in cards and eighteen wired connectors providing a total of 648 input/output lines. Combinations of from one to twelve plug-in cards within the R1340 perform the various functions desired.

The block diagram in Fig. 1 shows four major application areas using the R1340. (Type numbers of TEKTRONIX instruments used in our automated measurement systems are shown in the appropriate blocks.) Although not apparent from the diagram, data logging from a system using the 230 and 240 can be performed through the R1340 without using the computer. Data is logged on computer-compatible magnetic or punched paper tape.

INTERFACE OPTIONS

Since different applications or functions require different interfaces, we should discuss the various interface options available for the R1340 before getting into specific applications. An option consists of a package which includes one or more plug-in circuit cards, interconnecting cables and an instruction manual. Several options (up to a total of 12 cards) can be accommodated in the unit at one time. There are ten options presently available with several more in the design stage. Briefly they are:

1. R1340 to PDP-8/L Computer Interface
2. R1340 to IBM 1800 Computer Interface
3. R1340 to R230/R240 Interface
4. R1340 to Paper Tape Punch/Reader Interface
5. R1340 Data Logging Interface
6. 16-bit Input/16-bit Output Interface
7. 32-bit Input Interface
8. 32-bit Output Interface
9. R568 to R1340 Waveform Digitizing Interface
10. Vertical and Horizontal Signal References Interface.

The waveform digitizing and the signal reference interfaces merit special consideration since they bring new capability to automated testing.

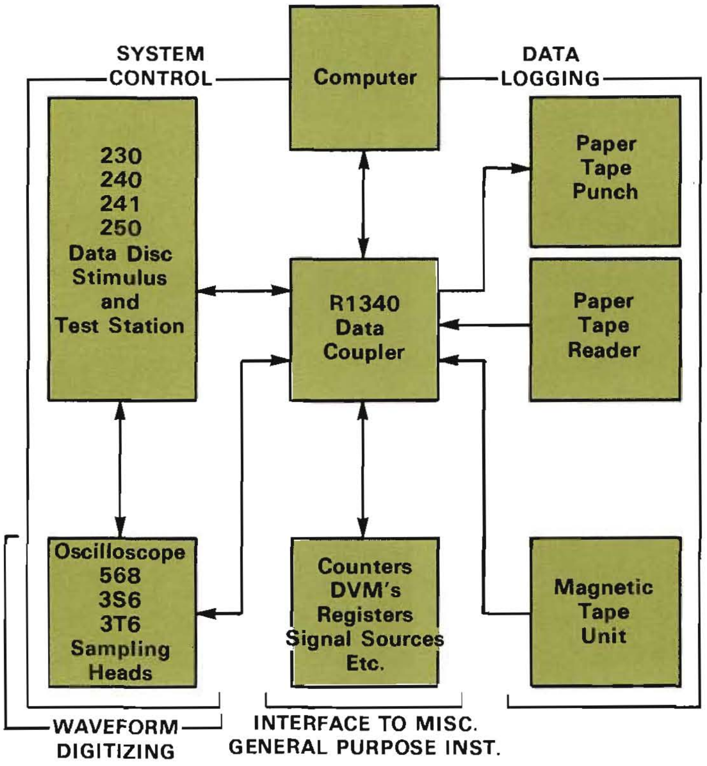


Fig. 1 Four major application areas of the R1340 include system control, data logging, waveform digitizing and interfacing to many general purpose instruments.

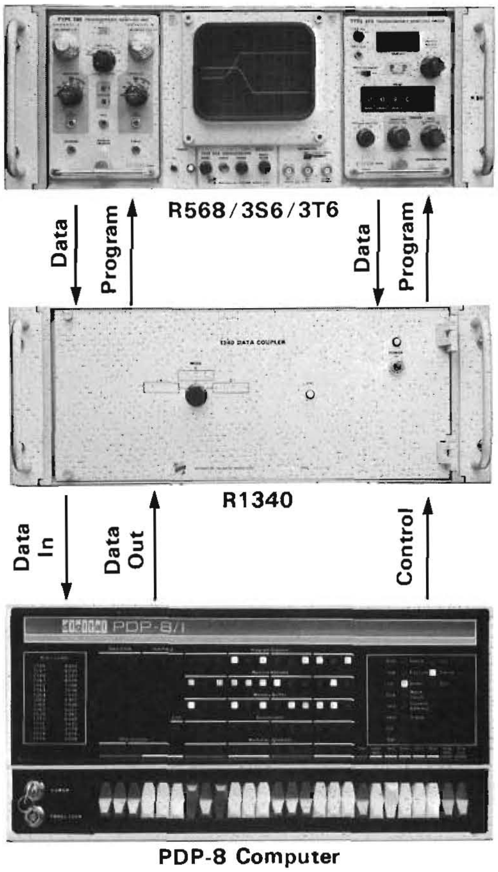


Fig. 2 A basic waveform digitizing system consisting of the R1340 Data Coupler, an R568/3S6/3T6 Oscilloscope and a DEC PDP-8 minicomputer.

WAVEFORM DIGITIZING

Waveform digitizing, as the name implies, is a means of converting an analog waveform into its digital equivalent. A computer can then be used to measure whatever parameters are desired such as risetime, pulse width, period, or delay between two pulses. Smoothing or noise reduction can be performed to improve measurement accuracy or to extract a low-level signal from noise.

A block diagram of the basic waveform digitizing system is shown above. It consists of the R568/3S6/3T6 programmable oscilloscope, the R1340 and a PDP-8 minicomputer. A total of seven interface cards reside in the R1340. Three cards are required to interface the computer to the R1340, two cards program the R568 and plug-ins, and the remaining two cards are the digitizer interfaces.

One of the digitizer interface cards has two, 10-bit A-D converters, buffers and control logic to convert the 3S6 channel A and B analog information to binary numbers. These numbers are then made available to be read by the computer under software control.

The other card consists of a buffered 10-bit D-A converter which outputs an analog voltage to the 3T6 to determine the time position of a particular sample. It, in essence, generates the analog ramp for the sampling sweep unit. Both cards rely on computer-generated operating instructions.

WAVEFORM DIGITIZER LOGIC

Three operating modes are available for the waveform digitizer. One is called the SCAN, SAMPLE and HOLD mode, wherein the horizontal sweep is stepped across the screen in 1023 increments. This is like the normal sampling scope operation with one important difference. The sweep is prevented from going to the next time position until the data in one or both of the A-D buffers has been read by the computer. This enables the memory location itself to be used as a time position pointer for that data word.

The second operating mode is called PARK, SAMPLE and HOLD. In this mode, the self-incrementing operation of the register driving the D-A converter is disabled and now becomes a simple 10-bit latch which will accept a data

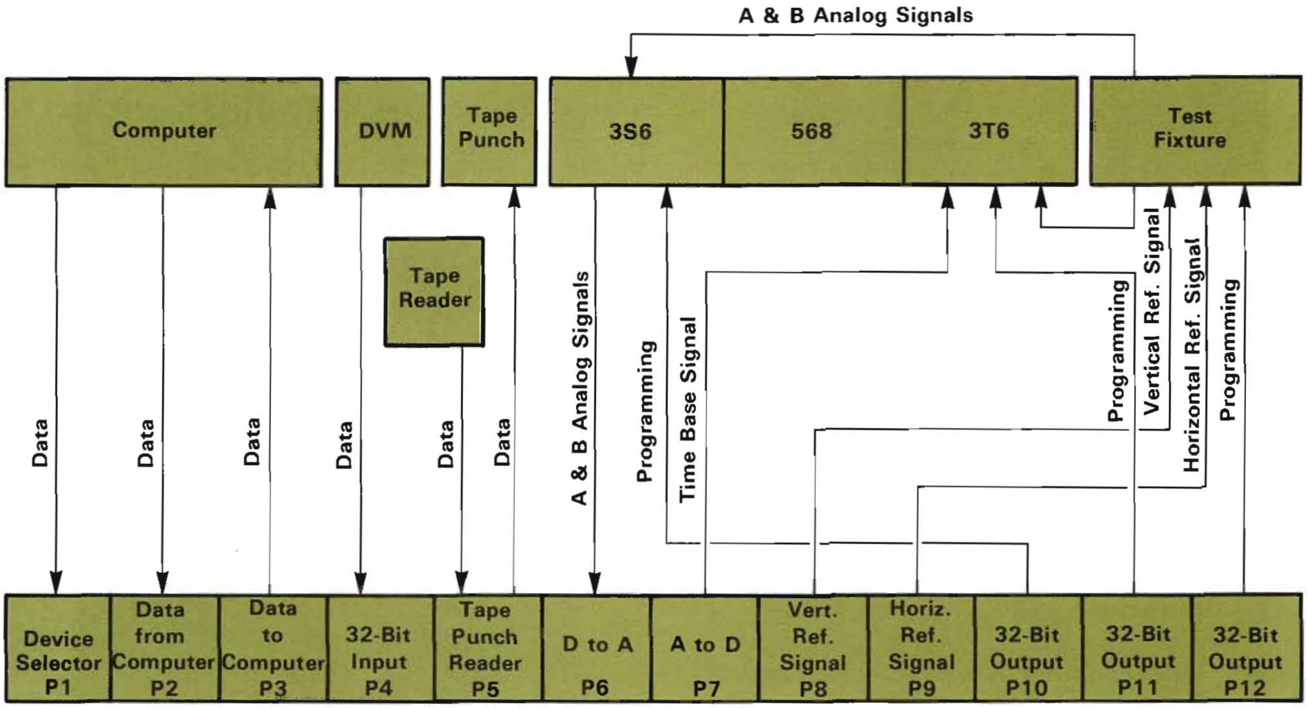


Fig. 3 Block diagram of a computer-controlled system which includes waveform digitizing and vertical and horizontal reference signals.

word from the computer. The sampler now makes samples at any one of 1023 time positions on the waveform being measured. Any number of samples desired may be read at that single time location by the computer. A new word may be loaded into the D-A register at any time to select a new time position or the mode may be changed back to SCAN, SAMPLE and HOLD. Thus, any segment or segments of a waveform may be stored in core, or multiple measurements at single-time locations may be stored for use in noise reduction.

The third operating mode is called SCAN, FREE RUN. Here the sweep D-A operates in the self-increment mode and the logic loop requiring the computer to read the A-D converter before allowing the D-A to move to the next time position, is disabled. This mode is most useful for initial setup of the package since in the SCAN, SAMPLE and HOLD mode, only one sweep can be seen, and in the PARK, SAMPLE and HOLD mode, only a single dot can be seen on screen.

Any of those three modes can be entered via computer, while the SCAN, FREE RUN mode may also be entered by a front panel control on the R1340.

APPLICATION CONSIDERATIONS

Of the two data acquisition modes discussed, the SCAN, SAMPLE and HOLD mode offers the greatest flexibility in the range of measurements that can be made. However, it requires up to 2048 words of computer memory to store a complete sweep of data from channels A and B. Since most standard minicomputers have only 4K of memory, the user would almost certainly have to add storage capacity to accommodate a comprehensive program package.

It should be apparent that a great deal of redundant information is contained in a typical oscilloscope display. This leads to a second type of acquisition routine which uses the PARK, SAMPLE and HOLD mode. It requires somewhat more sophisticated software but has several important advantages over the first method.

Prior to the data acquisition stage, the user specifies the type of measurement and what points must be measured on the waveform. For example, suppose we want to measure risetime, amplitude and channel A to channel B delay. These measurements require 0%, 10%, 50%, 90% and 100% points of the pulses on both channels to be stored.

A 0% zone is established by parking the sweep at the left edge of the screen and then reading the channel A and B samples. Next, the sweep is parked a few tens of increments to the right, samples read and compared with the first ones. A zero slope area is quickly found by stepping the time position around as necessary. Once a suitable time-position is established, several readings of the A-D converters at that one time position are averaged and then stored as the 0% locations for channels A and B. Similarly, to locate the 100% time and amplitude, the time position (sample) is programmed to the right edge of the screen then moved to the left or backward in time. Now the 50% voltage value is calculated and the sampling time position moved around until this value, or something near it, is found. Multiple A-D readings are then made at adjacent time positions with each time location given some average value of these readings. These noise-reduced values are then used to calculate the time position of the "smoothed" 50% crossing. The 10% and 90% points are found in a similar way.

The required parameters of the two vertical channels are stored in only 20 memory locations (10 amplitude and 10 time) compared to 2048 memory locations for storing the complete waveform. Furthermore, the noise level and, hence, repeatability of the measurement have been greatly enhanced, and the whole process carried out with fewer than 100 samples, depending upon the number of samples used for noise reduction purposes.

VERTICAL AND HORIZONTAL SIGNAL REFERENCE INTERFACE

Designed to be used with the Waveform Digitizing Interface, a programmable time standard and programmable voltage standard are available as plug-in cards for the R1340. These standard signals are made available at the system measurement fixture so that all combinations of sampling heads, channel A or B, and 3S6 sensitivity will have a calibration coefficient tabulated in the computer memory. Similarly, a calibration table can be stored for all sweep rates of the 3T6 between 500 ms/div and 1 ns/div. Time and amplitude measurements can thus be made to better than 1% with traceability to NBS.

COMPUTER-CONTROLLED WAVEFORM DIGITIZING SYSTEM

Pictured on the preceding page is a block diagram of a computer-controlled system using the Waveform Digitizer and the Vertical and Horizontal Reference interfaces. The computer has master control over all of the cards in the coupler via Pl, the Device Selector.

The Device Selector takes data from the computer, converts it from a binary number to a selection code and uses it to select one or more cards in the data coupler. The selected card immediately transfers data to or from the interface bus in the R1340. The computer generates a strobe pulse when it sends or receives data.

The Device Selector also receives a signal from each card which indicates the status of that card. When the computer is ready for data from the coupler, it looks for a signal from the Device Selector and then handles the data as the computer program requires.

SOFTWARE

No software is presently available as part of the R1340 except as part of an operating S3150 system, and that software is in a language closely related to the particular hardware in the system.

Existing hardware interfaces used in the R1340 for the DEC PDP-8/L and IBM 1800 computer are well documented and allow machine-language drivers to be easily written. Hardware interfaces for other computers (including the DEC PDP-11) are under development. Special software, a high-level language written in DEC PDP-11, FORTRAN IV, will be available in 1972. The TEKTRONIX programming language being developed for the PDP-11 will allow interactive English-language control of computer peripherals and test instruments interfaced through the R1340. Digitized waveform data acquired by the Waveform Digitizing Interface can be computer processed through measurement routines for determining such parametric data as risetime, pulsewidth, etc. Measurement routines may be interactively altered or extended for unusual applications by writing FORTRAN routines to perform special functions. Arithmetic, data-logging, instrument programming and display operations are to be included.

CONCLUSION

The R1340 Data Coupler greatly expands system flexibility with or without the use of a computer. Through waveform digitizing and accurate voltage and timing references it brings new measurement capability to dynamic testing. Your TEKTRONIX field engineer can help you apply the R1340 to solving your measurement problems.

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September 1971

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- ☐ 7L12 Spectrum Analyzer Plug-in
- ☐ 7CT1N Curve Tracer Plug-in
- ☐ 5103N/D15 Storage Oscilloscope
- ☐ 5A13N Differential Comparator Amplifier
- ☐ 5A14N 4-Trace Amplifier
- ☐ 5A22N Differential Amplifier
- ☐ 5CT1N Curve Tracer Plug-in
- ☐ 172 Programmable Test Fixture
- ☐ 1501 Time Domain Reflectometer
- ☐ P6056/P6057 Probes
- ☐ 603 Storage Display Unit
- ☐ 604 Display Unit
- ☐ 4602 Video Hard Copy Unit
- ☐ S3160 IC Test System

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Area Code: 503
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ANNOUNCING PRICE REDUCTIONS
for
TEKTRONIX DESK-TOP CALCULATORS

Tektronix, Inc. is replacing its Scientist 909 Calculator with a lower cost, higher performance version. The original 909, priced at $3780, had 85 program steps and 26 storage registers. Its replacement, priced at $3200, has 256 program steps and 26 storage registers and is warranted for a full year. Price reduction was achieved through increased use of MOS/LSI chips and new manufacturing techniques. A similar increase in performance and decrease in price is available in the Statistician 911 Calculator.

All of the popular operating features and performance characteristics of the earlier model 909 are retained. The mathematical keyboard, which contains programmable keys for trigonometric and hyperbolic functions plus inverse trig and hyper functions, is standard at no extra cost.

The math oriented keyboard also contains one-key functions for logarithms, raising any number to any power over a dynamic range of ±10 digit mantissa times $10^{\pm 99}$, a square root of the sum of the square key, and keys which provide unlimited nesting. These and other unique keys, plus the machine's ability to observe mathematical hierarchy, make the TEKTRONIX Calculator easy to use. Even more significant is the calculator's power to solve complex mathematical problems involving as many as 5120 steps when used with the optional 926 Programmer.

The operator never has to learn a machine language or develop techniques for circumventing nonprogrammable keys which are often found on other machines. Some of the reasons are: The TEKTRONIX Calculator speaks the universal language of mathematics, all keys are programmable, and less programming effort is required than with machines with thumbwheels, toggle switches or key notations.

Availability: Stock

RECEIVED SEP 17 1971

Tektronix, Inc.
Calculator Products Division

8/71

TEKTRONIX®

SEPTEMBER 1971

NEW PRODUCTS

SUPPLEMENT NO. 2 to the MARCH '71 CATALOG

This is the second in the series of New Product Supplements designed to keep you up to date on products introduced by Tektronix, Inc. It supplements your TEKTRONIX March 1971 catalog and should be filed with it. Most of the products included in this supplement were introduced at WESCON and are available for demonstration by your local field engineer.

7000-SERIES PRODUCTS

7L12

The 7L12 Spectrum Analyzer is a swept front-end analyzer in plug-in form, covering 1 MHz to 1.8 GHz. Dynamic range is greater than 70 dB with intermodulation distortion less than 70 dB. An amplitude and frequency calibrator is provided. Resolution bandwidth is selectable 300 Hz to 3 MHz in decade steps with a shape factor of 4:1 (60 dB to 6 dB). All display parameters are calibrated and quantitative information is displayed on both front panel and CRT readout. CRT readout is one of the unique 7L12 features. The multiple plug-in concept of the 7000-Series allows simultaneous display of both frequency and time-domain data. Much effort has gone into human engineering to make the 7L12 easier to use and to reduce the chance of human error.

7L12 Spectrum Analyzer............................... $4850

7CT1N

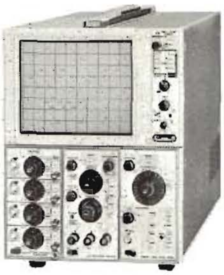
The 7CT1N Curve Tracer is a plug-in unit used in TEKTRONIX 7000-Series Oscilloscope Systems for displaying characteristic curves of small-signal semiconductor devices to power levels up to 0.5 watts.

A variable collector/drain sweep produces a maximum peak voltage of at least 250 volts; a base/gate step generator produces up to 10 calibrated current or voltage steps. Ranges of step amplitudes are 1 μA/step to 1 mA/step for current and 1 mV/step to 1 V/step for voltage. In addition the unit has a vertical display amplifier with deflection factors ranging from 10 nA/div to 20 mA/div and a horizontal amplifier output compatible with other 7000-Series Plug-ins.

7CT1N Curve Tracer................................... $400

For further information or a demonstration of these products, please contact your local TEKTRONIX Field Office or return the enclosed inquiry card.

5100-SERIES PRODUCTS



5103N/D15

The 5103N/D15 Storage Oscilloscope features a single beam, 6½ inch 8 x 10 div (½ in/div) CRT with bistable, split-screen storage and an internal graticule. 5103N/D15 storage writing speed is at least 200 div/ms in the normal mode and 800 div/ms in the enhanced mode. Accelerating potential is 3.5 kV and the phosphor is similar to P1.

Storage time is at least one hour at normal intensity, increasing to ten hours at reduced intensity. View time is at least one hour at normal intensity. Erase time is approx 250 ms.

5103N/D15 Storage Oscilloscope (without plug-ins).......... $1095

R5103N/D15 Storage Oscilloscope (without plug-ins)......... $1095

5A13N

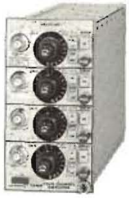
The 5A13N Differential Comparator is a plug-in amplifier for all 5100-Series Oscilloscope systems. It incorporates a number of performance features which make it particularly versatile, especially for measurements in difficult low-amplitude, low-frequency areas. The following three operational areas describe the functions of the 5A13N.

As a conventional amplifier the 5A13N has DC-to-2 MHz or 10 kHz bandwidth over the 1 mV/div to 5 V/div deflection factor range.

As a differential amplifier it maintains its conventional features and provides a balanced input for applications requiring rejection of a common-mode signal. The CMRR is 10,000:1 from DC to 20 kHz, decreasing to 100:1 at 2 MHz.

The 5A13N may be used to apply a signal of up to ±10 volts to either input with the deflection factor set at 1 mV/div. The signal may then be viewed in 10,000 1-mV increments by offsetting the signal with the opposing comparison voltage.

5A13N Differential Comparator.......................... $550



5A14N

The 5A14N Four Trace Amplifier is a solid-state amplifier for use in the 5103N Oscilloscope. Four identical channels with simplified controls have deflection factors from 1 mV/div to 5 V/div, with bandwidth at least 2 MHz at all deflection factors. The 5A14N may be used in any combination with any other 5100-Series Plug-in for displaying up to eight traces. For instance, two 5A14N Amplifiers

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provide eight traces; one each 5A14N and 5A15N Amplifiers provide five traces. Each amplifier may be used in the 5103N horizontal plug-in compartment for X-Y operation.

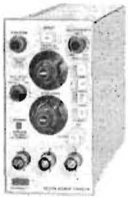
5A14N operating modes are each channel separately, and alternate or chop between any combination of channels. Internal trigger is available from channel one only or from each displayed trace.

5A14N Four Trace Amplifier $575

5A22N

The 5A22N Differential Comparator is a differential amplifier for use with all 5100-Series Oscilloscope Systems. Significant performance features are 10 μV/div to 5 V/div deflection factors, DC-to-1 MHz bandwidth, selectable HF and LF −3 dB points, common-mode rejection ratio of 100,000:1 at 10 μV/div DC coupled, and a DC offset feature with ±0.5 V range from 10 μV/div to 50 mV/div and ±50 V range from 100 mV/div to 5 V/div.

5A22N Differential Amplifier $425



5CT1N

The 5CT1N Curve Tracer is a plug-in unit used in TEKTRONIX 5100-Series Oscilloscope Systems for displaying characteristic curves of small-signal semiconductor devices to power levels up to 0.5 watts.

A variable collector/drain sweep produces a maximum peak voltage of at least 250 volts; a base/gate step generator produces up to 10 calibrated current or voltage steps. Ranges of step amplitudes are 1 μA/step to 1 mA/step for current and 1 mV/step to 1 V/step for voltage. In addition, the unit has a vertical display amplifier with deflection factors ranging from 10 nA/div to 20 mA/div and a horizontal amplifier output compatible with other 5100-Series Plug-ins.

5CT1N Curve Tracer $350

576 CURVE TRACER TEST FIXTURE

172

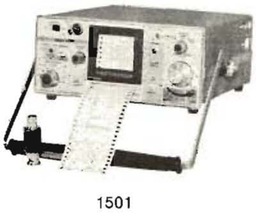
The 172 Programmable Test Fixture, when used with the TEKTRONIX 576 Curve Tracer, permits the operator to program up to eleven sequential tests on FETs, transistors and diodes. This fixture saves measurement time in applications where a series of tests are to be made on a number of devices. To make the same tests without this fixture requires manual setting of the 576 controls for each particular test. This process is repeated for each test. The programmable fixture sequences through as many as eleven different tests on each device without readjusting panel controls and while the device remains in the test socket.

The 172 sequences through the various tests either automatically or manually. A variable RATE control is provided for the operator to set the test sequence at a rate which is best for him. A new operator requires more time per test, but with experience he will want to test at a faster rate. A front-panel switch or an optional foot switch advances the test in the manual mode.

Programming is straightforward. Inserting plastic pins in holes in the programming card sets individual test conditions. Omit the pin from a particular test hole and the 172 skips that test. After installing the program pins in the card, the card is put into the card reader portion of the 172 and the operator starts the test sequence.

172 Programmable Test Fixture $1400

PORTABLE TDR SYSTEM



1501

The 1501 Time Domain Reflectometer (TDR) is a portable, battery-operated system, used to detect and locate faults and to measure impedance variations in transmission cables out to 10,000 feet through the use of test pulses. Resultant reflections from any discontinuities indicate the seriousness and character of the faults.

The 1501 is especially designed for use with a 323 battery-powered oscilloscope, but other oscilloscopes can be used. The 1501 can be used without an oscilloscope if a strip chart recorder is plugged into a center compartment in the 1501. Each strip chart recording is four centimeters wide by sixty centimeters long to allow permanent, inexpensive, high-resolution TDR plots of entire cables, or any particular portion of a cable.

The chart recorder in the 1501 can also be driven by the 1401A or 1401A-1 Spectrum Analyzer.

1501 Time Domain Reflectometer (with recorder)........... $1900

1501, Option 1 (without recorder)........................ $1425

PROBES

The P6056 Probe is a miniature 10X attenuation, low-capacitance probe for use with 50 Ω, wide-band oscilloscopes. Bandwidth DC to 3.5 GHz. This probe can also be used with 50 Ω sampling systems, such as the 3S1 plug-in, or the S1 and S2 sampling heads, with a BNC male to GR adapter (017-0063-00). The probe is equipped with a special BNC connector that provides trace identification and CRT readout information when used with plug-in units and mainframes that have these features.

The P6057 Probe is a miniature 100X attenuation probe with a bandwidth of DC to 1.7 GHz that has all other features of the P6056 probe, including the 6-ft and 9-ft probe length.

P6056 Probe $45

P6057 Probe $45

U.S. Sales Prices FOB Beaverton, Oregon

For further information or a demonstration of these products, please contact your local TEKTRONIX Field Office or return the enclosed inquiry card.

INFORMATION DISPLAY PRODUCTS

603

The 603 Storage Monitor is a compact half-rack width display monitor with 2-MHz bandwidth X-Y amplifiers. Vertical rackmount space required is only 5¼ inches. Two 603s rackmounted side-by-side fit into a standard rack width.

True differential, 1 MΩ input, X and Y amplifiers have less than 1° phase difference to 500 kHz. The 5 MHz Z-axis is DC-coupled.

The 603 provides stored displays of alphanumeric and graphic information from computers and other data-transmission systems. Viewing time is at least one hour and may be extended to ten hours. Fast information-storage rate of at least 200,000 dots per second qualifies it well for computer-processed data display. The TEKTRONIX-developed bistable storage CRT used in the 603 eliminates the need of costly memory devices for refreshing the information display.

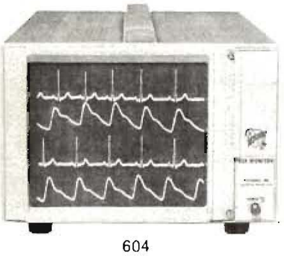
The 603's relatively large (6½-inch) storage CRT in a small package meets the display size and mechanical space requirements of system designers. The 603 Storage Monitor is well suited for many display applications in ultrasonic detection systems, electron microscope systems, radiation and thermal scanning systems, speech therapy, mechanical pressure, volume and vibration analysis, medical and biophysical systems.

The 603 has a Variable Brightness control which adds new versatility to the bistable storage tube.

Operating functions are remotely programmable through contacts at the remote-program connector on the rear panel. X-Y-Z differential inputs are provided through rear BNC connectors. X-Y-Z inputs are also available at the remote-program connector.

A unique option offers an internal time base with six decade-range sweep rates from 1 μs to 0.1 s. Triggering is by internal source, + and — slope, DC-coupled.

603 Storage Monitor **$1100**



604

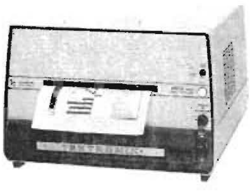
The 604 Display Monitor is a compact, half-rack width, bright 6½ inch CRT monitor requiring only 5¼-inch vertical rackmount space. Two 604s rackmounted side-by-side can fit into a standard rack width.

True differential, 1 MΩ input, 2-MHz bandwidth X and Y amplifiers have less than 1° phase difference to 500 kHz. The 5 MHz Z-axis is DC-coupled.

The 604's relatively large (6½-inch) CRT with 8 x 10 div (½ in/div) in a small package ideally meets the display and space requirements of system designers in applications such as pulse height analysis, infrared detection, data-communication systems testing, component and logic testing, vibration analysis and medical instrumentation. The 604 is well suited for many other applications including: phase shifts and frequency ratios using Lissajous figures, raster displays with intensity modulation and apparent dynamic three-dimensional illustrations that change size and shape. Visual display of computer-processed data enhances understanding of the processed information and improves ease and time of analyzing the results.

A unique option offers an internal time base with six decade-range sweep rates from 1 μs to 0.1 s. Triggering is by internal source, + and — slope, DC-coupled.

604 Display Monitor **$700**



4602

The 4602 Video Hard Copy Unit provides permanent facsimile copy from static television signals. Composite television picture video is applied to a loop-through input connection on the 4602 rear panel. The TV signal is copied by the 4602 providing an accurate gray scale representation of the television inputs. High contrast copies of alphanumeric and graphic displays are also furnished using the 4602.

Installation consists merely of connection to the power line and to the video information to be copied since the 4602 is completely self-contained. Front-panel controls allow the user to standardize and copy video signals in the range of 0.2 V p-p to 3 V p-p. Copy command is initiated by pressing a front-panel control, or by supplying an external command. Contrast and Density are adjusted by the operator with simple-to-use front-panel controls.

Easy-to-handle 8½ x 11-inch dry copies are convenient for communication, documentation, recording and filing uses in unlimited applications, a few of which are: education, banking and finance, law enforcement, refreshed video terminals, legal, medical and industrial firms.

Composite television picture video is applied to a loop-through input connection on the 4602 rear panel. Internal synchronization is derived from the composite video signal. Video information is required to be unvarying during a brief sampling period (about 20 seconds). An additional 20 seconds is required to process the hard copy.

3M Brand Type 777 Dry-Silver Paper provides the high image contrast required for high-resolution copies of complex graphics and alphanumerics. It offers the user the stability normally associated with wet-process photosensitive paper, plus the convenience of dry printout papers. Cost is low: 5 to 8 cents per 8½ by 11 inch copy, depending on usage. Roll size is 8½ inches by 500 feet.

4602 Video Hard Copy Unit **$3750**

For further information or a demonstration of these products, please contact your local TEKTRONIX Field Office or return the enclosed inquiry card.

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AUTOMATED TESTING SYSTEMS

The S-3160 LSI/MOS Test System performs parametric, functional and dynamic tests on all types of MOS and bipolar shift registers, random-access memories, read-only memories and complex logic arrays. The system configuration includes a two-bay rack, a separate Graphic Display Terminal and Test Station(s).

Devices with up to 64 pins may be tested with combined input-output electronics. Devices with up to 128 pins may be tested by splitting the input-output connections.

FUNCTIONAL TESTS are conducted with a high-speed driver and dual, strobed comparators for each pin. A four-phase clock serves four selected pins. Clock-cycle repetition rate is 500 Hz to 20 MHz (two ranges). Clock transitions are independently programmed in 5-ns increments. Comparator and data strobes are positioned throughout the clock-cycle in 1-ns increments.

A 20-MHz shift register at each pin stores data patterns and address sequences for input forcing, as well as mask and expected data patterns for output comparison. Direct output data or errors may be stored on-the-fly for subsequent analysis or display. 1024 bits per pin may be recirculated or chained at adjacent pins for greater pattern length. Mode change micro-instructions issue directly from computer memory during run time.

DYNAMIC TESTS including risetime, propagation delay and access time are performed in a separate subsystem. There are five time ranges, ±100 ns to ±1 ms, with 100-ps resolution and 1% accuracy. Dynamic test rates are up to 250 per second.

PARAMETRIC (DC) TESTS such as stress, leakage, breakdown, resistance, I_{out}, V_{out}, I_{in}, and V_{in} are performed in a separate parametric test subsystem. Measurements can also be made with forcing function and dual, strobed comparators at each pin. The DUT may be functionally initialized with programmable clock, data and strobe signals and dc stimuli. Parametric test rates are up to 250 per second.

The S-3160 is controlled by a Digital Equipment Corporation PDP-11 with 16-bit word length. Memory includes an 8K core and a 65K disc.

Software includes pattern generator, translator/editor and executive programs. A procedure-oriented, interactive English-language source is used. An English-language executive is used for test-sequence control.

Auto-handlers, manual insertion, environmental handlers, wafer probers or EC-board test stations are all served by the same test circuitry.

THE FOLLOWING PRODUCTS WERE INCLUDED IN THE JULY 1971 NEW PRODUCT SUPPLEMENT

7904 500-MHz Oscilloscope System

432 25-MHz Portable Oscilloscope

434 25-MHz Portable Storage Oscilloscope

453A-1,-2,-3,-4 60-MHz Portable Oscilloscopes

1401A/1401A-1 Portable Spectrum Analyzers

147 NTSC Test Signal Generator

148 EBU Insertion Test Signal Generator

630 Monochrome Picture Monitor

650 Color Picture Monitor

2620 Stimulus Isolator

26A2 Differential Amplifier

C-5 Camera

C-59 Camera

Writing Speed Enhancer

P6060/P6061 Probes

Calculators

1711 Machine Control Unit

1791 NC Program Verifier

4002A Graphic Computer Terminal

For further information or a demonstration of these products, please contact your local TEKTRONIX Field Office or return the enclosed inquiry card.

Tektronix, Inc.

P. O. BOX 500 · BEAVERTON, OREGON 97005 · Phone: (Area Code 503) 644-0161 · Telex: 036-691
Cable: TEKTRONIX · OVERSEAS DISTRIBUTORS IN OVER 30 COUNTRIES
TEKTRONIX FIELD OFFICES in principal cities throughout the world. Consult Telephone Directory

Tektronix, Inc.

Revised Price List

Effective July 12, 1971

These prices supersede all other published prices including those currently appearing in advertisements, catalogs, booklets, and all other literature.

OSCILLOSCOPES

Type	Price
310A	$1050
317	1250
RM17	1325
321A	1250
323	1050
324	1225
360	450
410	1025
410 MOD 950A	975
410 MOD 950B	985
422	1600
422 MOD 125B	1850
422 MOD 146B	1575
R422	1675
R422 MOD 150B	3250
432	1585
R432	1625
434	2150
R434	2190
453A	2050
453A MOD 127C	2135
453A MOD 163D	2150
R453A	2135
R453A MOD 127C	2220
R453A MOD 163D	2235
453A-1	1850
453A-2	1875
453A-3	1900
453A-4	1700
454A	3200
454A MOD 163D	3300
R454A	3285
R454A MOD 163D	3385
502A	1485
RM502A	1750
503	850
RM503	865
RM503 MOD 171A	915
504	735
RM504	750
RM504 MOD 171A	800
507	4300
515A	1400
RM15	1475
516	1750
519	5200
520	2825
R520	2850
521	2825
R521	2850
522	3075
R522	3100
528	1000
528 MOD 146B	975
528 MOD 147B	1030
528 MOD 188G	1000
529	1560
529 MOD 147B	1590
529 MOD 188D	1970
RM529	1575
RM529 MOD 188D	1990
531A*	1500
533A*	1650
535A*	2050
RM35A*	2200
536*	1850
543B*	1950
RM543B*	2050
544*	2025
RM544*	2175
545B*	2100
RM545B*	2200
546*	2350
RM546*	2450
547*	$2350
RM547*	2450
549*	2700
551*	2750
556*	4100
R556*	4200
561B*	695
R561B*	745
R561B MOD 171A*	795
564B*	1195
564B MOD 08*	1195
564B MOD 121N*	1350
564B MOD 08, 121N*	1350
R564B*	1245
R564B MOD 08*	1245
R564B MOD 121N*	1400
R564B MOD 08, 121N*	1400
R564B MOD 171A*	1295
R564B MOD 08, 171A*	1295
R564B MOD 121N, 171A*	1450
R564B MOD 08, 121N, 171A*	1450
565*	2100
RM565*	2200
567*	1050
RM567*	1150
568*	1250
R568*	1300
575	1500
575 MOD 122C	1800
576	2800
576 MOD 301W	2300
581A*	2050
585A*	2600
RM585A*	2700
647A*	1925
R647A*	2050
5030	1850
R5030	1850
R5030 OPTION 4	1850
5031	2500
R5031	2500
R5031 OPTION 4	2500
5103N*	220
5103N OPTION 1*	220
5103N/D10*	540
5103N/D10 OPTION 1*	540
R5103N/D10*	540
R5103N/D10 OPTION 1*	540
5103N/D11*	1020
5103N/D11 OPTION 1*	1020
R5103N/D11*	1020
R5103N/D11 OPTION 1*	1020
5103N/D12*	870
5103N/D12 OPTION 1*	870
R5103N/D12*	870
R5103N/D12 OPTION 1*	870
5103N/D13*	1370
5103N/D13 OPTION 1*	1370
R5103N/D13*	1370
R5103N/D13 OPTION 1*	1370
D10	320
D11	800
D12	650
D13	1150
7403N*	950
R7403N*	1050
R7403N OPTION 5*	1100
7503*	1875
7503 OPTION 1*	1475
7503 OPTION 3*	1950
7504*	2100
7504 OPTION 1*	1700
7504 OPTION 2*	2175
7504 OPTION 3*	2175
7514*	$3500
7514 OPTION 1*	3100
7514 OPTION 2*	3575
7514 OPTION 3*	3575
7704*	2550
7704 OPTION 1*	2150
7704 OPTION 2*	2625
7704 OPTION 3*	2625
R7704*	2650
R7704 OPTION 1*	2250
R7704 OPTION 2*	2725
R7704 OPTION 3*	2725
R7704 MOD 101K*	2700
R7704 OPTION 1*	2300
R7704 OPTION 2*	2775
R7704 OPTION 3*	2775
7904*	2900
7904 OPTION 1*	2500
7904 OPTION 2*	2975
7904 OPTION 3*	2975
7904 OPTION 4*	3250

PLUG-IN UNITS

Type	Price
CA	450
L	375
M	825
O	825
Q	600
T	450
W	800
1A1	725
1A2	460
1A4	1150
1A5	750
1A6	400
1A7A	575
1S1	1400
1S2	1525
2A60	200
2A63	275
2B67	300
2B67 MOD 730A	450
3A2	800
3A3	950
3A5	1350
3A6	600
3A7	750
3A8	875
3A9	600
3A10	800
3A72	450
3A74	900
3A74 MOD 730A	950
3A75	285
3B2	950
3B3	680
3B4	495
3B5	1440
3C66	650
3S1	1400
3S2*	1000
3S5*	2100
3S6*	2100
S1	375
S2	430
S3A	580
S4	875
S5	375
S6	875
S50	525
S51	500
S52	550
S53	425
S54	325
3S7	575
3T2	1400
3T5	$2100
3T6	2100
3T7	620
3T7 MOD 950A	620
3T77A	1000
5A15N	115
5A18N	265
5A20N	165
5A21N	185
5A23N	65
5A24N	25
5B10N	175
5B12N	450
5B13N	85
6R1A	3800
7A11	950
7A12	900
7A13	1250
7A14	700
7A15	270
7A16	625
7A18	535
7A18 OPTION 1	500
7A19	500
7A19 OPTION 1	700
7A22	575
7B50	450
7B51	575
7B52	950
7B53N	750
7B70	625
7B71	725
7B92	1400
7D13	560
7D13 OPTION 1	495
7D14	1400
7M11	325
7S11*	575
7S12*	1200
7S12 OPTION 1*	1200
7T11	1625
10A1	1125
10A2A	985
11B1	800
11B2A	1070
81A	230
82	1000
86	600

CALCULATOR PRODUCTS

Type	Price
905	75
909	3200
909 OPTION 3	3700
911	3200
911 OPTION 3	3700
920	150
923	600
926	1495
928	245
941	995

MACHINE CONTROLS

Type	Price
1701	9750
1701 OPTION 5	10,600
1701 OPTION 9	10,050
1701 OPTION 10	10,250
1702	11,000
1702 OPTION 5	11,850
1702 OPTION 9	11,300
1702 OPTION 10	11,500
1704	11,500
1704 OPTION 5	12,350
1704 OPTION 9	11,800
1704 OPTION 10	12,000
1711	5300
1791	11,500

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*Prices do not include plug-in units.

INFORMATION DISPLAY PRODUCTS

Type	Price
601	$1400
601 MOD 146B	1375
602	950
602 MOD 146B	925
602 MOD 174K	950
611	3175
611 MOD 162C	3175
630	1050
630 MOD 08	1050
650	2500
4002A	8800
4002A OPTION 1	8820
4002A OPTION 2	8950
4002A OPTION 3	9100
4002A-1	8400
4002A-1 OPTION 1	8420
4002A-1 OPTION 2	8550
4002A-1 OPTION 3	8700
Interface Units for 4002A & 4002A-1	600-750
T4005	7850
Interface for T4005 & 4201	850
4201	4950
4501	3175
R4501	3175
4551	1800
4601	3750
4601 OPTION 1	3750
4601 OPTION 2	3750
4601 OPTION 3	3750
4701	1500
R4701	1525
4901	525
4902	750
4951	300

MEASUREMENT SYSTEMS

Type	Price
S3110	15,500
S3110 Model 651A	16,350
S3111	17,500
S3111 Model 651A	18,350
S3120	36,850
S3121	28,850
S3122	35,500
S3130	53,500
S3131	45,150
S3132	51,750
S3150	140,000
S3150 Model 651B	100,000

SPECTRUM ANALYZERS

Type	Price
1L5	1300
1L10	1400
1L20	2550
1L40	2550
3L5	1400
3L10	1500
491	4895
491 MOD 139L	3500
491 MOD 139M	3700
R491	4995
R491 MOD 139L	3600
R491 MOD 139M	3800
1401A	2400
1401A-1	2450
1401A/323	3450
1401A/324	3625
1401A-1/323	3500
1401A-1/324	3675

AUXILIARY INSTRUMENTS

Type	Price
106	750
106 MOD 146B	725
109	550
111	500
113	350
114	350
114 MOD 146B	325
115	1075
115 MOD 146B	1050
R116	2100
R116 MOD 703L	$3365
122	230
FM122, RM122	235
125	400
FM125, RM125	405
127	1125
129	1100
130	350
132	650
134	225
140, R140	2150
141A, R141A	2150
141A MOD 703Z	2335
R141A MOD 703Z	2335
142, R142	2350
144, R144	2500
146, R146	2500
147, R147	2900
160A	300
161	225
162	225
163	225
175	2125
176	1600
184	760
191	695
191 MOD 146B	670
230	4100
R230	4150
240	4850
R240	4900
241	2800
R241	2850
R250, R250 MOD 29	1800
262	2125
263	450
281	95
282	95
282 MOD 125D	100
284	700
284 MOD 146B	675
285	225
286	825
287	850
R287	900
R288	1200
R293	1600
R293 MOD 703M	1875
1101	300
R1140	5000
R1140 MOD 950A	6125
R1340	3000
R1340 MOD 950A	4800
1501	1900
1501 OPTION 1	1425
2101	800
2601*	495
2601 OPTION 1*	450
R2601*	495
R2601 OPTION 1*	450
26A1	280
26A2	550
26G1	430
26G2	300
26G3	485
2620	450
2901	740

SCOPE-MOBILE® CARTS

Type	Price
200-1	120
200-2	120
201-1	165
201-2	185
202-1	165
202-1 MOD 52	250
202-2	185
203-2 (Formerly 201-3)	155
204-2	225
204-3	195
205-1	190
205-2	210
205-3	210
206-1	90

CAMERAS

Type	Price
C-5	$185
C-10	450
C-12	590
C-12-E	860
C-12-N	505
C-12-NE	775
C-12-R	625
C-12-RE	895
C-12-547	610
C-12-547 E	880
C-12-547 N	525
C-12-547 NE	795
C-12-547 R	645
C-12-547 RE	915
C-12-549	630
C-12-549 E	900
C-12-549 N	545
C-12-549 NE	815
C-12-549 R	665
C-12-549 RE	935
C-12-608	795
C-12-608 E	1065
C-12-608 N	710
C-12-608 NE	980
C-12-608 R	830
C-12-608 RE	1100
C-12-662	770
C-12-662 E	1040
C-12-662 N	685
C-12-662 NE	955
C-12-662 R	805
C-12-662 RE	1075
C-27	590
C-27-E	860
C-27-N	505
C-27-NE	775
C-27-R	625
C-27-RE	895
C-27-547	610
C-27-547 E	880
C-27-547 N	525
C-27-547 NE	795
C-27-547 R	645
C-27-547 RE	915
C-27-549	630
C-27-549 E	900
C-27-549 N	545
C-27-549 NE	815
C-27-549 R	665
C-27-549 RE	935
C-27-608	795
C-27-608 E	1065
C-27-608 N	710
C-27-608 NE	980
C-27-608 R	830
C-27-608 RE	1100
C-27-662	770
C-27-662 E	1040
C-27-662 N	685
C-27-662 NE	955
C-27-662 R	805
C-27-662 RE	1075
C-30A-G	490
C-30A-GE	760
C-30A-N	440
C-30A-P	525
C-30A-PE	795
C-30A-R	560
C-30A-RE	830
C-31-G	605
C-31-GE	875
C-31-N	555
C-31-P	640
C-31-PE	910
C-31-R	675
C-31-RE	945
C-32-G	680
C-32-GE	950
C-32-N	630
C-32-P	715
C-32-PE	985
C-32-R	750
C-32-RE	1020
C-50-G	$715
C-50-N	665
C-50-P	750
C-50-R	785
C-51-G	1015
C-51-N	965
C-51-P	1050
C-51-R	1085
C-52-G	1065
C-52-N	1015
C-52-P	1100
C-52-R	1135
C-59-G	415
C-59-N	365
C-59-P	450
C-59-R	485
C-70-G	815
C-70-N	765
C-70-P	850
C-70-R	885

PROBES†

Type	Price
P6006	31
P6007	35
P6008	50
Environmentalized	80
P6009	66
P6011	25
P6012	40
P6013A	200
P6015	275
P6027	20
P6028	20
P6034	50
P6035	50
P6045	325
Power Supply	125
Probe w/Power Supply	450
P6046	470
Amplifier	380
Probe & Amp	850
P6048	65
P6051	375
P6052	55
P6053	55
P6054	50
P6055	75
P6060	35
P6061	38
P6021	
w/Passive Termination	129
without/Passive Termination	98
Passive Termination	37
w/Type 134 Amp & Pwr. Supply	352
Type 134 Amplifier only	225
Power Supply only	40
P6022	
w/Passive Termination	170
without/Passive Termination	127
Passive Termination	49
w/Type 134 Amp. & Power Supply	383
P6040	20
CT-1 Current XMFR	30
P6040/CT-1 Current Probe	50
P6041	20
CT-2 Current XMFR	35
P6041/CT-2 Current Probe	55
CT-5	450
P6042	725

ACCESSORIES

Type	Price
015-0108-00	230
015-0126-00	1000
020-0031-00	525
122-0603-00	120
122-0754-00	120
122-0929-00	120

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†Probe prices apply to all cataloged variations of each probe, except the P6008 as noted.

TEKNIQUE:

THE 7D14 COUNTS CURRENT TO MINIMIZE CIRCUIT LOADING

by Emory Harry, Field Engineer

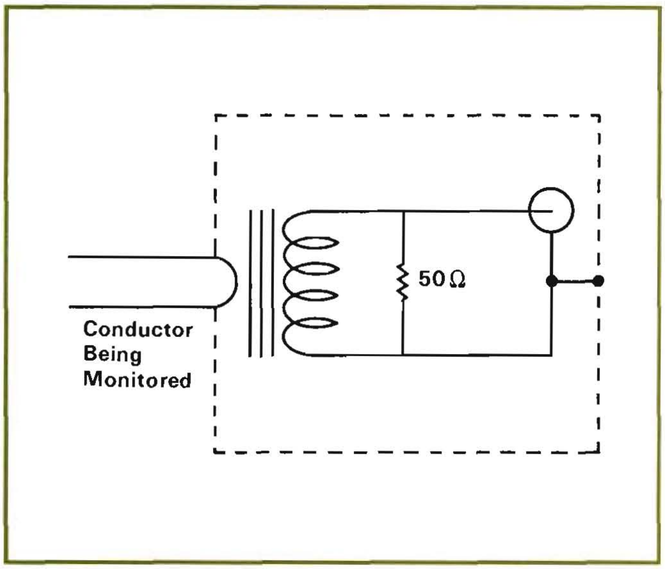


Fig. 1 Simplified circuit of the CT-1 probe.

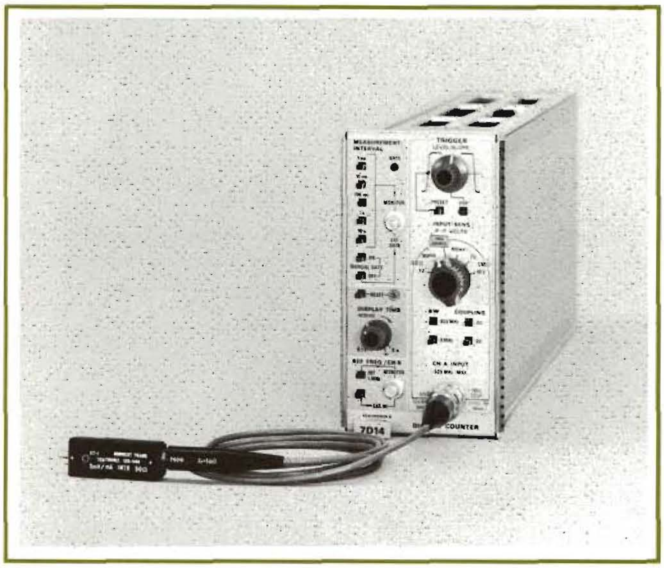


Fig. 2 The 7D14 Counter plug-in with P6041/CT-1 Probe

The 7D14 is a 525 MHz direct-reading counter. Circuit loading is often a problem when coupling to circuits operating in this frequency range. Often it is possible to use a current probe to couple the signal to be counted to the 7D14 and realize much less loading. No electrical connection is made and the current probe heads are not grounded, therefore, the possibility of accidental grounding is also avoided.

The current probe which offers the most performance coupled to the 7D14 is the P6041/CT-1. This combination makes available the full 525 MHz bandwidth of the 7D14.

Pictured at left above is a simplified circuit of the CT-1 Current Transformer. It has a frequency response of 35 kHz to 1 GHz with a sensitivity of 5 mV/mA when operated into 50Ω. It can be used with either the 50Ω or 1MΩ input impedances of the 7D14; however, the insertion impedance is lower when the 50Ω input is used (1Ω shunted by 5 uH vs 2Ω shunted by 5 uH).

The capacitance added to the conductor when passed through the CT-1 is determined primarily by the wire size. It will be 0.6 pf for No. 20 bare wire and 1.5 pf for No. 14 bare wire. This capacitance and the inductance of the conductor form a transmission line with Zo of approximately 50Ω for No. 14 wire and approximately 100Ω for No. 20.

The maximum voltage on the circuit under test is limited to 1000 V DC and the RMS current to 100 A peak with an amp-second product of 1A-us. When the amp-second product is exceeded, the core saturates and the output of the CT-1 falls to zero.

Since the input sensitivity of the 7D14 is 100 mV and the sensitivity of the CT-1 is 5 mV/mA it can be seen that approximately 20 mA must be flowing through the circuit under test to drive the counter.

The 1MΩ rather than the 50Ω input of the 7D14 can be used to effectively double the sensitivity of the CT-1, however, the insertion impedance also doubles. When operating the probe into the 1MΩ input of the 7D14 it is only necessary for 10 mA to be flowing in the circuit under test.

If the signal current is less than 10 mA, the wire can be looped through the CT-1 more than once if the conductor is small enough. The insertion impedance will go up approximately as the square of the number of times the wire is looped through the CT-1. For example, five loops will result in an insertion impedance of about 50Ω when operating into the 1 MΩ input.

SERVICE SCOPE

A PRACTICAL APPROACH TO REGULATED POWER SUPPLIES AS OPERATIONAL AMPLIFIERS

By F.J. Beckett, Engineer

From time to time, Service Scope articles are written with the intent of broadening the technician's understanding of basic circuits used in TEKTRONIX oscilloscopes rather than discussing troubleshooting techniques. Such is the intent of this article on regulated power supplies.

Most sophisticated electronic equipment uses some form of regulated power supply. Generally speaking, these supplies fall into two categories: constant voltage or the constant current form or, in some cases, a combination of both types.

By far the most common is the constant voltage type. A constant voltage generator is defined as "a two-terminal circuit element with a terminal voltage independent of the current through the element" (extract from the I.R.E. Dictionary of electronic terms and symbols). This definition implies that a constant voltage generator has a zero source impedance.

Source impedance is that impedance we see looking back into the output terminals. In the strict sense of the definition, we cannot build a power supply whose output impedance is zero.

At this point, we must ask the question, why does it matter if the output impedance is not close to zero? To answer this question, let us look at an amplifier and its power supply (Fig. 1). We see that the power supply output impedance (Z_o) appears in series with the load resistance (R_L) of the amplifier. If Z_o is not low, the result will be that the power supply will not deliver a constant voltage but will vary with I_s.

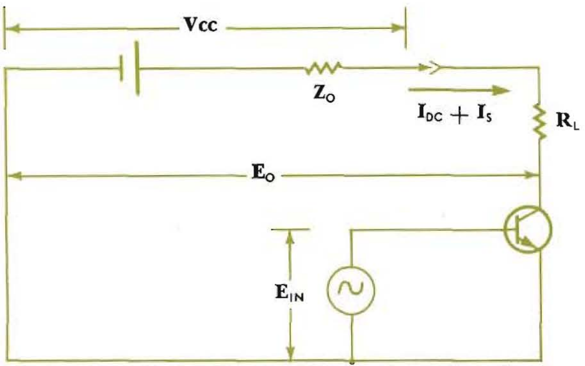


Fig. 1 Equivalent circuit showing that the output impedance of the power supply appears as part of the load.

We should keep in mind that in oscilloscopes, the varying load presented by the sweep, trigger, unblanking and other circuits could generate an I_s of several hundreds of milliamps on a peak-to-peak basis. This calls for a supply having not only a low output impedance, but it should be capable of handling wide variations in load as well.

A power supply employing feedback principles provides an ideal solution. It can accommodate varying loads and the output impedance can be made very low.

Let's take a look at the low voltage power supplies in the 453A (Fig. 3). A careful examination of the feedback networks in the amplifier portions of the circuitry shows that these are, indeed, operational amplifiers. A simplified equivalent circuit is shown at the right of each supply.

Before analyzing these supplies in detail, we need to consider operational amplifiers in general and examine some of their limitations. Shown at right is a DC analysis of the inverting and non-inverting type of operational amplifier. The analysis suggests that the most important parameter to be considered is the open-loop gain (A_{OL}). If A_{OL} is high, then the feedback resistors (R_F and R_i) are the sole factors determining the amplifier closed-loop gain. Further, we see from equation (2) that with A_{OL} very large, E_s will be very small (in the order of a few millivolts) and so E_{out} will be essentially proportional to E_{IN}.

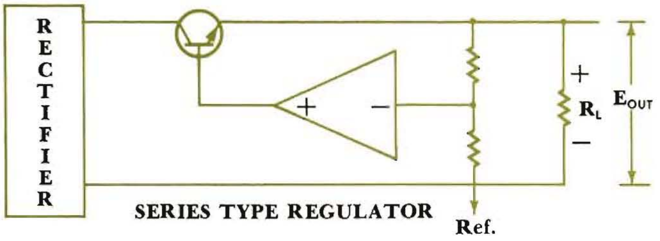
OPERATIONAL AMPLIFIER LIMITATIONS

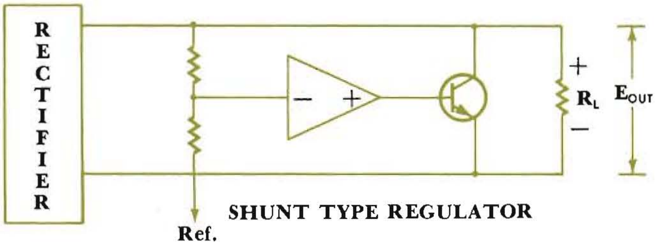
At lower right are typical plots of A_{OL} in terms of frequency and output impedance (Z_o). We see that if we are to achieve a true constant voltage power supply, A_{OL} must be infinite. This is not possible, of course, but we can approach the ideal situtation at frequencies approaching DC. However, note that as the signal frequency increases two things happen: open-loop gain decreases and output impedance increases. The result is that we do not have a constant-voltage supply at all frequencies. Since the power supply is a common meeting point for many circuits, the variations in supply voltage caused by high-frequency circuit loads are coupled into other circuits and cause problems. This coupling can be minimized by filters and decoupling networks but is still a persistent problem to circuit designers.

TYPICAL CONSTANT VOLTAGE SUPPLIES

Let us now turn our attention to the more practical aspects of the constant voltage power supply. In analyzing a power supply circuit, we must first recognize the type of regulator and its control amplifier. At upper right are the two types of regulator circuits commonly used, the series type and the shunt type. The most common is the series regulator for the reason of the power dissipated across the regulating element.

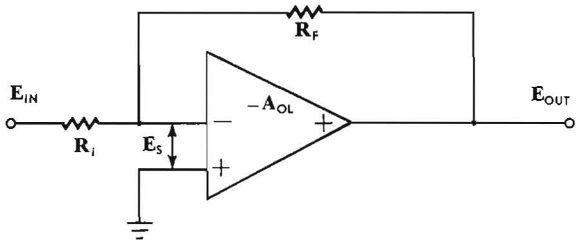
Once the type of regulator is determined, it then becomes an exercise to recognize the type of feedback amplifier involved and the feedback networks.





DC GAIN ANALYSIS OF OPERATIONAL AMPLIFIERS

INVERTING



Now, using the superposition theorem:

$$E_S = \frac{R_F E_{IN}}{R_i + R_F} + \frac{R_i E_{OUT}}{R_i + R_F} \qquad (1)$$

and $E_{OUT} = -A_{OL} E_S$ where A_{OL} is the open-loop gain (2)

$$\text{so} \qquad -\frac{E_{OUT}}{A_{OL}} = \frac{R_F E_{IN}}{R_i + R_F} + \frac{R_i E_{OUT}}{R_i + R_F} \qquad (3)$$

rearranging Eq(3) in terms of closed-loop gain, $\frac{E_{OUT}}{E_{IN}}$ or $A_{(V)}$

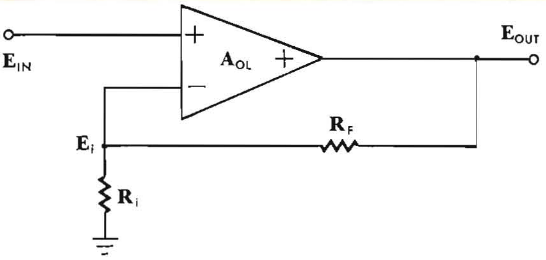
$$\frac{E_{OUT}}{E_{IN}} = A_{(V)} = -\left[\frac{\frac{A_{OL} R_F}{R_i + R_F}}{1 + \frac{A_{OL} R_i}{R_i + R_F}}\right] \qquad (4)$$

$$A_{(V)} = -\frac{A_{OL} R_F}{R_F + R_i (A_{OL} + 1)} = -\left[\frac{R_F - \frac{R_F}{A_{OL} + 1}}{R_i + \frac{R_F}{A_{OL} + 1}}\right] \qquad (5)$$

Now if $A_{OL} \longrightarrow \infty$

then $A_{(V)} = -\frac{R_F}{R_i}$ (6)

NON-INVERTING



Using the superposition theorem:

$$E_i = \frac{R_i E_{OUT}}{R_i + R_F} + \frac{E_{OUT}}{A_{OL}} = E_{OUT}\left(\frac{R_i}{R_i + R_F} + \frac{1}{A_{OL}}\right) \qquad (1)$$

$$\frac{E_i}{E_{OUT}} = \frac{R_i A_{OL} + R_i + R_F}{(R_i + R_F)(A_{OL})} = \frac{R_i(A_{OL} + 1) + R_F}{(R_i + R_F)(A_{OL})} \qquad (2)$$

Now $E_{IN} = E_i$ because of the null situation between the inputs. So subst. E_{IN} for E_i and inverting Eq(2) we have:

$$\frac{E_{OUT}}{E_{IN}} = A_{(V)} = \frac{A_{OL}(R_i + R_F)}{R_i(A_{OL} + 1) + R_F} \qquad (3)$$

where $A_{(V)}$ = closed-loop gain

$$= \frac{A_{OL}(R_i + R_F)}{(A_{OL} + 1)\left(R_i + \frac{R_F}{A_{OL} + 1}\right)}$$

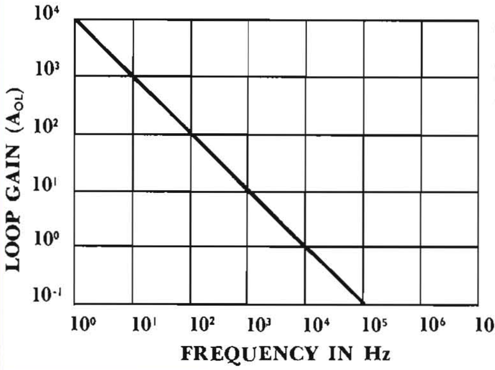
and for values of $A_{OL} \gg 1$

$$A_{(V)} = \frac{R_i + R_F}{R_i + \left(\frac{R_F}{A_{OL} + 1}\right)} \qquad (4)$$

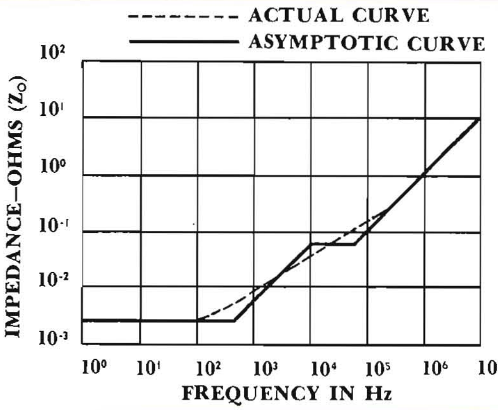
and if $A_{OL} \longrightarrow \infty$ then $A_{(V)} = \frac{R_i + R_F}{R_i}$ (5)

$$\text{OUTPUT IMPEDANCE} = Z_O = \frac{Z}{1 + \beta A_{OL}}$$

where Z_O is the output impedance with feedback
Z = output impedance without feedback
$$\beta = \frac{R_i}{R_i + R_F}$$



CONSTANT VOLTAGE FEEDBACK AMPLIFIER OPEN-LOOP GAIN CHARACTERISTIC



OUTPUT IMPEDANCE OF CONSTANT VOLTAGE REGULATED SUPPLY

Fig. 2

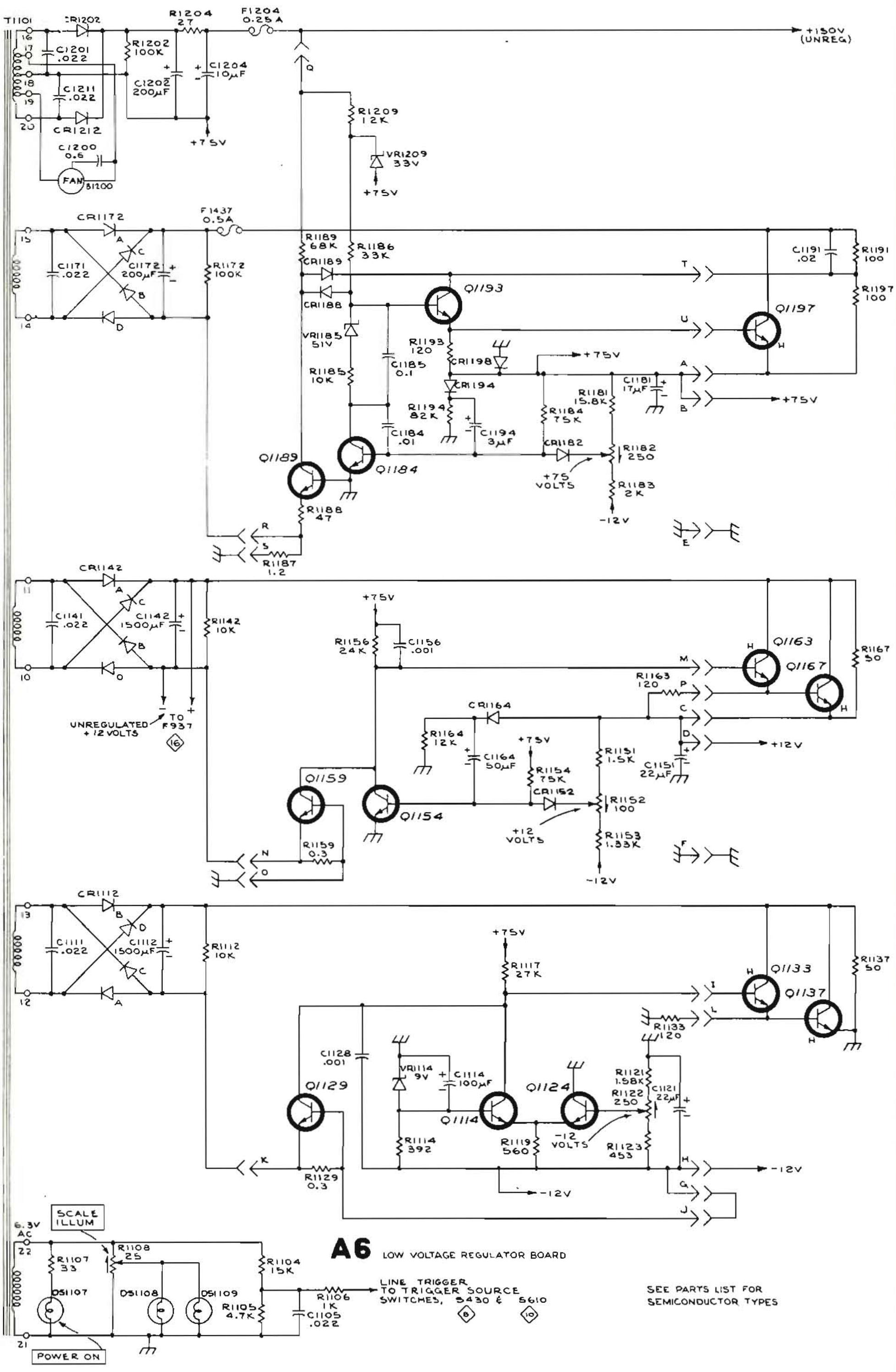
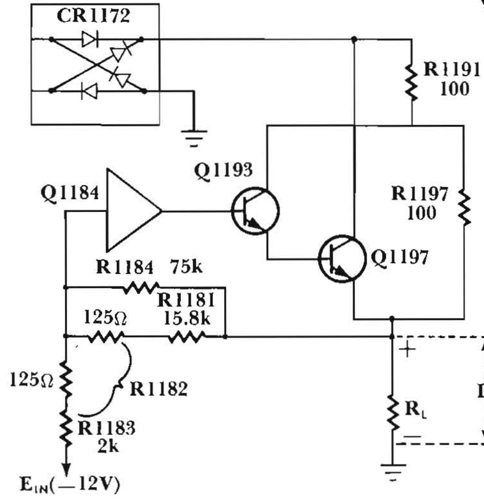
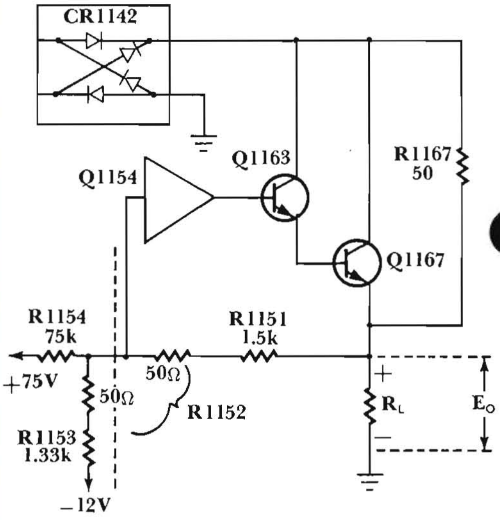


Fig. 3 Low voltage power supplies for the 453A with their simplified equivalent circuits at right.

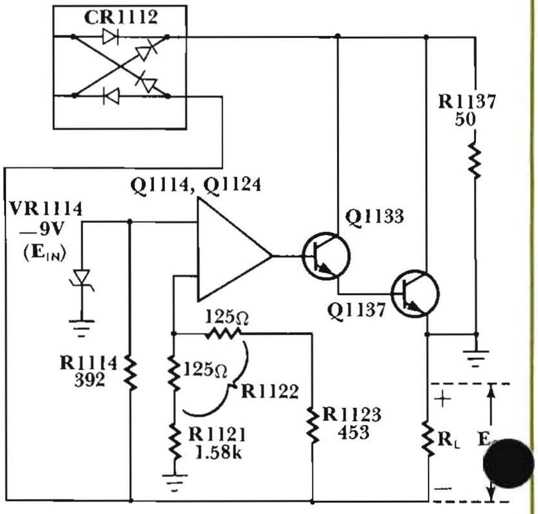
(a) +75 VOLT SUPPLY



(b) +12 VOLT SUPPLY



(c) −12 VOLT SUPPLY



Let's look again at the low voltage power supplies for the 453A (Fig. 3) and analyze them as operational amplifiers.

+75 VOLTS SUPPLY ANALYSIS

Fig. 3(a) shows the +75 volt supply in its simplified form. Recognize that this supply is a series regulator, Q1197 and Q1193 being the series element, with Q1184 the regulating amplifier (operating as an inverting amplifier). Notice we consider R1182, 250Ω potentiometer at mid range, half of R1182 is with R_F and the other half with R_i. R1182 is adjusted for the final value of +75 volts.

E_{IN} is the DC reference voltage for the supply.

So

$$\begin{aligned} R_F &= 15800\Omega + 125\Omega \text{ in parallel with } 75000\Omega \\ &= 13130\Omega\text{s} \end{aligned}$$

$$\begin{aligned} \text{and } R_i &= 2000\Omega + 125\Omega \\ &= 2125\Omega \end{aligned}$$

$$\therefore \frac{E_O}{E_{IN}} = -\frac{R_F}{R_i}$$

$$\frac{E_O}{-12} = -\frac{13130}{2125}$$

$$\therefore E_O = \frac{12 \times 13130}{2125}$$

$$= 74.2 \text{ volts}$$

A slight adjustment of R1182 will bring E_o to exactly +75 volts.

+12 VOLTS SUPPLY ANALYSIS

Fig. 3(b) shows the +12 volt supply in its simplified form. We proceed along the same lines as we did in the +75 volt analysis. Q1167 and Q1163 are the series regulator elements while Q1154 is the regulating amplifier, once again the inverting type. R1152, 100Ω pot, is the adjustment for setting the supply to +12 volts. Consider R1152 set at mid range, half of which is associated with R_F while the other half we find associated with R_i. However, the values of R_i and E_{IN} are not so apparent here. We must first calculate these values. R_i is Thevenin's equivalent resistance, while E_{IN} is the Thevenin equivalent voltage to the left of the dashed line.

So

$$\begin{aligned} R_i &= \frac{(1330 + 50) \times 75000}{(1330 + 50) + 75000} \Omega\text{'s} \\ &= 1355 \Omega\text{s} \end{aligned}$$

$$\begin{aligned} \text{and } E_{IN} &= -12 + \frac{87 \times (1335 + 50)}{(1335 + 50) + 75000} \text{ volts} \\ &= -12 + 1.57 \\ &= -10.43 \text{ volts} \end{aligned}$$

$$\begin{aligned} \text{now} \quad R_F &= 1500\Omega + 50\Omega \\ &= 1550\Omega \end{aligned}$$

so finally

$$\frac{E_O}{E_{IN}} = -\frac{R_F}{R_i}$$

$$\begin{aligned} \frac{E_O}{-10.43} &= \frac{1550}{1355} \\ &= \frac{+10.43 \times 1550}{1355} \text{ volts} \\ &= +11.93 \text{ volts} \end{aligned}$$

A slight adjustment of R1152 will bring E_o to exactly +12 volts.

-12 VOLTS SUPPLY ANALYSIS

Fig. 3(c) shows the -12 volt supply in its simplified form. Q1137 and Q1133 are the series regulating elements. Q1124 and Q1114 are the regulating amplifiers. Notice that the simplified form is of the *non-inverting* type of operational amplifier. This is not so apparent at first glance and is determined by the fact that the reference voltage (E_{IN}) is a negative voltage and results in a negative output voltage. However, the feedback loop is connected to the opposite input of the amplifier and any change in output voltage is amplified and inverted to move the output back to its original level. E_{IN} in this case is the reference voltage provided by the zener diode VR1114. R1122, the 250Ω pot is the -12 volt adjustment, so as before, we identify R_F and R_i.

So

$$\begin{aligned} R_F &= 453\Omega + 125\Omega \\ &= 578\Omega \end{aligned}$$

$$\begin{aligned} R_i &= 1580\Omega + 125\Omega \\ &= 1705\Omega \end{aligned}$$

$$\therefore \frac{E_O}{E_{IN}} = 1 + \frac{R_F}{R_i}$$

$$\begin{aligned} \frac{E_O}{-9} &= 1 + \frac{578}{1705} \\ &= \frac{2283}{1705} \end{aligned}$$

$$\begin{aligned} \text{hence} \quad E_O &= \frac{-9 \times 2283}{1705} \\ &= -12.05 \text{ volts} \end{aligned}$$

A slight adjustment of R1122 will bring E_o to exactly -12 volts.

CONCLUSION

In summary, we find that the typically high open-loop gain and low output impedance of operational amplifiers make them ideal for use in achieving a constant voltage power supply. They do, however, have limitations as to the range of frequencies over which they can maintain a constant output voltage.

TEKSCOPE

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Editor: Gordon Allison Graphic Designer: Jim McGill For regular receipt of TEKSCOPE contact your local field engineer.

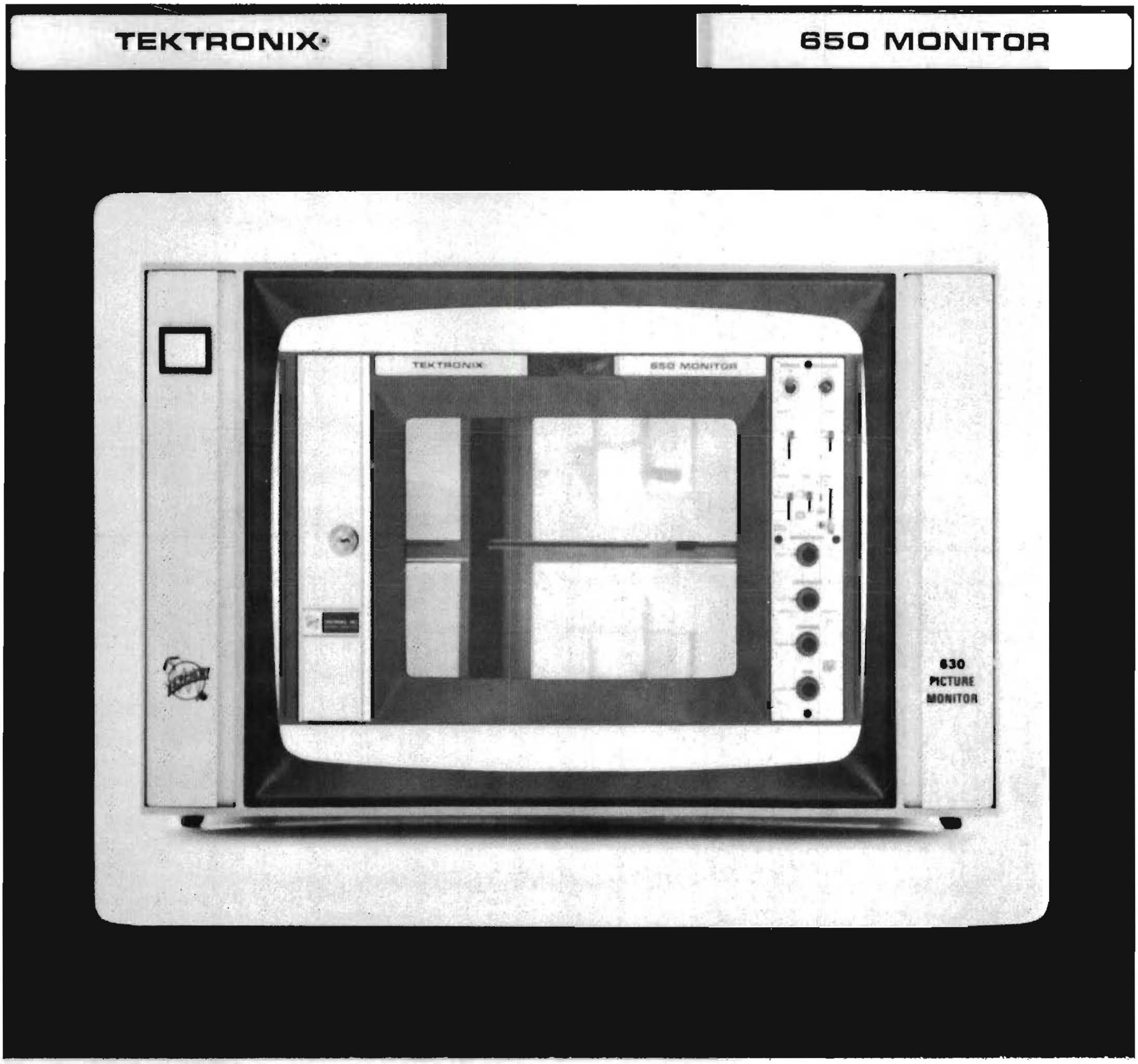
At left, top to bottom, the Programmer 926, the Printer 941 and the Instructor 928

INTRODUCING THE TEKTRONIX CALCULATOR FAMILY

At right, top to bottom, the Statistician 911 and the Scientist 909 Calculators

TEKSCOPE

NOVEMBER 1971



Tektronix and the World of Television Measurements

Measuring Distortions in the Television Signal

Using the 144 as a Simple Special Effects Generator

A Quick-Cal Procedure for the 520 Vectorscope

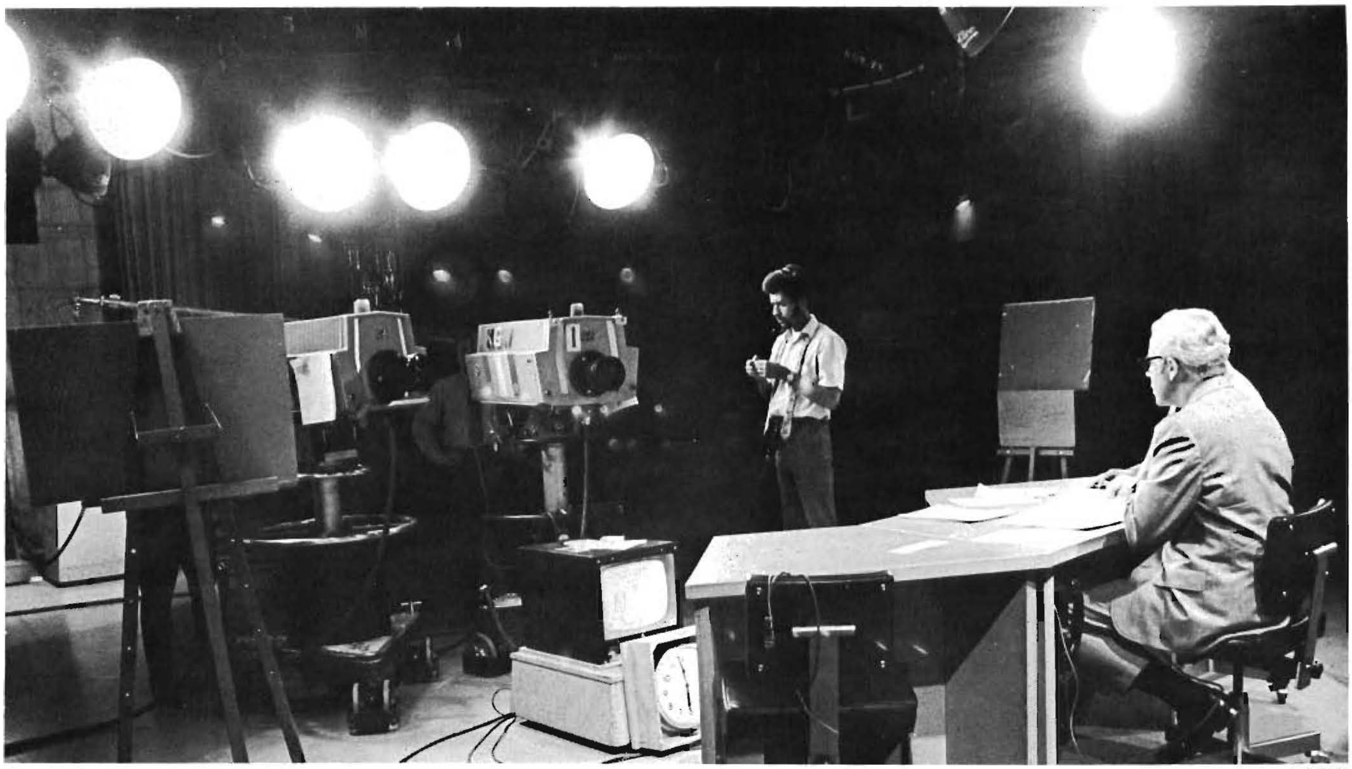


Photo courtesy of KGW

Tektronix and the World of Television Measurements

by Stephen D. Kerman
Manager of Television Product Market Development

__Cover:__ Two new TEKTRONIX picture monitors are featured on the cover. The display on the center 650 Color Picture Monitor is called "Pulse Cross" and is used for on-the-air testing by the broadcaster. The 630 is a monochrome picture monitor.

From Swiss Chalet to a flat in London to a split-level home in Suburbia USA, one common scene is the family watching television. The languages are different, the systems by which color television is transmitted are different, but today hundreds of millions of people are accustomed to viewing in their own home, scenes from the moon and around the world, live and in color.

TEKTRONIX television instruments, waveform monitors, vectorscopes, test, transmission and synchronizing generators, and picture monitors will be found at almost every point in the television broadcasting system.

In addition to manufacturing television measurement products used in nearly every country in the world, Tektronix, Inc. plays an active part within the television engineering community developing measurements and techniques that help make the 25-inch color picture in your home a reality.

There are three color television systems in use around the world. The U.S. system, N.T.S.C. was the first system in regular use. The National Television Systems Committee developed the system which was put into regular use in the early 1950's. The NTSC signal adds a phase modulated subcarrier frequency to the rather predictable monochrome signal. In the U.S., this signal is an analog of scene brightness (luminance) one volt in amplitude. Each horizontal line in the U.S. is 63.5 microseconds long. During the first 11 microseconds, a synchronizing pulse and a reference burst of the color subcarrier occur to keep the system in step.

In Europe the PAL, or Phase Alternate Line system, is in wide use. Similar to NTSC in that there is a phase modulated subcarrier on the luminance signal, PAL has one major advantage over the U.S. system. The phase of the reference burst alternates on succeeding lines of the television picture. By comparing phase errors on succeeding lines which, by the nature of PAL, are equal but opposite, these errors may be nulled out and cancelled.

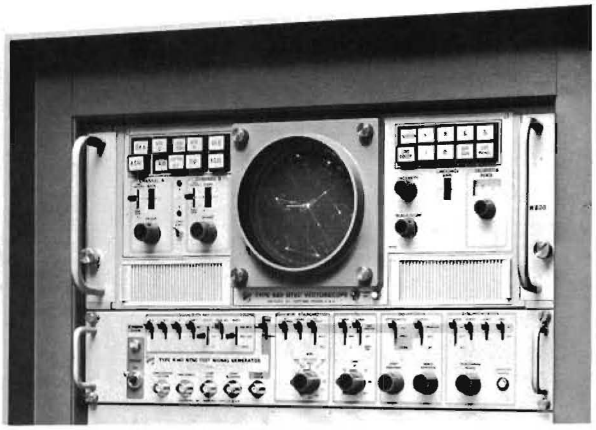
In France, Russia and many eastern European countries, SECAM, the French color system is in use. SECAM uses a frequency modulated subcarrier as its color transmission medium. SECAM receivers are the simplest of the three systems as neither chroma nor hue controls are needed.

Irrespective of the system in use, the television system must have synchronizing equipment. At this most important place in the system one finds the first of the TEKTRONIX television products. At present there are TEKTRONIX sync generators for European PAL (141A), South American PAL (142) and NTSC (140, 144, 146). These generators also include test signals for system checkout which we will discuss later. Use of the 144 to provide a special effects horizontal wipe function is described in the Teknique section of this issue. All of the generators derive the signals by digital means and represent the state-of-the-art in reliability, so important when the whole television system depends on these signals.

In addition to synchronizing and reference color burst signals, the television video signal contains information on scene brightness called "luminance" and scene color called "chrominance". Chrominance has two components, hue and saturation, which are represented by the phase and amplitude of the chrominance subcarrier. The video signal must be processed many times before it appears on the kinescope of your home TV set. It is sent by cable, microwave and satellite transmission and is eventually radiated by your local television station. Subscribers to community antenna systems (CATV) receive signals after further processing. Considering the gyrations the television signals undergo, it is remarkable that we see pictures at all. We like to think that Tektronix helps to make this possible.

Let's follow the picture from its creation in the studio and define some of the parameters to be measured and the instruments used to make these measurements. Details on the test signals and the measurements are found elsewhere in this issue. The live or film (telecine) television camera optically splits the light reflected by the scene into the three primary colors, red, green, and blue. These primary color components are converted into individual electrical video signals and then, in the camera control unit, the first of many measurements is made. The signal level (brightness) and balance between the three primary signals is measured and adjusted using a waveform monitor.

The waveform monitor is similar to a conventional wide band oscilloscope. The major differences are in triggering, sweep speeds and vertical amplifier response. Waveform monitors trigger on either the line or field sync information.



The TEKTRONIX 520 Vectorscope and 140 NTSC Signal Generator play a vital role in color broadcasting.

The sweep speeds are selected to display one or two lines or fields of information. Magnifiers permit close examination of small portions of these signals. Digital as well as variable delay permit rapid, accurate selection of discrete lines which, as you will see later, may contain test signals.

The vertical response of the waveform monitor must be very flat within the 6 MHz video band. It is usually within 1%. To accomplish this waveform monitors have a -3db bandwidth of about 18 MHz. Special filters are also available to limit response. A notch filter at the color subcarrier frequency enables viewing of the chrominance information only. A high pass filter permits measurement of differential gain with the waveform monitor. Differential gain is the amplitude change of the color subcarrier signal component as it changes from a low (black) to high (white) luminance level. The modulated staircase test signal is used to make this measurement.

From the camera control unit, the signals pass to an encoder where the three primary color video signals are encoded into a single signal of the system in use (NTSC, PAL, or SECAM). A second TEKTRONIX instrument, the vectorscope, may now be used to check the encoding process. The vectorscope is an X-Y oscilloscope which displays the chrominance component of an encoded video signal. The display of vectors shows both hue and saturation and may be used to accurately set up encoders and other signal processing equipment. The vectorscope is also used to match the relative phase of two color signals. Since it is phase sensitive, it is used to measure differential phase. Differential phase is the change in the phase of the color subcarrier signal as it changes from a low (black) to high (white) luminance level. Like the waveform monitor, the vectorscope can display discrete lines in the vertical interval to make in-service tests. Vectorscopes also make differential gain measurements as well as measurements of luminance cross-modulation.

Video tape recorders provide another source of program material. These complex machines use waveform monitors as well as vectorscopes for signal analysis. In addition to video signal processing, VTR's must provide the operator with information on the electromechanical operation of the machine. Servo control, head switching and other related signals are monitored by special oscilloscopes. One VTR manufacturer uses a modified waveform monitor to

TEKTRONIX Waveform Monitors are an integral part of these broadcast video tape recorders. Photo courtesy of KGW

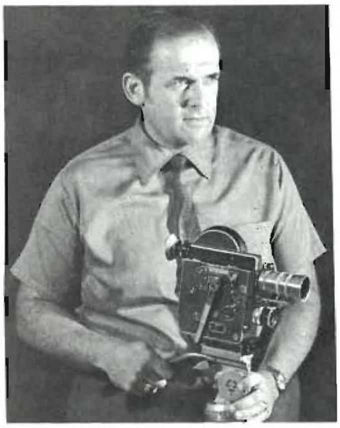
display these signals. A second manufacturer uses a TEKTRONIX X-Y display unit with a companion waveform monitor.

We have not mentioned pictures in this discussion of the television system. Even though test signals are important measurement tools, the picture is the end product and is all-important. Television picture monitors used by broadcasters have several features not found in home television sets. They must be very linear and have high bandwidth and resolution to accurately display the picture. Picture monitors should also have some measurement capability. Quality picture monitors must have standard phosphor colors so that they match each other and their reliability and ease of calibration cannot be overstressed.

Tektronix Inc. has recently introduced both monochrome and color picture monitors which meet these criteria. The 650 family of color monitors are made in single or dual standard versions for displaying television signals encoded in different parts of the world. Rapid retrace time enables the broadcaster to display the entire field of picture information. Observation of both vertical and horizontal blanking insures the broadcaster that he is seeing the whole picture. By delaying the start of the display vertically and horizontally, the vertical and horizontal sync signals are displayed on screen. This display, called "PULSE CROSS", combined with another unique capability of TEKTRONIX picture monitors, A-B or differential input display, makes visual comparison of sync timing errors easy. On the 650 color monitors, reference burst is also displayed in PULSE CROSS. Using the A-B input mode, burst phase errors appear as a color band. When the burst time, width and phase of each signal is equal, they subtract leaving a null on the kinescope display.

After the programs are assembled from the various sound and picture sources, they are sent from the studio to the transmitter or a network of many stations. It is easy to check a video system while off the air as test signals filling the full picture field may be used. This is not possible while on the air, however, because the actual picture fills the field. The first 20 lines of the television picture do not include picture information. This interval, the vertical blanking and sync interval, affords the broadcaster some time for in-service testing. Insert test signals, Vertical Interval Test Signals (VITS), described in detail elsewhere in this issue, are placed on individual lines at the end of the vertical blanking interval. They are out of the active picture area and hence do not interfere with viewing. They undergo the same changes as the rest of the picture signal, however, and provide a fine source of measurement information. TEKTRONIX test signal generators are available to provide both full field and insertion test signals. They are easily programmed so that the broadcaster may insert signals in any available line of either field of the vertical interval. For some applications specific signals have been assigned to specific locations by legislation or by industry agreement.

As you now see, television is not all cartoons and comedy. In addition to the drama on the screen, there is an electronics drama taking place at hundreds of locations between the originating studio and your home. TEKTRONIX television products are at each of these points, from generators for sync and test signals, waveform and vector oscilloscopes for signal analysis, to picture monitors for final evaluation. Around the world one common thread in the television measurement field is the TEKTRONIX television product.



***Stephen D. Kerman** — Steve has a broad background in television broadcasting, having worked closely with the TV broadcasters and networks during his nine years as a field engineer in the New York area. He authored a book entitled "Color Television and How It Works", written for the high school level student. Steve received his B.E.E. from Rensselaer Polytechnic Institute in 1960 and is a member of the Royal Television Society and the Society of Motion Picture Television Engineers. His leisure time is shared with his wife and three children, playing the tuba with the Beaverton Community Band and producing motion pictures.*

TEKTRONIX®

November 1971

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- ☐ **AN/USM 281C Oscilloscope**
- ☐ **7A21N Direct Access Plug-in**
- ☐ **X-Y Plotter 915**
- ☐ **Teletype Interface 944**
- ☐ **3003 Computer Operated Waveform Digitizer**
- ☐ **147 Option 1 NTSC Test Signal Generator**
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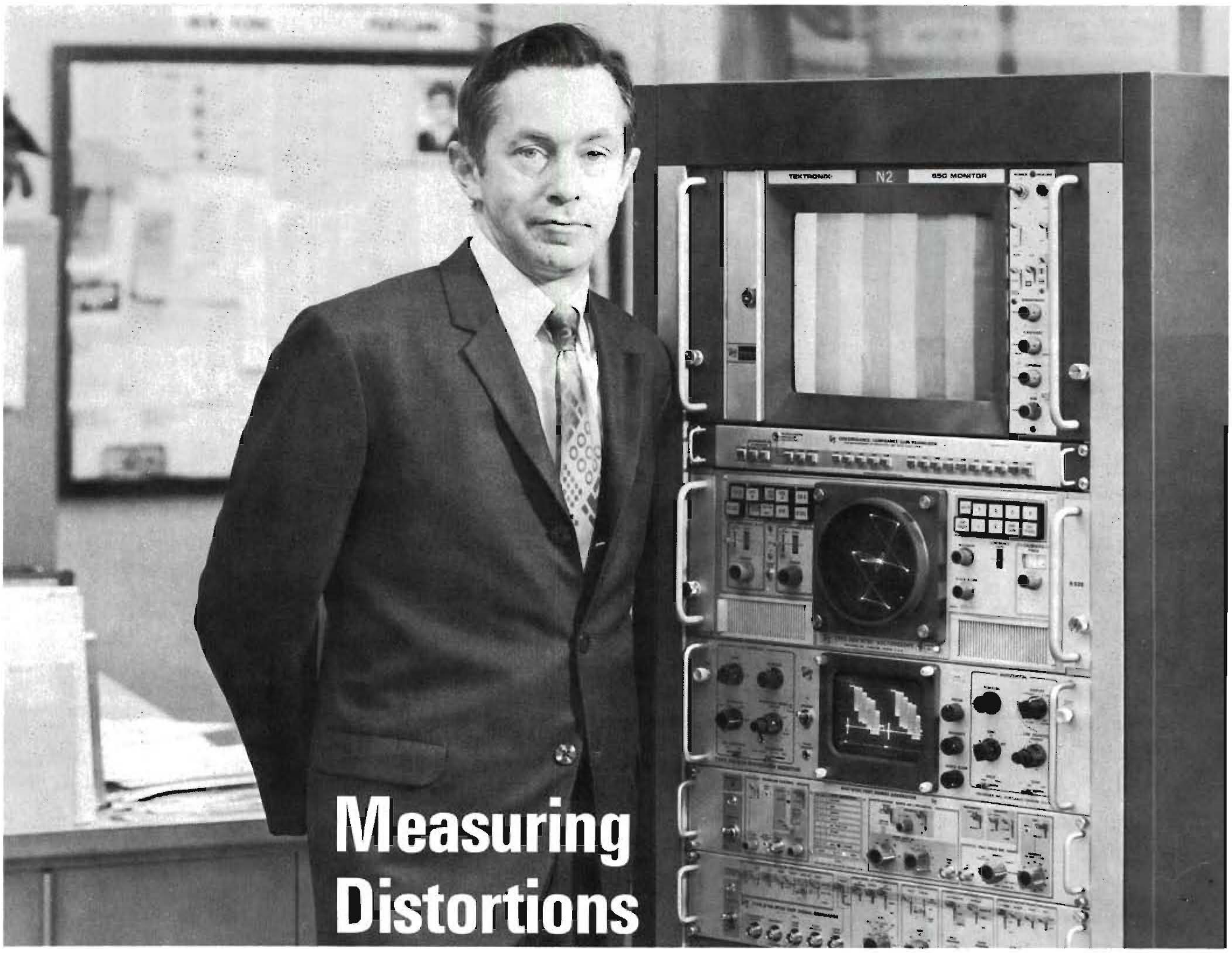

Measuring Distortions in the Television Signal

by Charles W. Rhodes
Manager, TV Products Development

The television picture signal presents a constant challenge to the state-of-the-art in transmission and measurement capability. As the state-of-the-art improves, the objectives in transmission distance increase; witness the "live-in-color from the moon" pictures sent via satellites, microwave radio relay and coaxial cables to a large portion of the world populace. However, as the novelty of color wore off, increased expectations for more consistent, pleasing and plausible color were felt.

Only a few years ago, distortions were large enough that they could easily be measured, usually after or before the broadcast day began. Today, nearly all measurements are on an "in-service" basis using the vertical interval test signals (VITS). These accompany the program video because, in some cases, the broadcast day is 24 hours long. In other cases, test time over a satellite is just too expensive to justify. The distortions have decreased in recent years adding to the difficulty in measuring them because of noise masking. This is especially true when measured, as is now nearly universal, by means of VITS.

Some of the television test signals are highly sophisticated, but the concepts underlying them and their measurement techniques are hardly confined to television.

Tektronix plays a leading role in the television measurements field. We thought many readers of TEKSCOPE, both in and out of television, might find this measurement technology of interest. Three major aspects of the picture signal establish the basic measurements requirements:

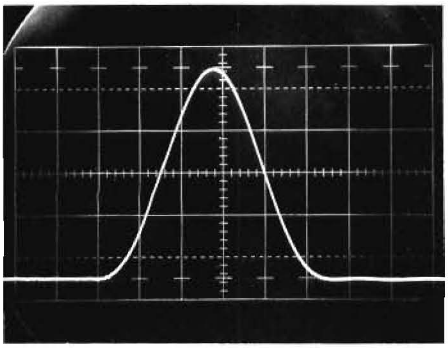

Fig. 1 The sine-squared pulse widely used in testing TV and other bandlimited systems.

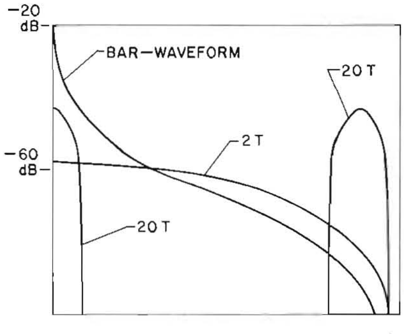

Fig. 2 Energy distribution of sine-squared 2T, 20T and bar signals.

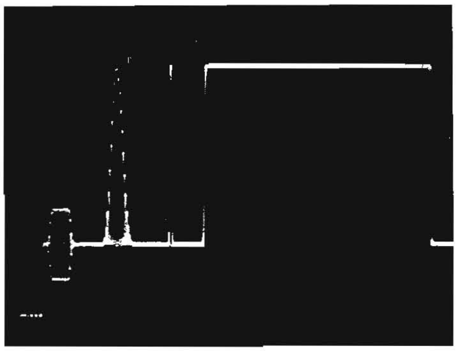

Fig. 3 Sine-squared pulse and bar with modulated 20T pulse.

1) Being an analog signal, serious picture impairments result from small non-linearities in any one of several transfer characteristics. Both PAL and SECAM color systems were developed to reduce picture impairment due to these non-linearities.

2) The signal is band limited due to the scarcity of RF spectrum vs demand. Each TV channel is 6-9 MHz wide. TV is the greatest consumer of the spectrum below 1 GHz and uses significant spectrum above 1 GHz.

3) The mean level of signal is not constant, i.e. average brightness of the TV scene represents a DC video signal level. This must be transmitted with accuracy.

While the highest video frequency is limited by both spectrum conservation and noise, the TV signal is not considered in the frequency domain for measurement purposes. Video waveforms are nearly always non-sinusoidal. Hence, time domain measurements permit measurements which can be correlated with picture impairments such as smear or streaking. For example, tilt in a 10 ms squarewave produces objectionable streaking from left to right; in a 10 ms squarewave, it produces a variation in picture shading from top to bottom.

The time domain may be conveniently broken up into four parts, each giving rise to differently perceived picture impairments:

1) Short Time Distortions (0.125 µs to 1 µs). These affect picture crispness or resolution, horizontally. Undershoots make the picture "soft" or blurry. Overshoots, if not too great in amplitude, tend to enhance picture sharpness. Ringing results in echoes or halos.

2) Line Time Distortions (1-50 µs). These cause horizontal streaking which is positive if due to overshoot or negative if due to undershoot.

3) Field Time Distortion (50 µs-16 ms). These cause shading in the vertical direction.

4) Long Time Distortions (> 16 ms)—cause flicker.

In television, the limit on bandwidth (4.2MHz in North and South America, Japan) makes the usual fast rise squarewave type of test signal of very limited usefulness. Such pulses, introduced into sharp cutoff systems, suffer out-of-band component attenuation which results in ringing in the output pulse at the approximate cutoff frequency (f_c) of 4.2 MHz. This behavior is predicted by theory; there is no need to obscure inband distortions with the out-of-band distortion.

The sine-squared pulse (Fig. 1) is widely used in TV measurements and in other band limited systems. It possesses negligible energy at frequencies above $f=\frac{1}{\text{h.a.d.}}$, where h.a.d. = half amplitude duration, or pulse width, as measured at the 50% points. It is important to note how its energy is distributed within its passband. This is shown in Fig. 2. At $f=\frac{1}{2\,\text{h.a.d.}}$, energy is at −60 dB, thus energy is rather evenly distributed across the passband.

In testing, where the response is not limited by a sharp cutoff at f_c, we use a pulse whose h.a.d. = 0.125 µs. Where the system does have a sharp cutoff characteristic (e.g. the broadcast transmitter, video tape recorder or CATV modulator or demodulator) we use a pulse of 0.25 µs h.a.d. These pulses are 1T and 2T pulses respectively. T, the Nyquist interval, is taken at 0.125 µs in the Western Hemisphere and Japan (where $f_c = 4.2$ MHz).*

The sine-squared pulse may be compared to impulse testing in time-domain reflectometry. The step type test signal corresponds with the "sine-squared bar" which is actually an integrated sine-squared pulse (See Fig. 3). Mathematically, the risetime, 10-90% amplitude, of an integrated sine-squared pulse = 0.96 of its h.a.d. Its energy spectrum is shown in Fig. 2. In actual practice, this test signal is usually generated by driving a very fast step signal of the desired width and repetition rate into a sine-squared shaping filter. Such filters were originally developed by Mr. W.E. Thompson in England about 1951 (See Fig. 4a).

Recently, Mr. Arend Kastelein of the Television Engineering Staff, Tektronix, Inc., designed very similar filters, but having somewhat improved properties.[1] These are used in nearly all TEKTRONIX sine-squared pulse formation circuits. Fig. 4 b compares the ideal sine-squared pulse with that of Kastelein's 9-pole filter.

It is possible to use the sine-squared pulse or bar to measure Short Time Distortion, one being the integral of the other. The bar is used to measure Line Time Distortion. To facilitate these measurements when using a television waveform monitor, special graticules are often used. Fig. 5 shows one such recently developed graticule[2], which will be available for the TEKTRONIX 529 Waveform Monitors. It is intended to measure the waveform distortion in terms of a picture impairment K factor. In such testing, the worst distortion of the bar establishes the picture

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**On the European scene, $T = 0.100$ us to correspond with a nominal $fc = 5$ MHz (although some countries actually have somewhat higher bandpass limits).*

TEKTRONIX®

NEW PRODUCTS

NOVEMBER 1971

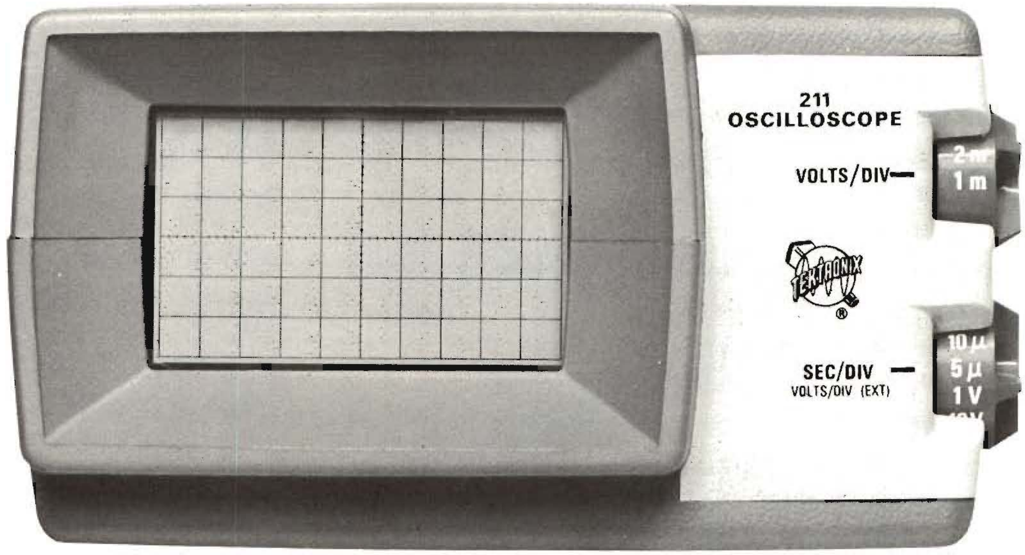
SUPPLEMENT NO. 3 to the MARCH '71 CATALOG

PORTABLE OSCILLOSCOPES

The 211 Oscilloscope weighs only 3 pounds, measures only 3 x 5¼ x 9 inches. Yet it is a complete measurement tool for field maintenance and other applications where space and portability are primary considerations. It's the first laboratory-quality miniscope offering performance, plus unmatched portability and carrying convenience, at a lower price than many other 500-kHz scopes.

In many industrial applications, it's frequently necessary to "float" an oscilloscope. The 211 may be elevated to 700 V (DC + peak AC) above ground when operated from batteries, and 250 V RMS when operated from AC.

The 211 is designed to withstand the shock, vibration and other extremes of environment associated with portability.



Actual Size

Ease of use is evident in the 211. Deflection factors from 1 millivolt to 50 volts/div, and sweep rates from 5 microseconds to 200 milliseconds/div are read out directly from the front panel, where they are related easily to the CRT display. Triggering requires only one rotary control.

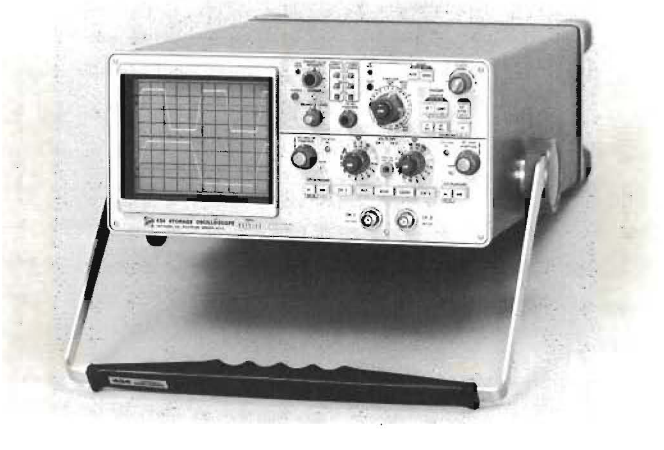
The 211 is equipped with an integral flip stand which tilts the scope to a convenient viewing angle for bench-top operation. The integral probe and power cord wrap around a recessed area in the case. They are out of the way, and you know exactly where they'll be when you reach your next job.

An oscilloscope used in maintenance applications should be ready to travel when needed. This means that it has to be easy to service to eliminate the purchase of back-up scopes. The 211 disassembles quickly and easily into its modular components for easy access to internal components.

The internal DC source contains 10 NiCd cells providing 3.2 to 4.5 hours of operation. A battery meter indicates charge level. An external AC source can be used to operate the 211 and the internal charger. Maximum recharge time is 16 hours.

The 211 covers an extremely wide range of applications including industrial controls, mobile electronic facilities, audio communications, telephone and military applications, office equipment, logic level isolation, numerical control equipment, electronic scales, motor controls, interoffice and interplant communications, avionics, marine electronics, frequency translator maintenance and others.

211 Oscilloscope $545



The 434 Storage Oscilloscope, Option 1, a companion to the 434 Storage Oscilloscope described in the July Supplement, provides an increased single sweep writing speed of 500 cm/ms. Enhanced writing speed is increased to 5000 cm/ms.

Bandwidth is DC to 25 MHz and deflection factors are 1 mV/div to 10 V/div. A wide range, direct-reading magnifier expands the horizontal display up to a maximum of 50 times in six steps. 20 ns/div is the fastest magnified sweep. To save operator time and reduce errors, lighted knob skirts read out scale factors even when using the recommended 10X probe.

434 Storage Oscilloscope, Option 1 . . . . $2175

U.S. Sales Prices FOB Beaverton, Oregon

For further information or a demonstration of these products, please contact your local TEKTRONIX Field Office or return the enclosed inquiry card.

The PLOT-10 software provides outstanding versatility and is compatible with over 20 timesharing systems, with IBM 360/370 systems and a host of mini-computers. Also, PLOT-10 provides the most extensive capabilities in graphing and application-interface routines. The new PLOT-10 software package lets computers display more information in less time than ever before.

The 4610 Hard Copy Unit provides permanent copies of the alphanumerics and graphics displayed on the 4010 Computer Display Terminal. Copy medium is 3M Type 777 Dry-Silver paper and copy size is 8½ x 11 inches. The easy-to-handle copies are convenient for communication, documentation, recording and filing uses.

4610 Hard Copy Unit	$3550

U.S. Sales Price FOB Beaverton, Oregon

THE FOLLOWING PRODUCTS WERE INCLUDED IN PREVIOUS NEW PRODUCT SUPPLEMENTS

Supplement No. 1

7904 500-MHz Oscilloscope System
432 25-MHz Portable Oscilloscope
434 25-MHz Portable Storage Oscilloscope
453A-1,-2,-3,-4 60-MHz Portable Oscilloscopes
1401A/1401A-1 Portable Spectrum Analyzers
147 NTSC Test Signal Generator
148 EBU Insertion Test Signal Generator
630 Monochrome Picture Monitor
650 Color Picture Monitor
2620 Stimulus Isolator
26A2 Differential Amplifier
C-5 Camera
C-59 Camera
Writing Speed Enhancer
P6060/P6061 Probes
Calculators
1711 Machine Control Unit
1791 NC Program Verifier
4002A Graphic Computer Terminal

Supplement No. 2

7L12 Spectrum Analyzer
7CT1N Curve Tracer
5103N/D15 Storage Oscilloscope
R5103N/D15 Storage Oscilloscope
5A13N Differential Comparator
5A14N Four-Trace Amplifier
5A22N Differential Amplifier
5CT1N Curve Tracer
172 Programmable Test Fixture
1501 Time Domain Reflectometer
P6056 Probe
P6057 Probe
603 Storage Monitor
604 Display Monitor
4602 Video Hard Copy Unit
S-3160 LSI/MOS Test System

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661, 5T3, 4S1. $1000. Mr. D. Kahler, Fincor, Inc. 1000 E. Boundary Av., York, Pa. 17403 (717) 843-7841

453, 2-P6010, 2-P6028 Probes. Make offer. Barry Noll, Famco Machine Co., 3100 Sheridan Rd. Kenosha, Wi. 53140 (414) 654-3516

517A. Best Offer. Robt. A. Miller, Renton School Dist, 410 Wells Av. S. Renton, Wa. 98055 (206) 235-2437

561B/3A6/3B3/P6006. $1500. Herman Bourgeois, 15432 Hobart Rd., Issaquah, Wa. 98027 (206) 392-5487

D-54 $475. Eric Breece, 30 Otis Way, Los Altos, Ca. 94022 (415) 941-2376

545B, 1A1, 1A6, 202-2. $1800. Larry Glassman, 5584 Benton Woods Dr. NE, Atlanta, Ga. 30342 (404) 255-5432

453 $1600. Henry Beyreis, HMB Enterprises, 4733 Brooks, Montclair, Ca. (714) 626-8015

TLD43 w/2-A plug-ins. $400. Mr. Vitale, Vitale's Electronics, RD 6, Box 377, Newton, NJ 07860 (201) 383-5565

524AD, 202-2 scope cart w/probe. Best offer. Dennis Dunbar, WSKG-TV, Box 954, Binghamton, NY 13902 (607) 798-7177

545A, CA, L, 132. $1300. Frank Cameron, 490 Cherry Av, Los Altos, Ca. 94022 (415) 941-2842

D Plug-in $100. James McCoy, Echometer Co., 1640 P.B. Lane, Wichita Falls, Tx. 76302. (817) 767-0218

454. Dan Stalling, Electra/Midland Corp. PO Box 760, Mineral Wells, Tx. 76067 (817) 325-7871

516A w/cover & viewer $700. Wm. Kraengel, 65 Sunset Rd., Valley Stream, NY 11580 (516) 825-6436

RM144, $1600. Bill Canora, WHNB-TV, 1422 New Britain Av., West Hartford, Ct. 06110 (203) 521-3030

524D w/Scopemobile $300. T. Arthur Bone, Poole Broadcasting Co. WPRI-TV, 24 Mason St., Providence, RI 02903 (401) 521-4000

543A, L, D, $850. Leo Wulff, PO Box 172, Cockeysville, Md. 21030

INSTRUMENTS WANTED

576. Jim Derda, 12741 Las Nietas Rd, Santa Fe Springs, Ca. (213) 698-3712

531A. Brian Y. McCay, 10288 Anderson Rd., Granger, In. 46530 (219) 674-5096

549/1A1. United Car Canada Ltd., Box 500, Stoney Creek, Ont., Canada. (416) 664-4401

507. Wm. A. Irby, ITE Imperial, 1900 Hamilton St., Philadelphia, Pa. (215) 822-1306

1A1. Ray Sollars, 4101 N. Figueroa St., Los Angeles, Ca. 90065 (213) 225-1564

TQ Scope. J.C. Cunningham, Cox Cable Communications, Inc. 1601 W. Peachtree St., Atlanta, Ga. 30309

535A w/ or wo plug-ins. Electronic Institutes, 1402 Penn Av., Pittsburgh, Pa. 15222 (412) 471-3962

535. M. Rice, Box 1460, St. Charles, Mo. 63301

TEKSCOPE Classified Ads Supplement

November 1971

INSTRUMENTS FOR SALE

561A, 3A1, 3B3, 2-P6006 Probes, $1100 package price. Richard Hertel, ITT Electron Tube Div, 3700 E. Pontiac St., Ft. Wayne, Ind. 46803 (219) 743-7571 X703

2-3T77 Plug-ins. $300 ea. John R. Sewell, RCA Corp, 3900 RCA Blvd. M/S 30-7, Palm Beach Gardens, Fl. 33403

565 w/3A3 Amp & 3C66 Amp; 205-3 scope cart. Peter Schiff, SMEC, Box 117, Schwenksville, Pa. 19473 (215) 287-8611

561A, 3A1, 63 Diff. Amp, 3B3, 2B67, Roger Kloepfer, 1428 Ormond St., Lansing, Mi. 48906 (517) 487-6111 X392

561A (2), 555, 3A74, 3A1, 2B67 (2), 503, C27P, CA (2), 21A, 22A. F. Modrarrad, Teledyne Ind., Inc. 703 37th Ave., Oakland, Ca. 94601 (415) 532-7404

585, 547, 544 (4), 543, 541, 533 (2), 531A (13), 53C (2), 53/54A (2), B (17), CA (2), L (13), M, 82, 1A1 (3). E. Pulaski, Ferroxcube Corp., Mt. Marion Rd., Saugerties, NY 12477

531A w/CA $800. J. Steskal (414) 224-7533

D54. D B Electronics, 76 Dennisville Rd., Cape May Ct. House, NJ 08210 (609) 465-5005

515A, 543, 545A, 547, CA, 1A4, 1A2, 2022, Ind. or as system. E.J. Oislander, 140 Sandford Blvd, East, Mt. Vernon, NY. 10550 (914) 664-7530

561A, 3A1, 3A72, 2B67. Max Scholfield, Crown Intl., PO Box 1000, Elkhart, Ind. 46514 (219) 523-4919

533A w/1A1. Make offer. G. Byrd, Mostek Corp, 1400 Upfield, Carrollton, Tx. 75006 (214) 242-1494

454 $2500 Gerald Durbin, Westminster, Ca., (714) 531-6008

316, $475. RM15, $525. Exc. cond.Cartronics, PO Box 3177, Indialatic, F1. 32903 (305) 723-1821

TLS54. C. Patnoi, Unirad, Inc. 4665 Joliet St., Denver, Co. 80239 (303) 364-7258

531, 53B, $300. Eugene Mirro, PO Box 274, Hightstown, NJ 08520 (609) 799-1495

180A, $150; P6019, $75; 81, $25; W, $225; 202-1, $45; 514, $225; 512, $200. Goslin Electronics, 2921 W. Olive, Burbank, Ca. 91505 (213) 848-0776

454, 200-1 Scopemobile, both for $1700, Franz Zenker, Box 72, Lake Peekskill, NY, 10537 (914) 528-8194

1L5, $600. Sell or trade. J.R. Stewart, Santa Rita Technology, 960 N. San Antonio Rd, Los Altos, Ca. 94022

CA Plug-in, new, $250. Barry Synder, Xerox Data Systems, 701 S. Aviation Blvd., El Segundo, Ca. 90245 (213) 679-4511

R140, 1½ yrs. old, exc. cond. $1700. Art Phelps, Davis, Ca. (916) 752-2182

453A, C30AP, P6011, like new, make offer. Ray Pitts, 4376 Haines Av, San Jose, Ca. 95123 (415) 966-2691

323, 1 yr. old, $800. Gen. Business Machines, 1108 Commonwealth Av., Boston, Ma. (617) 232-1186

611. Ernest G. Burgess, Computer Animation Ind., Inc., PO Box 832, Tullahoma, Tn. 37388

R564B (4), R561B (2), 2A63 (7), unused, Wm. Schell, % Computest Corp. (609) 424-2400

526. $650. Mr. Fred Hodge, Minnesota Mining & Mfg. Co., Camarillo, Ca. 93010.

422 S/N 13274. McPherson Industries, 20050 Sherwood, Detroit, Mi. 48234 (313) 892-3020.

543B/H/CA/Scopemobile cart/P6015/X10/X1. $1800. 515A/X10/X1, Scopemobile cart, $700. Daniel J. Kubat, Gen. Communications Co., 827 S. 20th St., Omaha, Nb. 68108 (402) 341-8069.

545B, 1A2, M, W. Larry Luce, Pac. SW Airlines, 3110 Goddard Way, San Diego, Ca. 92112 (714) 297-4781

535/CA/E $970. 515A, $630. John K. Green, Box 1038, Boulder, Co. 80302

535A/CA. db Electronic Enterprises, 13526 Pyramid Dr., Dallas, Tx. 75234 (214) 241-2888

531/CA/D. George Bolen, 1012 Hobbs St., Sac City, Ia. 50583 (712) 662-7860

575. Jim Derda, 12741 Las Nietas Rd, Santa Fe Springs, Ca. (213) 698-3712

422 w/2 Probes. AC only. $800. E.J. Hokanson, 6517 N. Atwahl Dr., Glendale, Wi. 53209 (414) 352-2336

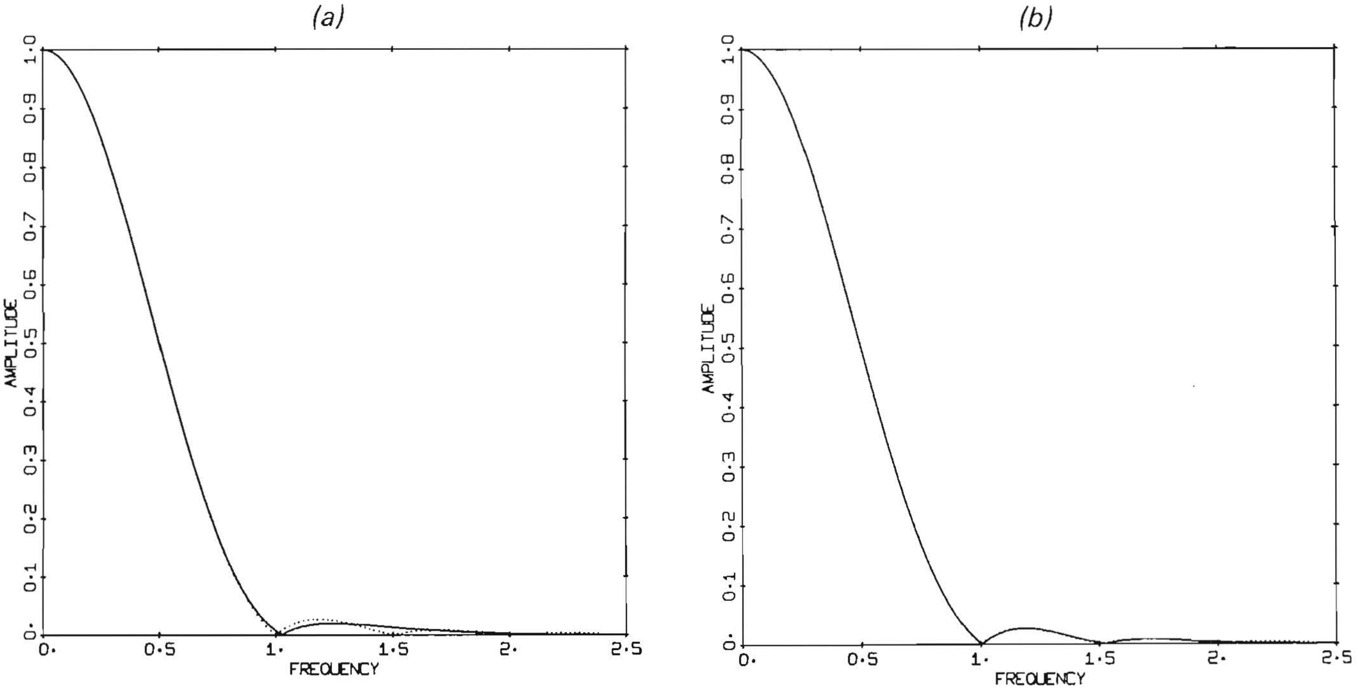

Fig. 4 Spectral distribution of approximated sine-squared pulses from Thompson's 7-pole network (a), and Kastelein's 9-pole network (b). The dotted line represents the spectral distribution of an exact sine-squared pulse.

impairment so measurement is reduced to a quality-oriented number. The derivation and exact manner of use are covered in Ref. 2.

In vertical interval testing, the test signal has a repetition rate of 30 Hz and it is gated into the video system on a chosen line in between fields during the vertical blanking interval. It is possible to conduct Short Time Distortion and Line Time Distortion tests in this way. It is not possible to test for Field Time Distortion, except in measuring the tilt of the vertical blanking pulse itself, a test not wholly adequate. Nevertheless, it is all one can do or needs to do on an in-service basis.

On an out-of-service basis, the most sensitive test signal for Field Time Distortion is a 60 Hz squarewave. This simple technique is not possible in testing TV transmitters and certain other equipment, e.g. stabilizing or clamping amplifiers which require sync pulses to be present for their proper operation.

Tektronix has developed a "field rate squarewave" with composite sync pulses added. This is in the new 147 and 148 test generators and is shown in Fig. 6. This is not a true squarewave because of the sync and blanking pulses. It will exhibit the same sensitivity to distortion as a true squarewave of 60 Hz (50 Hz in the 148, designed for 625/50 standards). Fig. 7 shows a tilt due to a 0.1 second RC coupling time constant.

The usual test signal used for both Field Time Distortion and Line Time Distortion is the "window". This consists of a sine-squared bar approximately 25 μs in duration which appears on about half the TV lines per field; hence, its appearance in Fig. 8 which exhibits less tilt for the same 0.1 second RC coupling time constant.

The new "field squarewave" signal is nearly twice as sensitive as the conventional window to Field Time Distortions. The TEKTRONIX 147 (and 148) generate both the field squarewave and window signal. Sensitivity of the window signal to Field Time Distortion is shown in Fig. 8. The window signal is unmatched in detecting Line Time Distortion in picture monitors or in using picture monitors. Frequently, in using the window, its sensitivity to Field Time Distortion hinders measurement of Line Time Distortion. The trace thickening in Fig. 9 is the result of Field Time Distortion, and in this case it is more difficult to assess Line Time Distortion.

The TEKTRONIX 147 (and 148) also provides a sine-squared pulse and bar signal. This is identical to the window, except that the bar component is present on every active picture line. This substantially reduces the 60 Hz

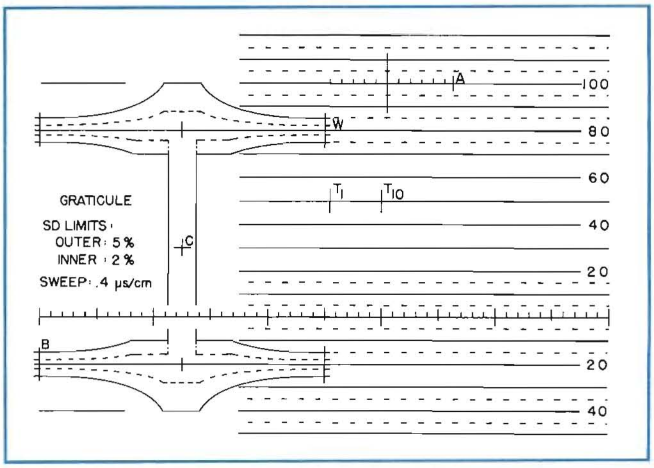

Fig. 5 The new TEKTRONIX graticule for K-factor evaluation of sine-squared pulse and bar testing.

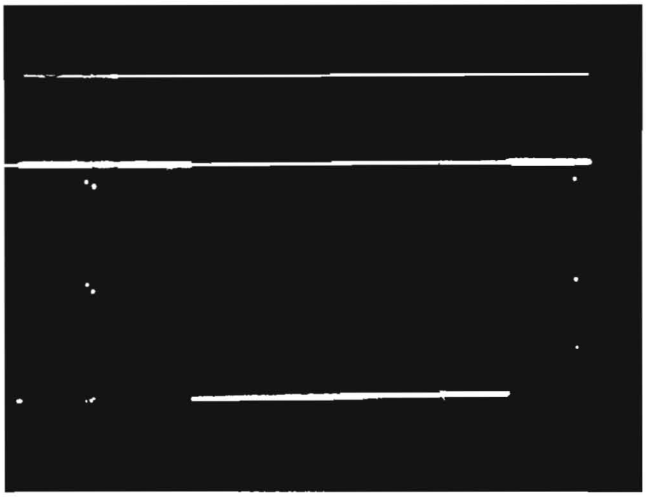

Fig. 6 Field rate squarewave available from the 147 and 148 test signal generators.

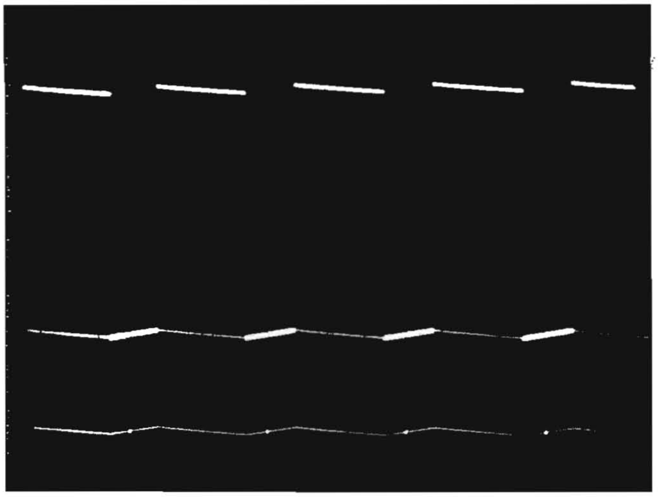

Fig. 7 Tilt in field rate squarewave due to 0.1 sec RC coupling time constant causes Field Time Distortion.

components present; hence, this signal is rather unaffected by Field Time Distortion (Fig. 10).*

Of the three test signals, the window is the best known, and is good for Field Time Distortion, Line Time Distortion and Short Time Distortion; but, it is fundamentally a full field signal. Better results in measuring Field Time Distortion may be had with the new field squarewave, or, to eliminate the effects of Field Time Distortion in measuring Line Time Distortion, the sine-squared pulse and bar signal is effective. Both the window and the sine-squared pulse and bar signals may be set up for 2T or T pulse and bar transitions as desired.

The sine-squared pulse and bar signal is available as a VIT signal and/or full field. Both pulse and bar and window signals include a modulated sine-squared pulse (12.5T). This pulse measures two transmission parameters of importance to color quality, relative chrominance-to-luminance gain and relative chrominance-to-luminance delay. Relative chrominance/luminance gain distortion causes errors in saturation. These errors are especially significant when viewing several stations, or even successive programs on one station. Of course, the home receiver can be readjusted, but with relative chrominance-to-luminance gain distortion kept low, the public does not have to correct it manually.

Relative chrominance/luminance delay is another matter. There is no customer control for this transmission distortion. The public is stuck with the color misregistry. This is not like misconvergence which is objectionable principally on black and white pictures. Relative chrominance/-luminance delay affects only the color programs. It is most easily detected with red lettering against a white background, the red blurring and displaced, generally to the right. This distortion is caused by group envelope delay distortion. It can occur at almost any part of the TV system, but it is especially important in TV transmitters, receivers themselves and in CATV systems.

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*This photo was taken using the 0.1 sec RC coupling, same as Fig. 7 and 8.

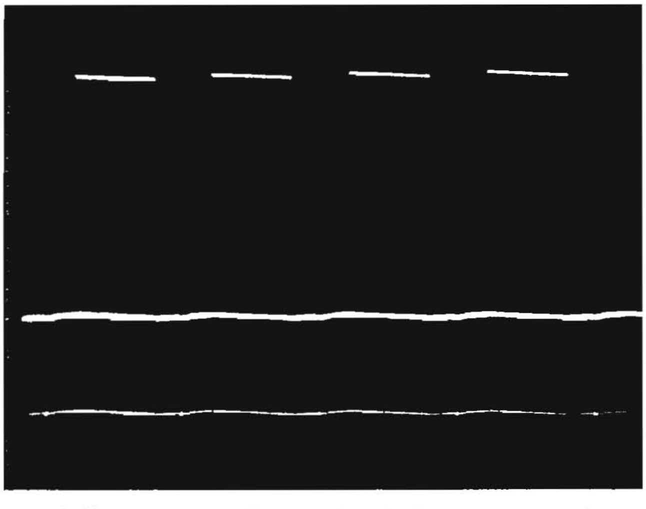


Fig. 8 The "window" test signal yields less sensitivity to Field Time Distortions as evidenced by less tilt due to the 0.1 sec time constant.

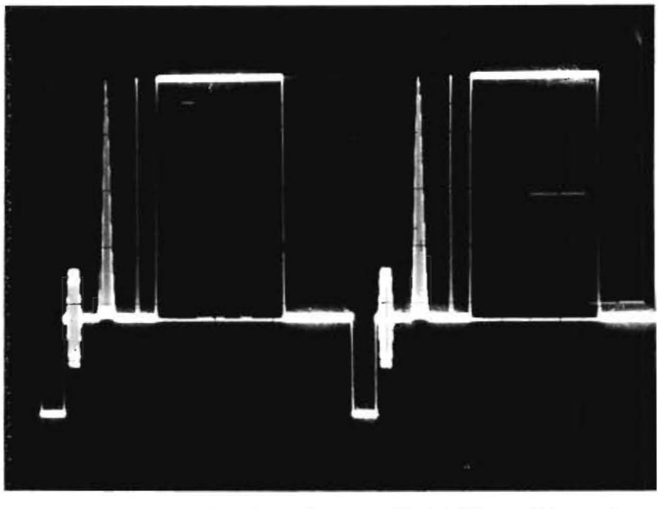


Fig. 9 Trace thickening due to Field Time Distortions makes it more difficult to assure Line Time Distortions.

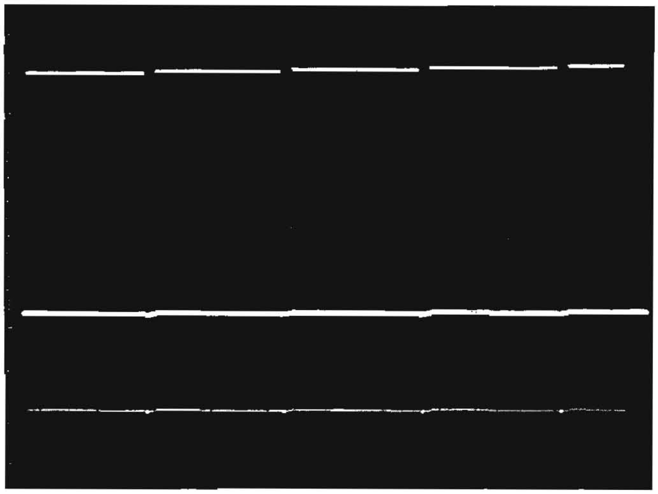


Fig. 10 The 147 and 148 sine-squared pulse and bar signal is present on every line thereby reducing 60 Hz components present.

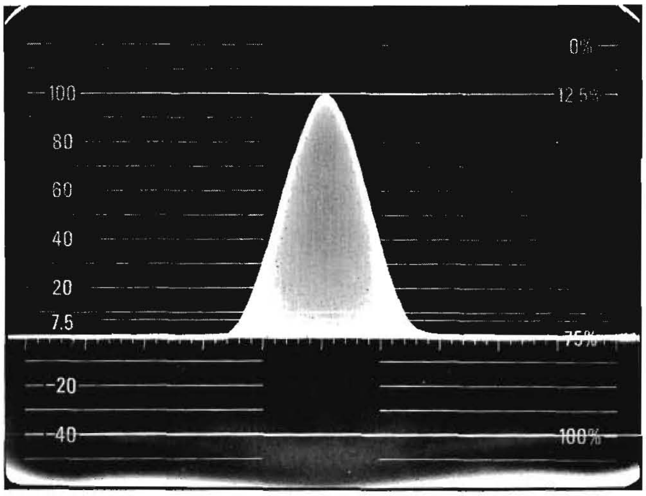


Fig. 11 The new 12.5T modulated sine-squared pulse developed by Tektronix to test for relative chrominance / luminance gain and delay distortions.

These distortions generally appear together. They may be measured using the new 12.5T modulated sine-squared pulse developed by engineers at Tektronix as a proper scaling of the 20T signal originated in Germany.

The 12.5T modulated sine-squared pulse will be standard (on Line 17) on NTSC transmissions via satellite to and from North America. It is expected to be used by the networks in North America on Line 18 or 19 as a component of national test signals. It is also required to be radiated by VHF transmitters operating under remote control, and by UHF transmitters operating under remote control after April 1, 1972 (by recent FCC rule making)[3].

The measurements we've been discussing are but a few of the many needed to insure faithful reproduction and transmission of the video program from the scene of action to your home television receiver. New techniques and products being developed at Tektronix will enhance, still further, the broadcasters' ability to bring you sharp, bright color pictures from any point on the earth, and beyond.

REFERENCES

Ref. 1 Arend Kastelein, "A New Sine-Squared Pulse and Bar Shaping Network," IEEE Transactions on Broadcasting, Vol. BC-16, Number 4, pp. 84-89, December, 1970.

Ref. 2 Hans Schmid, "The Measurement of Short-Time Waveform Distortion in NTSC TV Facilities," IEEE Transactions on Broadcasting, Vol. BC-17, Number 3, pp 83-87, September, 1971.

Ref. 3 Federal Communications Commission, FCC 71-879 66374, Docket 18425, Amendment of Part 73, Subpart E of the Commission's Rules and Regulations Governing TV Broadcast Stations.

Charles W. Rhodes*—Charlie attended the University of California at Berkeley and worked with the Columbia Broadcasting System for two years before coming with Tektronix in 1956. His projects have been largely centered around his continuing interest in the field of television. He has designed or directed the design of all of the vectorscopes, television waveform monitors and picture monitors introduced by the company since 1957.*

He holds several U.S. and foreign patents relating to television and has published several technical papers.

His professional affiliations include Senior Member IEEE, member of SMPTE and of the Royal Television Society. He is a member of the IEEE subcommittee 2.1.4 (Video Techniques), a subcommittee chairman of TR 4.4 of the Electronic Industries Association, a subcommittee chairman of the J.C.I.C. and has recently been asked to join the U.S. Study Group 10/11A (Audio/Video) for the CCIR (International Radio Consultative Committee) of the ITU (International Telecommunications Union).

TEKNIQUE:

USING THE 144 AS A SIMPLE SPECIAL EFFECTS GENERATOR

by Stu Rasmussen, Motion Picture and TV Producer

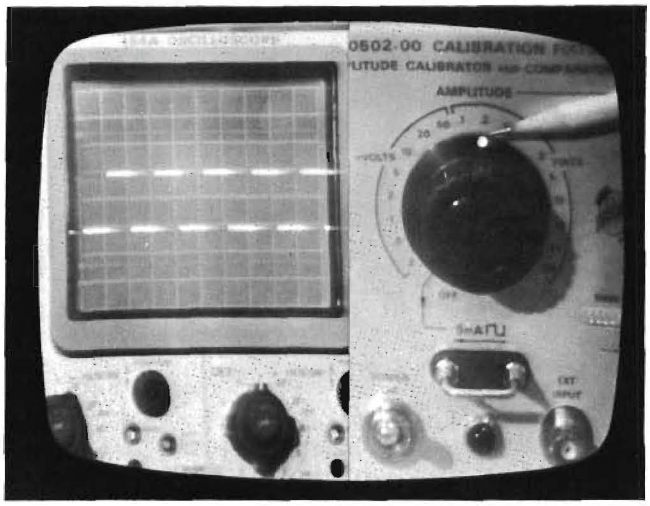
Maximum usefulness of each piece of equipment in a television production unit is a practical goal for any production staff. One instrument which can be used for a variety of purposes is the TEKTRONIX 144 NTSC Test Signal Generator. In addition to providing highly accurate monochrome and color test signals, the 144 can serve as the master sync and drive pulse generator for the entire station. It can also be used as a simple special effects generator to provide a wipe between two video sources.

The composite video output from the 144 is either of two types of test patterns, the components of which are determined by the programming of the generator. A front panel switch, the COMP VIDEO PATTERN, determines which of the two signals will be supplied to the output. In the SINGLE PATTERN position, the output is determined by the positions of the switches on the front panel. Color bars, modulated staircase or modulated pedestal can be selected. In the MULT PATTERN position, the output is internally programmed to provide convergence, color bars, gray scale, and two external video inputs. There is also a provision to wipe horizontally between the two external video inputs during the time they are displayed on the screen. Programming of this test signal is accomplished inside the instrument by movable jumpers which allow the user to change the pattern to suit his needs. With proper programming, the 144 can be used as a combination test signal generator and special effects generator.

The first step in changing the programming of the instrument to use it as an effects generator is to change the multiple pattern display to give a full field signal of the external video inputs. To do this, place the COMP VIDEO PATTERN switch in the MULT position. Locate the Field Timing circuit board situated on the upper side of the 144, directly behind the front panel SYNCHRONIZATION switches. On this board are five rows of colored jumpers, the functions of which are explained in the 144 manual. Rows B and A are, respectively, the external-video start and stop controls. These jumpers digitally select the line of the video signal at which the instrument will switch to and from the external video.

To set the unit for full field external video, a start line of 22 and a stop of 0 are required. To set the start line, remember that the actual line count is the binary count selected by the jumpers, plus 6. To set the start line to 22, it is necessary to set the jumpers in row B to a binary count of 16. The stop line is set to 0 (zero) so that the unit will reset during the vertical interval instead of during an active portion of the field. A continuous field display of the two external video signals is now programmed.

If video from two sources is applied to the rear panel A & B VIDEO INPUTS, a full field display of the video from these sources will appear at the VIDEO OUTPUT connector, and the position of the horizontal transition or wipe can be varied by the front panel EXT VIDEO WIPE control.



A horizontal wipe permits display of both the oscilloscope trace and the signal source.

If the 144 is mounted at some distance from the studio control room, as is often the case, some means of remote control of the generator function and wipe position would be desirable. The wipe position can be remoted by taking a +3.6 volt source and a ground from the 144 as shown in Fig. 1 and connecting them to a 2KΩ pot. The wiper is returned to the 144 and replaces the connection to the wiper of the EXT VIDEO WIPE control mounted in the 144. It will probably be necessary to add a fairly large capacitor between ground and the lead to the wiper of the remote wipe control. This will eliminate stray pickup which could cause the split transition to be noisy. A typical value would be 47 μF at 10 volts.

We now have control of the wipe position of the 144, but in order to switch it from the special effects mode to the test signal it is necessary to operate the front panel switch on the 144. (Changing the PATTERN switch to the SINGLE position will provide the 144 test signal programmed by the front panel switches.) It would be far more convenient to do this in the control room, and if it could be done automatically, that would be so much the better.

The video output of the 144 is most likely to go to the production switcher. Color bars should be available as one "camera" input and the special effects output as another input on the program row. All that is required to get automatic switching of the function of the 144 is to add a relay within the 144 to be operated by the tally light

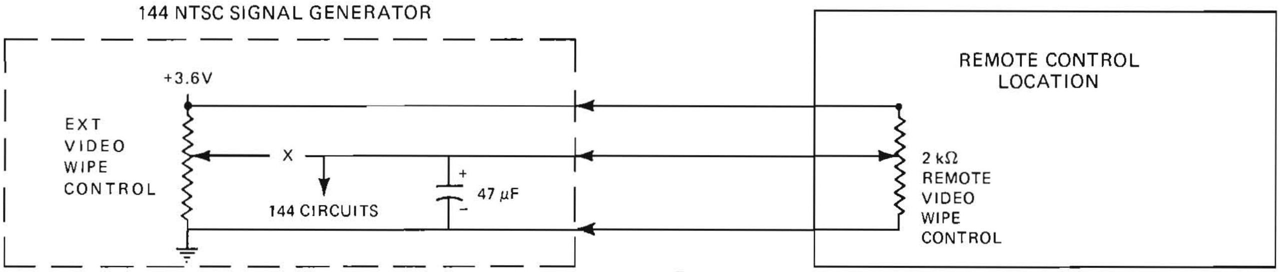


Fig. 1

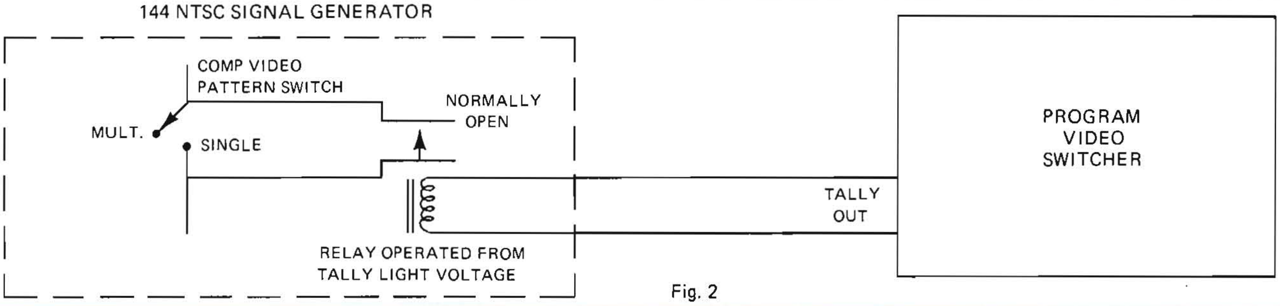


Fig. 2

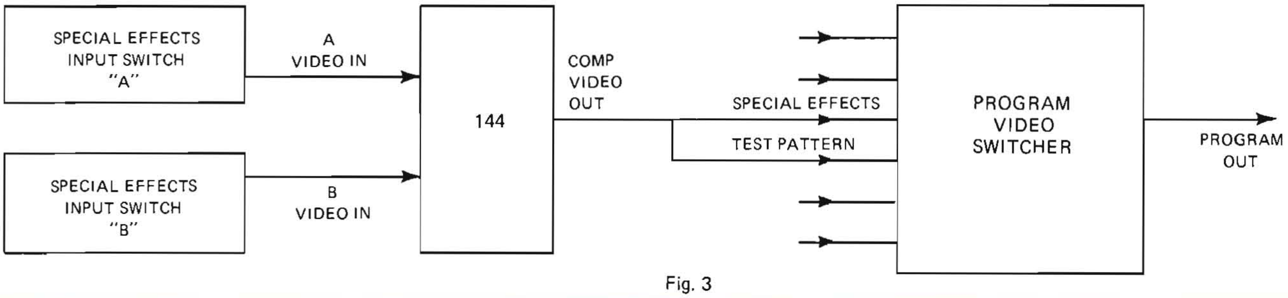


Fig. 3

voltage from the color bar input column. If the test pattern signal is desired, the relay closes the contacts of the PATTERN switch in the 144, and if it is desired to use it as an effects generator, the relay opens the circuit. See Fig. 2. Note that the PATTERN switch on the 144 must be in the MULT position for the relay to have any effect.

Since the composite video output appears at a single BNC connector on the rear panel of the 144, provision must be made at the video switcher to couple this single output to both the special effects and test pattern inputs of the switcher as in Fig. 3.

As an added benefit, the 144 can be programmed by front panel controls to insert VITS in the video output for on-the-air testing of video circuit functions and adjustments.

***Stewart A. Rasmussen** — Stu started his career with Tektronix three years ago calibrating and troubleshooting production line instruments. From the test department, he moved to the communications department, and then to the education and training group. Here, a long-standing interest in TV and movie production blossomed into a new career for Stu when an opportunity came to work with the group producing video tapes and movies used for training at Tektronix.*

Stu is currently pursuing studies in this field at Portland State University. He is also a member of the Society of Motion Picture Television Engineers.

SERVICE SCOPE

A QUICK-CAL PROCEDURE FOR THE 520 VECTORSCOPE

by Ed Handris, Factory Service Technician

A well-known quote says, "A workman is no better than his tools." Applying this to television broadcasting we might say, "Your color TV picture is no better than the equipment used to produce it."

The TEKTRONIX 520 Vectorscope plays a key role in providing the high-quality color TV programs we all enjoy so much. The quick-cal procedure that follows will help to assure that this important "tool" is in good working order.

This procedure is not intended to replace the more thorough calibration performed by TEKTRONIX Service Centers on instruments sent to them for repair and calibration. It does provide a check of the important operating characteristics of the 520 and, once the technician is familiar with the instrument, can be performed in an hour or less. Here is the equipment you will need:

- An oscilloscope with at least 10 MHz bandwidth such as the 453 or 547.
- A 140-Series NTSC Signal Generator.
- An NTSC Calibration Fixture (TEKTRONIX Part No. 067-0546-00)
- A precision voltmeter capable of measurements to better than 1%.
- A DC Voltmeter (VOM) 20,000Ω /volt.
- Three 75Ω cables, two 75Ω terminations, a BNC T connector and some adjustment tools.

Now let's take a look at the procedure:

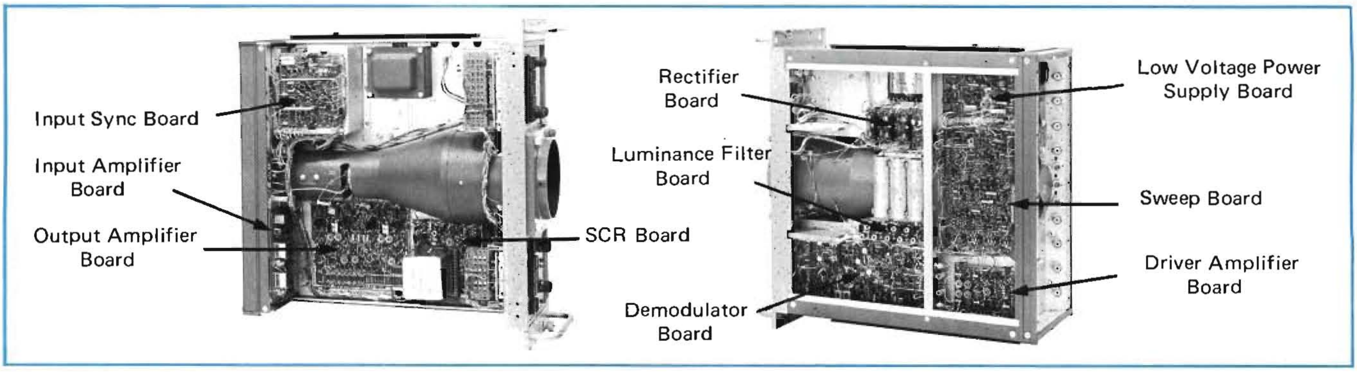
1) Check the crystal oven pre-heater operation:
Before turning on the 520, connect the VOM between test point 295 (TP295) on the Subcarrier Regenerator Board and ground. The voltage should be -15 volts when the 520 is first turned on and then rise to about +20 volts within three minutes. This indicates the crystal oven has come up to temperature.

2) Check the low voltage supplies:
Use the precision DC voltmeter to check the -15 volt supply. This supply is the reference for the other supplies. It should not be adjusted if it's within tolerance as it will cause a shift in the other supplies and possibly a change in the calibration of the 520.
   a) -15 volts, ±0.5%, read on pin Z of the low voltage power supply board. Adjust R1588 if necessary.
   You may use the VOM for checking the following supplies:
   b) +10 volts, ±3.5%, read on pin T of the low-voltage board.
   c) +100 volts, ±3.5%, read on pin H of the low-voltage board.
   d) +275 volts, ±7%, read on pin A of the low-voltage board.
   e) +3.6 volts, ±5%, read on pin X of the Input Sync board.
   f) -3875 volts, ±3%, with Intensity control set to mid-range. Read on pin 2 of the CRT socket. To get to this pin, turn off the power to the 520, remove the metal CRT protector cap on the rear, then remove the cover from the CRT socket. Pin 2 is the red-on-white wire.

   Check to see that the voltage stays within ±20V of the mid-range value when the Intensity control is set at the maximum and minimum positions.

3) Check the Luminance Calibrator:
Depress: Y
FULL FIELD
A CAL
Connect the precision DC voltmeter to pin X on the Demodulator board. Remove Q570 and note the reading (about -0.002 volts). Install Q570 and remove Q571. The voltage reading should be exactly 1 volt more positive than the previous reading or about +0.998 volts. Adjust R583 if necessary. Reinstall Q571.

4) Check the DC Balance of the R-Y, B-Y and Y Amplifiers:
Depress: VECTOR
FULL FIELD
Connect the VOM to the following test points in the Driver board and adjust as indicated:



Location of the circuit boards in the 520 Vectorscope.

TEKTRONIX®

January 1972

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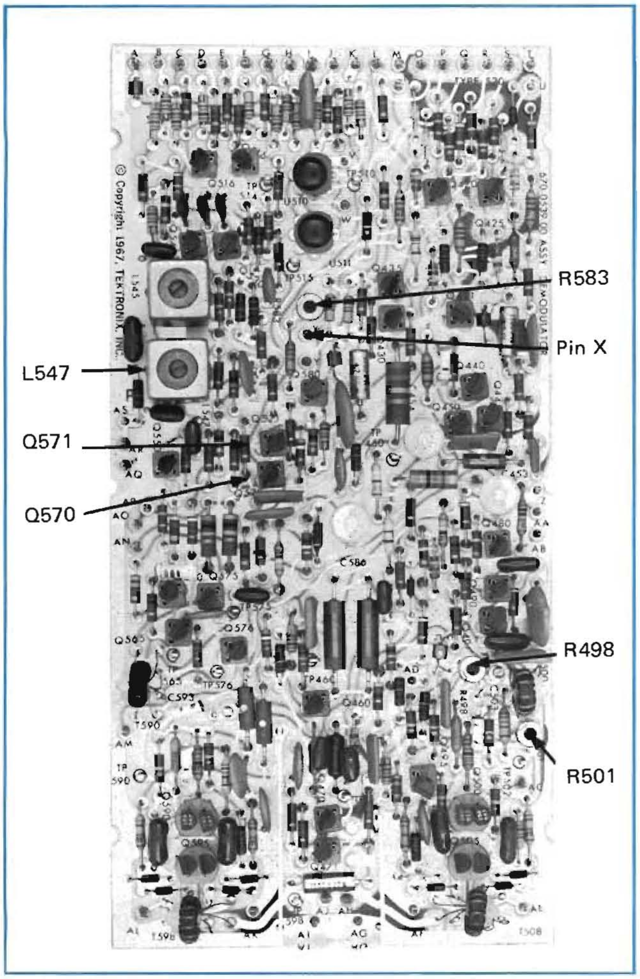


Demodulator Board test point and control locations.

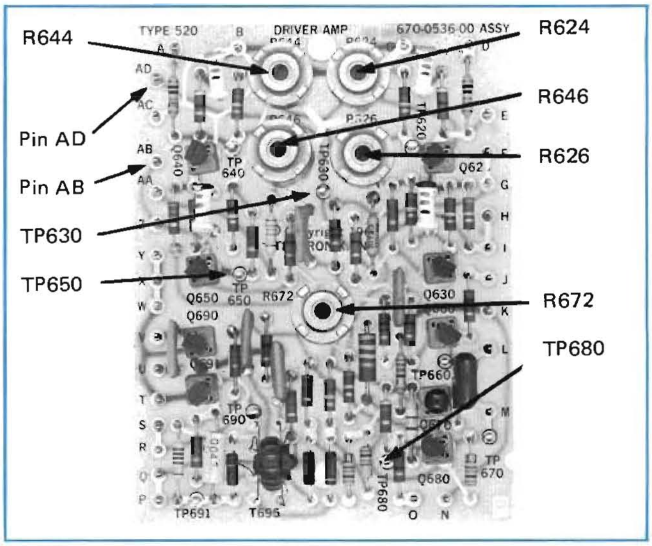
TP 630—Adjust R624 for 0 volts
TP 650—Adjust R644 for 0 volts
TP 680—Adjust R672 for +0.5 volts

5) Check the Unblanking Bias Adjustment:
   Depress: VECTOR
   FULL FIELD
   A CAL
   A circle will be displayed. Adjust R1478 on the rear panel of the 520 for uniform intensity of the circle.

6) Check the Common Mode Level Adjustments:
   Depress: VECTOR
   FULL FIELD
   Set the INTENSITY control so the displayed spot doesn't burn the phosphor. Center the spot using the HORIZ and VERT POSITION CLAMP controls on the 520 front panel. Connect the VOM to TP980 on the Output Amplifier board and adjust R985 for +5.6 volts. Check TP870 and adjust R875 for +5.6 volts.

7) Check FOCUS and ASTIGMATISM setting:
   The front panel FOCUS and rear panel ASTIGMATISM should be set for a well defined spot.

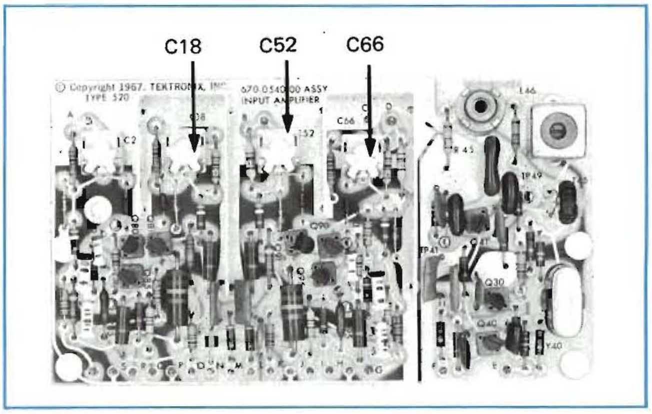
8) Check the BEAM ROTATE and ORTH adjustments:
   Depress: VECTOR
   FULL FIELD
   A CAL
   Remove the lead from pin AB on the Driver board. You should have a vertical line. Adjust BEAM ROTATE on the front panel if necessary. Reconnect lead to pin AB and remove lead on pin AD. You should have a horizontal line. Adjust ORTH control on the rear panel if necessary. Reconnect lead to pin AD. The BEAM ROTATE and ORTH controls interact so recheck as needed



Driver Amplifier Board test point and control locations.

9) Check Burst Flag Timing:
   Depress: VECTOR
   FULL FIELD
   CH A
   AΦ
   Feed composite video from the 140 NTSC Signal generator into CH A input on the rear of the 520. Terminate CH A and CH B loop-thrus with 75Ω. These terminations should remain in place for the remainder of the cal procedure unless noted otherwise. You should have a vector display. Set the A PHASE control so the burst vector is at the 90° position. Now depress the LINE SWEEP button. Turn down the intensity so you can see the brightened portion of the display and adjust the BURST FLAG TIMING control on the front panel for equal brightness either side of the peak of the waveform.

10) Check the Video Amplifier Gain:
   a) Luminance Gain:
   Depress: Y
   FULL FIELD
   A CAL
   B CAL
   You should have two calibrator waveforms displayed. Position the traces so you can compare amplitudes and



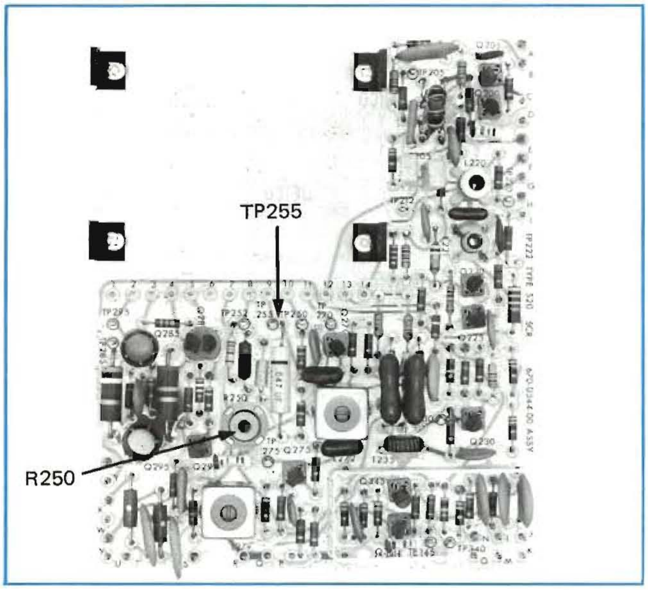
Input Amplifier board control locations.

set the front panel B CAL screwdriver adjustment so the waveforms are the same amplitude. Run the thumbwheel A and B GAIN controls through their range and check for open spots. Return them to the calibrated position.

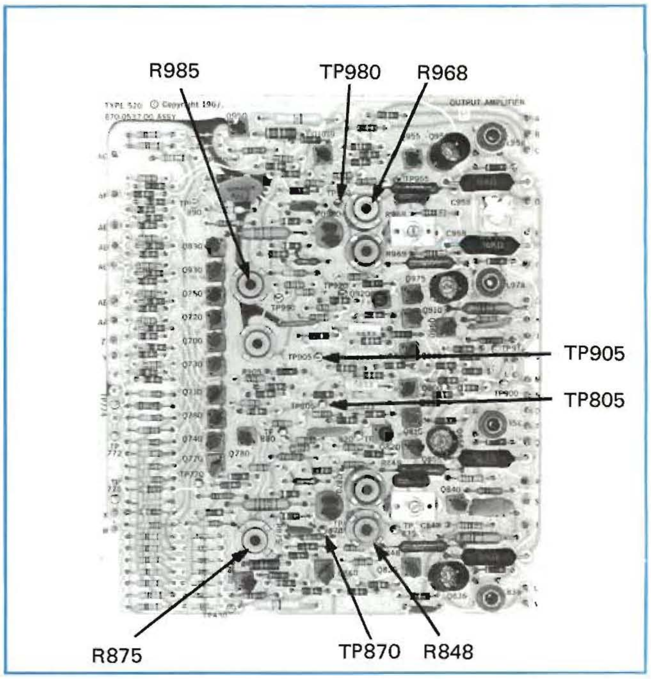
b) Chrominance Gain:
Depress: VECTOR
FULL FIELD
Aϕ/BϕALT
Feed composite video from the 140 into CH A and B inputs. You should have two vector displays. Superimpose the vectors using the A and B PHASE controls. Adjust C52 on the Input Amplifier board so the vectors for CH A and B are the same amplitude.

c) CH A and B Phase Difference:
Depress: VECTOR
FULL FIELD
CH A
CH B
Same inputs as in previous step (b). With the A PHASE and B PHASE controls set at 0, the two vector displays should be superimposed. Adjust C88 and C98 located on the back of the PHASE controls so that the vectors are superimposed and the burst vectors are on the 0° reference line.

11) Check the Subcarrier Regenerator Adjustment:
Depress: VECTOR
FULL FIELD
CH A
Feed composite video from the 140 into CH A input. Connect your test scope via a 10X probe to TP255 on the Subcarrier Regenerator board. Set test scope to 0.02 V/div, DC coupled, at a sweep rate of 1 ms/div. Establish a ground reference level on the test scope screen. The DC level on TP255 should be about 0.5 volts and the vector display should be locked in. If the display is spinning, adjust R250 on the Subcarrier Regenerator board until the display locks in. Note the voltage on TP255. Depress A CAL button and observe the voltage on TP255 for a few minutes to see if it drifts. Adjust R250 for the same voltage reading observed when CH A button was depressed. Depress CH A button again and the display should lock in within 15 seconds. Final adjustment of R250 should be set so there is no voltage change at TP255 when CH A and A CAL buttons are alternately depressed. Disconnect the 10X probe and 140 from the 520.



Subcarrier Regenerator Board test point and control locations.



Output Amplifier Board test point and control locations.

12) Check the Output Amplifier Gain:
a) Set Vertical Output Amplifier Gain.
Depress: Y
FULL FIELD
A CAL
You should have the calibrator waveform displayed. Be sure the front panel thumbwheel GAIN controls are in the calibrated position. Adjust R848 located on the Output Amplifier board for 140 IRE Units of cal signal.

b) Set Vertical Driver Amplifier Gain:
Depress: VECTOR
FULL FIELD
CH A
Connect the SIDEBAND VIDEO output of the 067-0546-00 NTSC Vectorscope Test Unit to the CH A input. You should have a circular display. Adjust R626 on the Driver Amplifier board so the top and bottom of the circle line up with the graticule circle.

c) Set Horizontal Output Amplifier Gain.
Depress: Same as Step (b)
Remove the leads from Driver Amp board pins AB and AD. Connect lead from pin AB to pin AD. You should have a horizontal line. Adjust R968 on the Output Amplifier board so the length of the horizontal trace is equal in length to the diameter of the graticule circle. Reconnect leads AB and AD to their respective pins.

d) Set Horizontal Driver Amplifier Gain.
Depress: Same as Step (b)
You should have a circular display. Adjust R646 on the Driver Amplifier board so the circle overlays the graticule circle on the horizontal axis.

13) Check the test circle oscillator amplitude:
Depress: VECTOR
FULL FIELD
A CAL
You should have a circular display. Adjust C18 on the Input Amplifier board so the test circle overlays the graticule circle. Neutralize A CAL and depress B CAL. Adjust C66 on the Input Amplifier board so the test circle overlays the graticule circle.

14) Check the Subcarrier Processing adjustments:
  a) Quadrature Phase Adjustment:
    Depress: VECTOR
      FULL FIELD
      A CAL
    If the adjustment is correct, you will have a circular display that overlays the graticule circle. If not, you will see two circles slightly displaced in phase. Adjust the front panel QUAD PHASE control so the two circles are superimposed. The control should set near mid-range.
  b) Check Demodulator Balance Adjust:
    Depress: I
      FULL FIELD
      A CAL
    Note the position of the horizontal line on the graticule. Depress the DIFF PHASE button and check to see that the horizontal line is within 2 minor divisions of its previous position. Adjust R501 on the Demodulator board if necessary. Recheck step (a) if R501 is adjusted.
  c) Check Demodulator Phase Shift Adjust:
    Depress: VECTOR
      FULL FIELD
      CH A
      Aϕ
    Feed composite video from the 140 into CH A. You should have a vector display. Set the CH A GAIN thumbwheel so the -I vector reaches the edge of the graticule circle. Now hold in the VECTOR button and depress the I button. The vectors should rotate 33° ± 2°. For example, the -I vector should be on the vertical graticule line. Adjust L547 on the Demodulator board for optimum phase shift in all four quadrants. Return CH A GAIN thumbwheel to calibrated position.

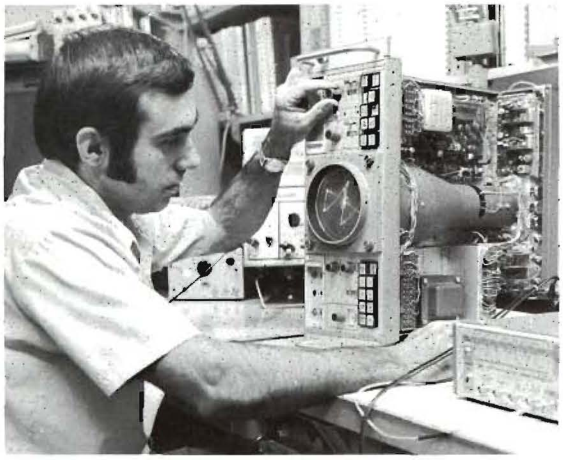
15) Check the Differential Gain Position Balance:
  Depress: Y
    VITS 18
    CH A
  Center the display using the Vert and Horizontal clamp controls. Set CH A VECTORS switch to MAX GAIN position. Depress the DIFF GAIN button and note if the display remains centered. Adjust R498 on the Demodulator board to recenter the display if necessary. Return the CH A VECTOR switch to the 75% position.

16) Check VITS selection of lines 18 and 19 for both fields:
  Depress: Y
    VITS 18
    CH A
  Select VITS line 18 and Field 1 positions on the 140. Set FIELD switch on the 520 to Field 1. You should see a staircase display on the 520. Now select VITS line 19 on the 140 and depress the VITS 19 button on the 520. You should again have a staircase display. Select Field 2 on the 140 and the 520 and check for a stable staircase display. Select VITS line 18 on the 140 and depress VITS 18 on the 520 and check for a stable staircase display.

17) Check the CALIBRATED PHASE adjustment:
  Depress: VECTOR
    FULL FIELD
    CH A
    Aϕ
  Set the 140 for composite video output. Set the CALIBRATED PHASE dial to 0. You should see a vector display. Set the Channel A PHASE control so the "yellow" vector is on the horizontal graticule line. Set the Channel A GAIN thumbwheel so the vector reaches the graticule circle. Now turn the CALIBRATED PHASE dial to +14° and check to see that the "yellow" vector has rotated 7 minor divisions or 14°. Adjust R335 on the rear of the CALIBRATED PHASE control if necessary. Return the CALIBRATED PHASE control to 0. Use CHANNEL A PHASE to set the vector on the horizontal line again. Now turn the CALIBRATED PHASE dial to -14° and check to see that the vector is rotated 14° from the horizontal reference line in the opposite direction. If necessary, adjust L331 on the rear of the CALIBRATED PHASE control. R335 and L331 interact so the +14° and -14° points should be checked after each adjustment.

18) Check the Color Bar Decoding.
  Depress: VECTOR
    FULL FIELD
    CH A
    Aϕ
  The 140 is still feeding composite video into CH A. You should have a vector display. Set the CHANNEL A PHASE and GAIN thumbwheel so the burst lies on the 75% mark on the vector graticule. Depress the R button. Set the sync tip at the -40 IRE Unit level. You should have two bars at the 77.5 IRE Units level. Depress the G button. You should have one large bar at 77.5 IRE Units. Depress the B button. You should have four bars at the 77.5 IRE Units level. The amplitudes of the bars should be nearly the same and within ±3% of the specified amplitudes.

This completes the calibration procedure. Your 520 should now give you reliable measurements of the color signals. If you have difficulty with your instrument, we suggest you contact your TEKTRONIX Field Engineer.



Ed Handris started his career with Tektronix six years ago in the production test department. After gaining a thorough knowledge of many Tek products, he transferred to factory service where he specializes in servicing television products. Ed spends his leisure hours with his family and furthering his education at Portland Community College.

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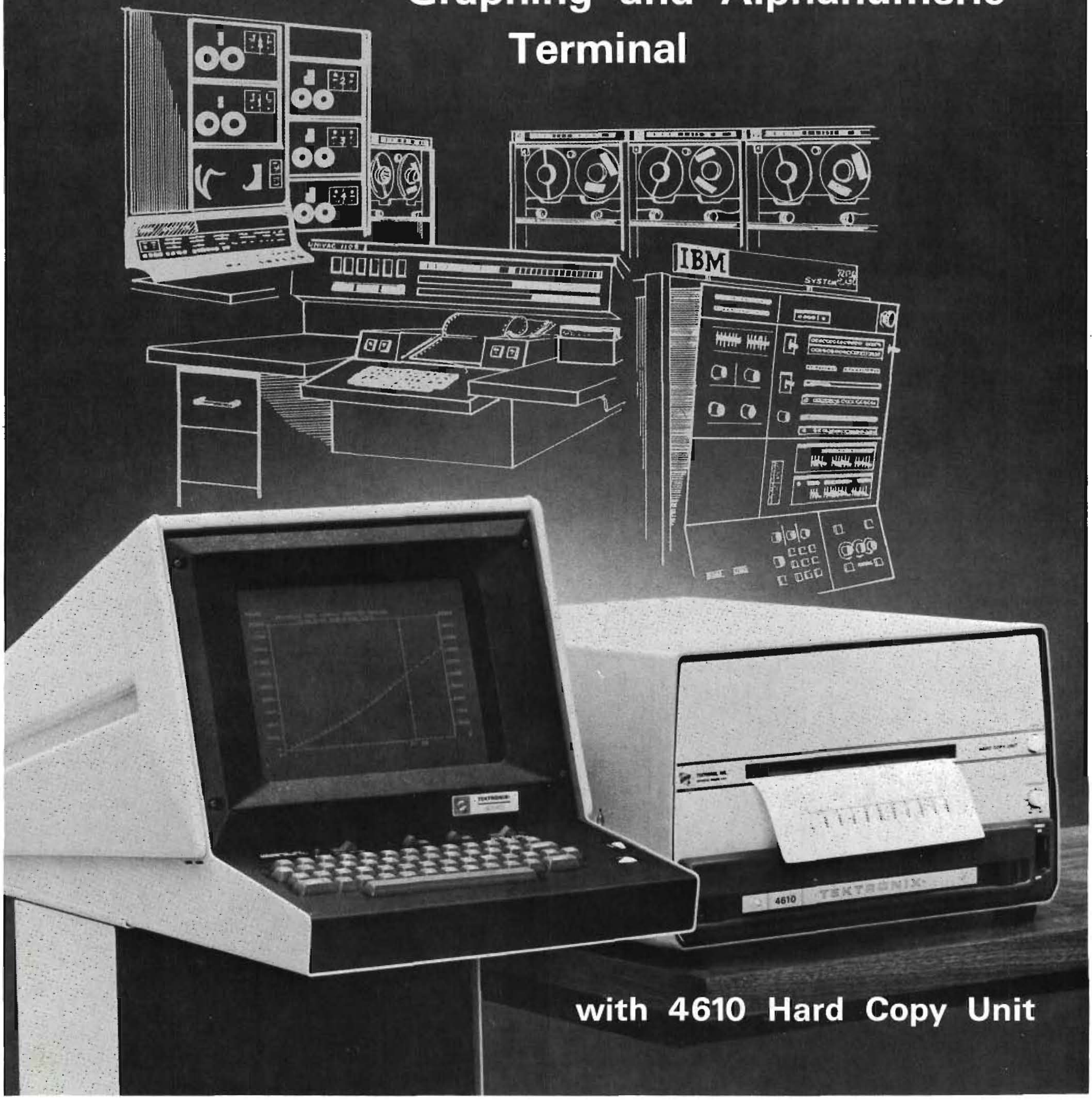

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TEKSCOPE

JANUARY 1972

The 7L12 Spectrum Analyzer Plug-In

Frequency Stabilization Techniques

Optimizing Mixer Performance Using the 7L12

Servicing the 1401A Spectrum Analyzer

A microwave spectrum analyzer for the 7000-Series Oscilloscopes

The authors, pictured above, are from left to right: Linley Gumm, Larry Lockwood, Morris Engelson and Al Huegli.

Cover: The 7L12 Spectrum Analyzer plug-in brings state-of-the-art spectrum analysis to users of TEKTRONIX 7000-Series Oscilloscopes.

The new 7L12 Spectrum Analyzer Plug-In for the 7000-Series Oscilloscope System features absolute amplitude and frequency calibration and complete freedom from unwanted responses. Covering the spectrum from 100 kHz to 1800 MHz, this unit has many unique design parameters that should bring it to the forefront in the range and ease of measurement. Some of the parameters not previously available are: a wide range of resolution bandwidths from 300 Hz to 3 MHz; automatic reference level computation with wider gain and/or attenuation settings; availability of both center and start frequency indication; CRT readout of measurement parameters; and, ability to make simultaneous time and frequency measurements.

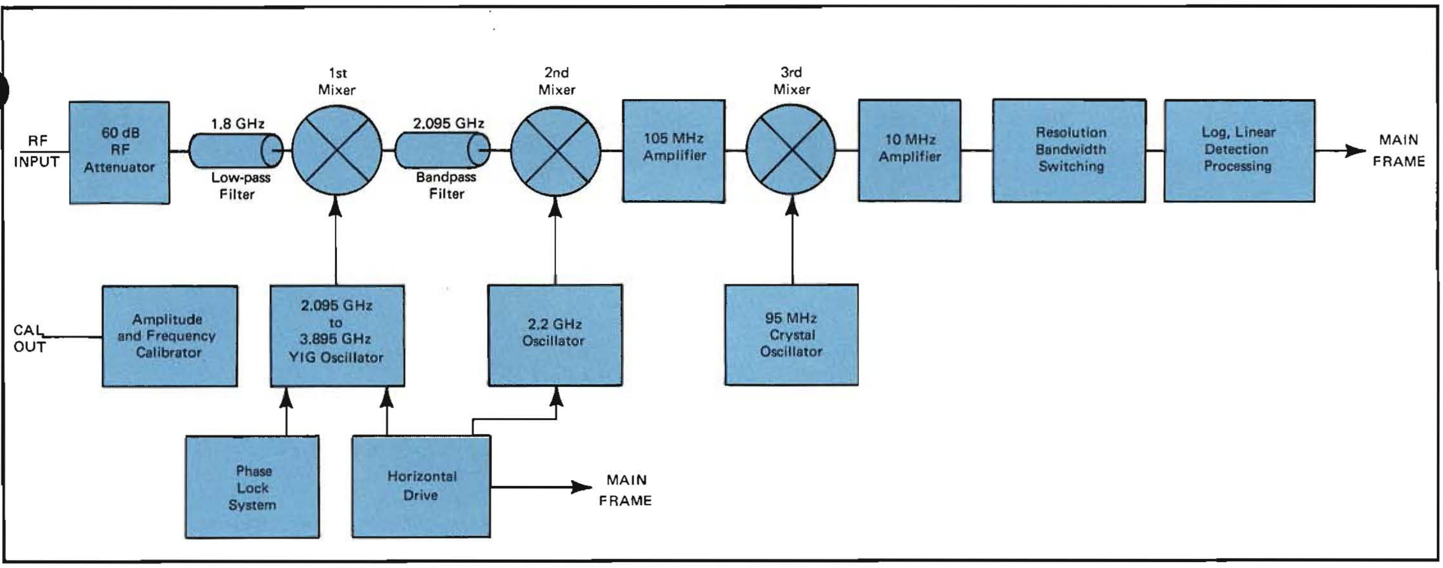


Fig. 1. Simplified block diagram of the 7L12 Spectrum Analyzer.

THE BASIC SYSTEM

Figure 1 is a simplified block diagram showing the overall system configuration. It will be observed that this is a straightforward front-end design with a first IF filter at 2095 MHz. The first local oscillator is phase locked at spans of 100 kHz/div and below, where the 2.2-GHz oscillator becomes the swept oscillator. System gain starts at 105 MHz with the majority of the gain at 10 MHz. The 10-MHz circuitry is also where all of the vertical mode display law shaping and the resolution bandwidth switching is done. Circuit and construction details are covered elsewhere in this issue.

PERFORMANCE CHARACTERISTICS

The capabilities of this versatile instrument are best illustrated by actual CRT displays. Here are some of the things that the 7L12 can do:

(a) Sensitivity—Figure 2 shows a —100 dBm signal displayed well above the noise level. The 7L12 can easily show signals less than —110 dBm.

(b) Resolution—Sensitivity alone is not enough. A good spectrum analyzer should be able to display the small signal in the presence of a large one. This is primarily determined by the resolution bandwidth and skirt selectivity shape factor. A flat-topped steep-sided filter gives the 7L12 unequalled resolution capabilities. This is illustrated by Figures 3, 4, and 5. Note that the 2-kHz sidebands in Figure 5 merge with the carrier almost 60 dB down. Note also that CRT readout obviates the need to describe separately the control settings for the photographs.

(c) Amplitude Differences—Sometimes the interest is in signals consisting of relatively equal amplitude components. Here the need is to measure small amplitude differences and for low intermodulation distortion to avoid generating spurious responses. Such measurements are illustrated in Figures 6 and 7. The former shows the ease with which one can measure the amplitudes of signals differing by only 1.5 dB, while the latter shows the absence of third order products for two —30 dBm signals.

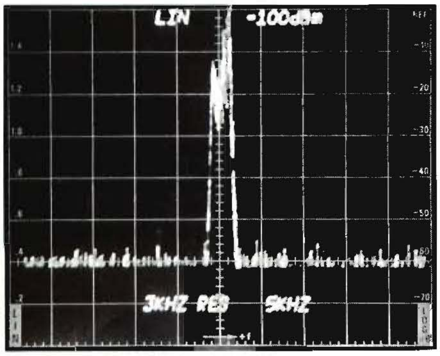
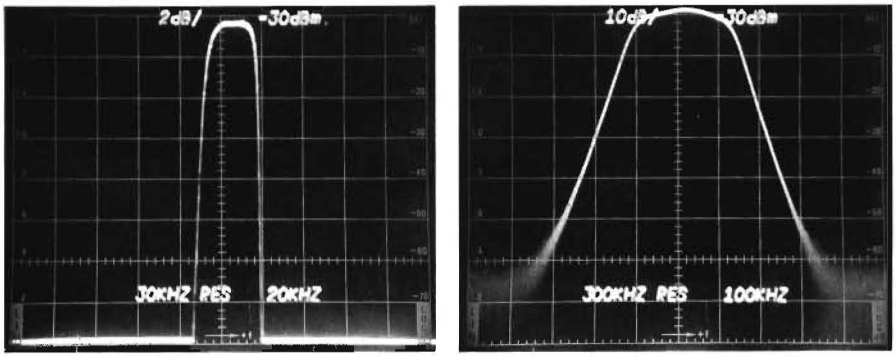


Fig. 2. A —100 dBm signal is displayed well above the noise level of the 7L12.



Figs. 3 & 4. Response curves of the 30 kHz and 300 kHz filters show the flat top and steep sides that give the 7L12 excellent resolution.

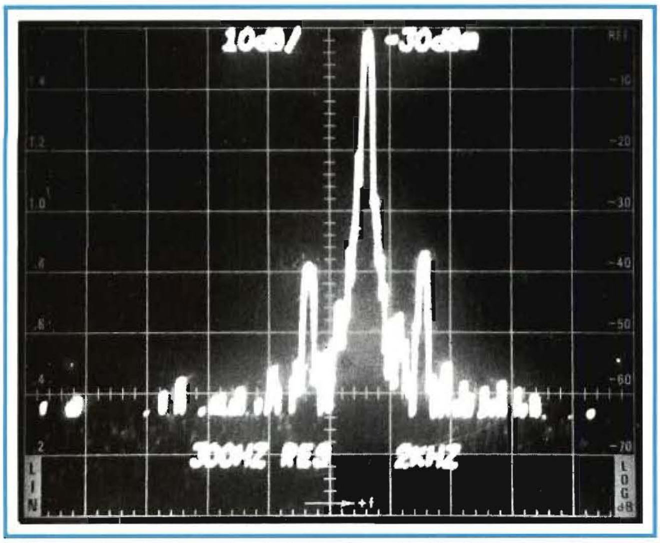


Fig. 5. *Resolution afforded by the 300 Hz filter is evidenced in this photo showing 2 kHz sidebands merging with the carrier 60 dB down.*

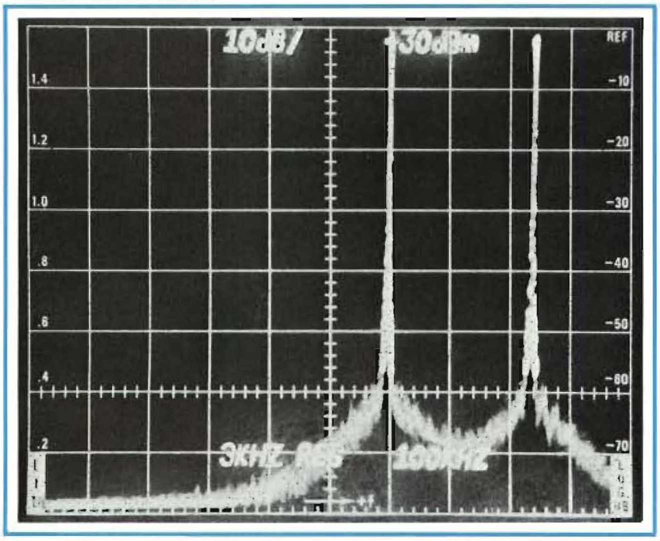


Fig. 7. *Low intermodulation distortion is illustrated in this photo showing absence of third order products for two —30 dBm signals.*

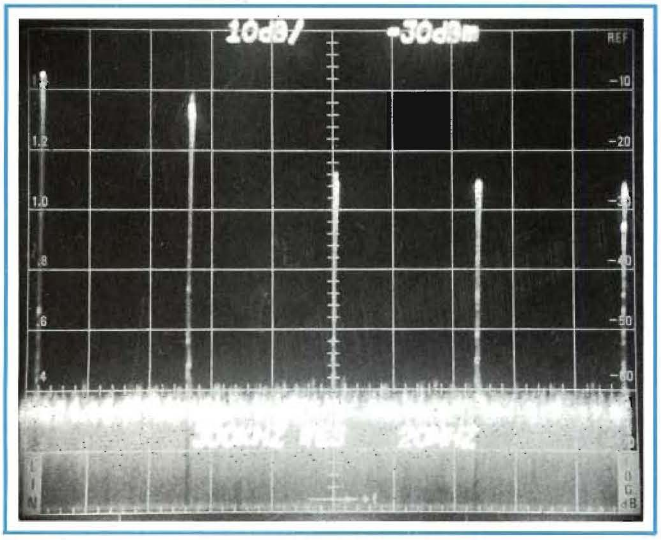


Fig. 9. *Frequency span is reduced to 20 MHz/div showing a 200 MHz window of the marker area in Fig. 8.*

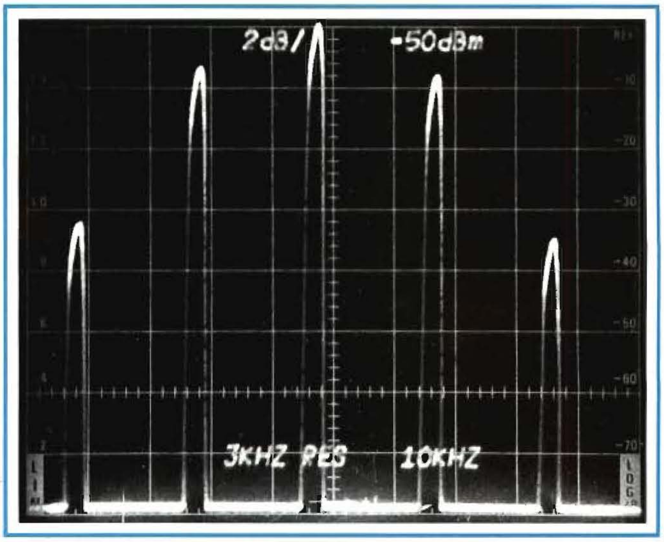


Fig. 6. *Signals differing in amplitude by less than 2 dB are easily measured on the 7L12.*

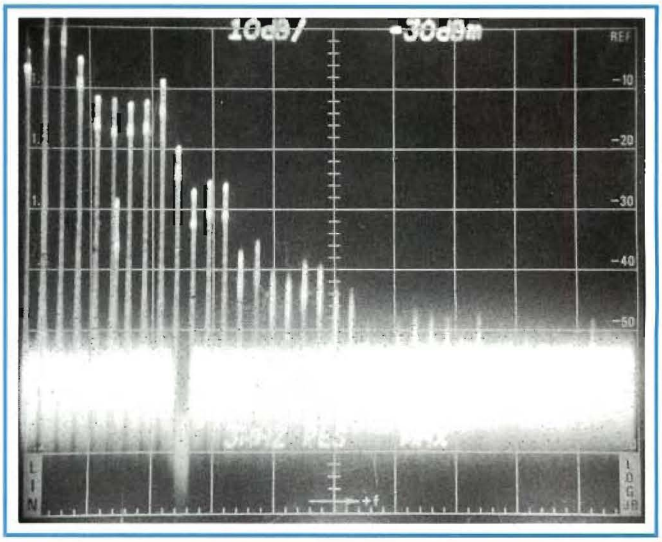


Fig. 8. *Maximum frequency span of 1800 MHz is displayed with negative-going marker indicating frequency dial setting.*

(d) Finding the Signal—Finding your signal is easy with the 7L12. Figure 8 shows the maximum frequency span capability of 1800 MHz. Here the frequency dial selects the position of a negative-going marker which indicates the part of the spectrum to be selected. Figure 9 shows the details of the comb lines as the span is reduced to 20 MHz per division. The choice of center or start sweep capability is also of considerable convenience. Thus, Figure 10 shows the 0-Hz marker in the center with an approximately 10-MHz signal and its harmonics to either side. The left-hand edge of the screen conveys no information since it's a mirror image of the right-hand side. Setting the frequency control to the start rather than center sweep results

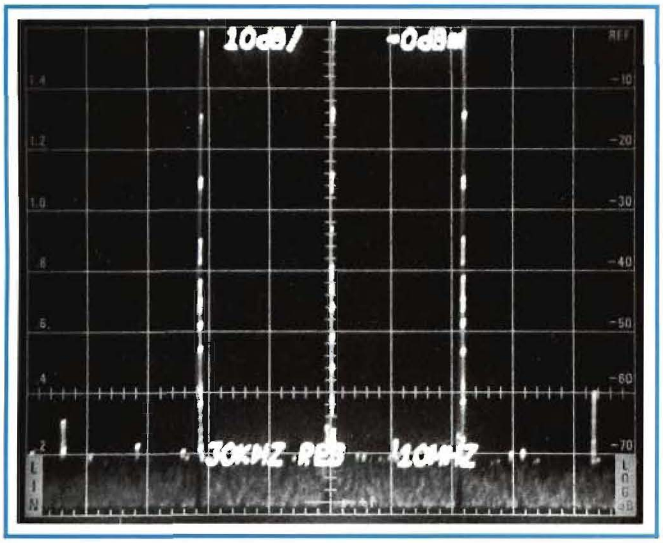


Fig. 10. *0-Hz marker is center screen with 10 MHz signal and its harmonics to either side.*

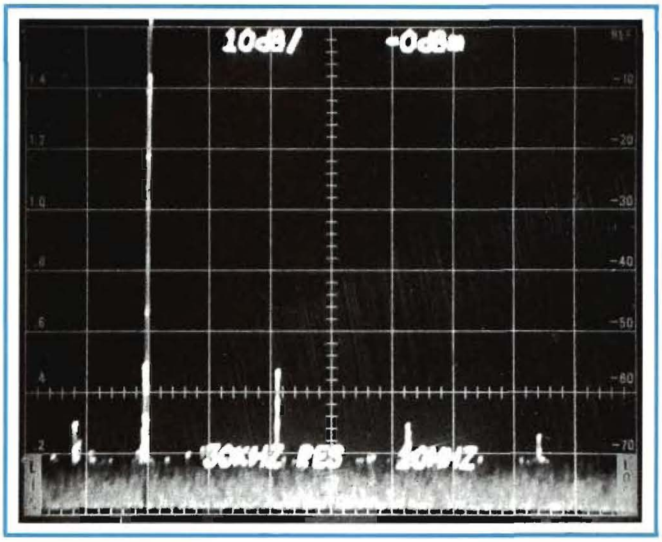


Fig. 11. *Same signal as in Fig. 10 with the frequency control set to "start" rather than "center" of sweep.*

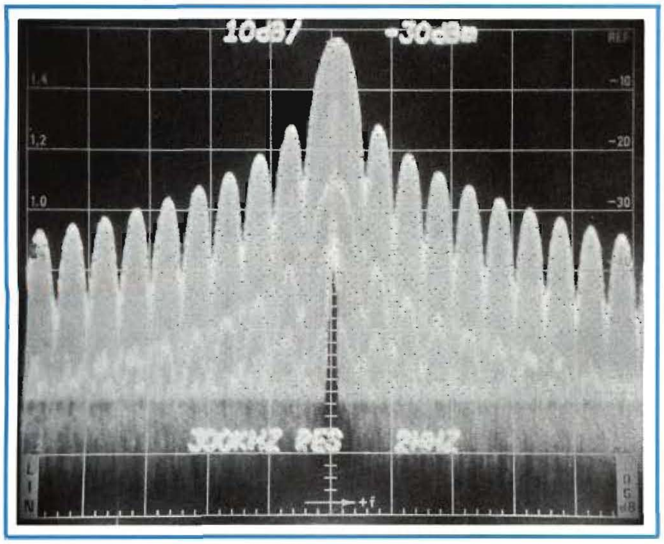


Fig. 12. *A 1-µs pulsed RF waveform displayed in the frequency domain.*

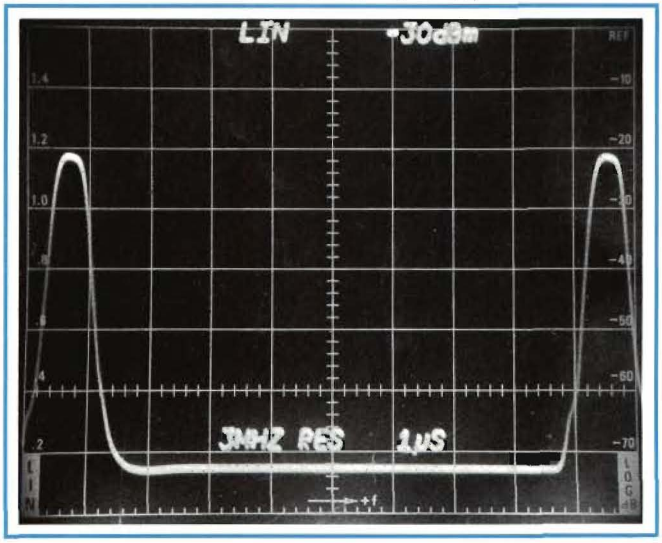


Fig. 13. *The same pulse displayed in Fig. 12 is detected and then displayed in the time domain using the 7L12.*

in Figure 11. Here we see the fundamental at about 0 dBm and the second, third and fourth harmonics at —56 dBm, —63 dBm, and —67 dBm, respectively.

(e) Time Domain Data—The wide (3 MHz) resolution capability of the 7L12 permits accurate reproduction of the modulating waveform by operating the analyzer in a non-sweeping mode. This is illustrated by two pairs of photographs. Figures 12 and 13 show a 1-µs pulsed RF waveform in the frequency domain and as a detected time domain pulse. Similarly, Figures 14 and 15 show the spectrum of amplitude modulation at a 1-MHz rate and the detected modulating waveform.

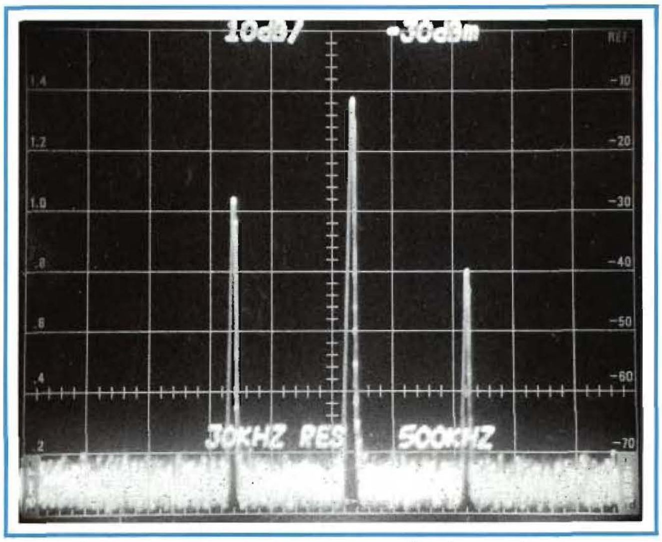


Fig. 14. *Frequency spectrum of amplitude modulation at a 1-MHz rate.*

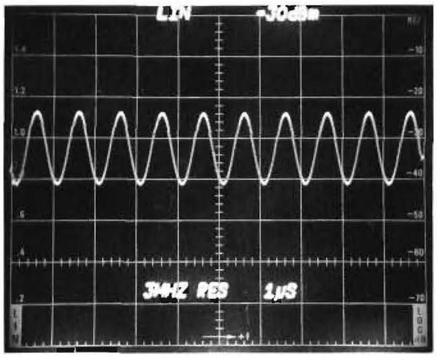


Fig. 15. *The signal displayed in Fig. 14, detected and displayed in the time domain.*

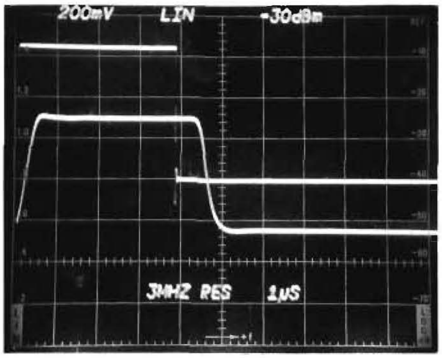


Fig. 16. *Modulating pulse and the same pulse after demodulation displayed on the 7504 Oscilloscope.*

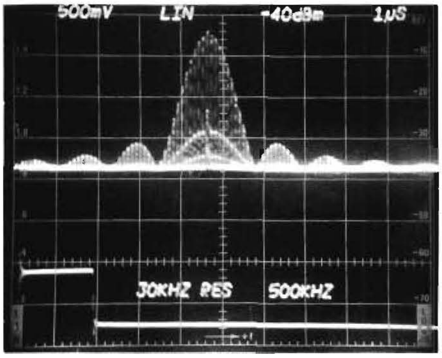


Fig. 17. *Spectrum analysis and oscilloscope data displayed simultaneously on the 7504.*

The availability of 7000-Series four-hole mainframes permits the simultaneous display of spectrum analyzer and oscilloscope data. This is shown in Figures 16 and 17. Figure 16 shows the original modulating pulse and the same pulse after demodulation. Figure 17 shows a square modulating pulse and the resulting (sin X)/X frequency spectrum.

Now let's look at some of the components and circuitry in the 7L12 in more detail.

THE RF COMPONENTS

The decision to make the 7L12 Spectrum Analyzer a plug-in unit dictated the use of thin film microwave integrated circuits. Previously used techniques would not have permitted components sufficiently small to fit in the available volume.

Design goals of this instrument centered around wide dynamic range and freedom from spurious responses. This called for components meeting some unusual requirements. Some of the needs were met with commercially available items. Others required in-house development of microwave circuits suited to the specific need. Following is a discussion of some of the unique microwave circuits developed especially for the 7L12.

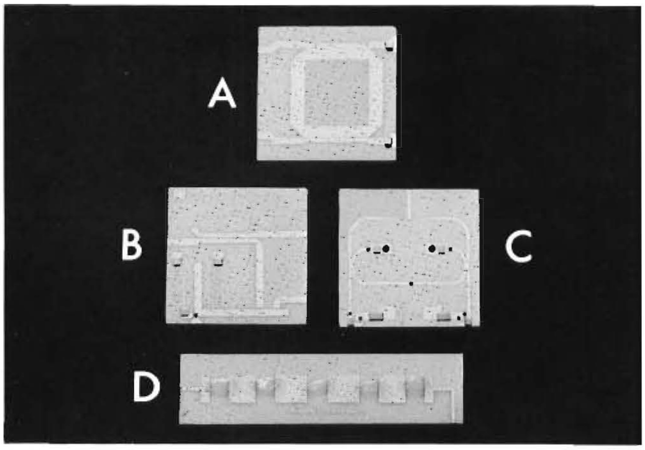


Fig. 18. Some of the RF components developed for the 7L12: ***(a)*** *Travelling-wave filter,* ***(b)*** *2.2 GHz oscillator,* ***(c)*** *phase detector,* ***(d)*** *2.4 GHz low pass filter.*

The phase detector, Fig. 18(c), is used to stabilize the first voltage tuned oscillator (VTO). Its output is related to a harmonic of the 2.21 MHz crystal reference and the local oscillator in the 2.1 to 3.8-GHz range. Its operation is best understood by considering what happens to a step voltage applied to a directional coupler. (See Fig. 20) If port one receives a voltage step, port two has no output, port three has a rectangular pulse and port four has the remaining energy. In the phase detector this property is used to differentiate a step formed by a snap-off diode, while maintaining an impedance match at all frequencies. The rectangular pulse is applied to a diode detector along with the 2.1 to 3.8-GHz signal. The detector output charges to the amplitude of the rectangular pulse plus the applied input signal. Two of these devices are summed, one having reversed detector and pulse polarities. The summed output corresponds to the RF input at the time the step voltage is applied, and forms the phase detection process.

Because of the good dimensional tolerances that can be obtained using the photolithograph process, the output of the 2.21-MHz step into the 2.1 to 3.8-GHz input can be kept very small.

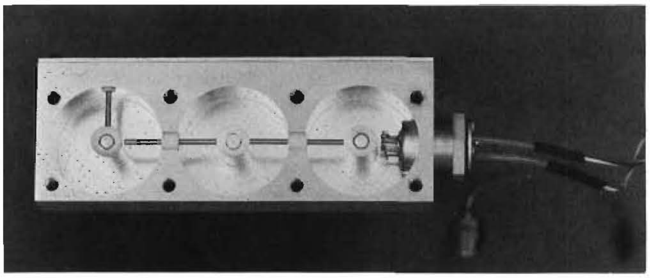


Fig. 19. *The 2.1-GHz narrow bandpass filter and second mixer.*

The 2.1-GHz narrow bandpass filter shown in Fig. 19 was machined from solid metal to minimize its insertion

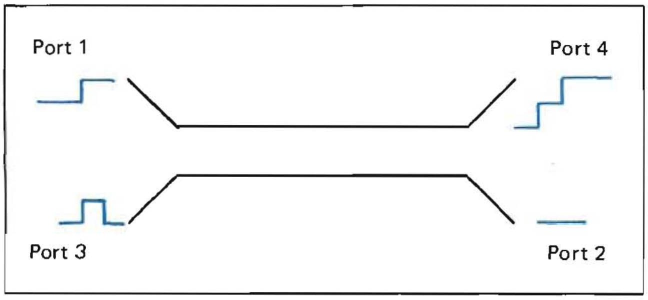


Fig. 20. *Signal outputs of directional coupler with a step voltage applied to port 1.*

loss. The filter is designed with relatively large capacitance loading which helps reduce the volume of the resonators without raising the insertion loss excessively. The coupling is done with capacitive probes as pictured in the photograph. A small single balanced mixer is placed inside the cavity and is magnetically coupled. It is used for the second conversion mixer.

During the development of the 7L12 it was learned that the impedance at the output of the first mixer, at the sum frequency of the first local oscillator and the input signal, was of special significance. A large reflection at this frequency affected both the flatness and the intermodulation performance. A traveling wave filter provides optimum transfer of energy between the first and second mixer at 2.1-GHz and serves as a termination for other frequencies. This improves the sensitivity and dynamic range by eliminating the need for a lossy attenuator to absorb the unwanted energy. The device is shown in Fig. 18(a).

Fig. 18(d) shows a 2.4-GHz low pass filter. Its function is to maintain the step band properties of the 2.1-GHz bandpass filter. This is of straightforward design. The 2.2-GHz oscillator in Fig. 18(b) is used with an external resonator similar to one section of the bandpass filter. This resonator improves the stability and noise performance of the oscillator by raising the effective Q of the oscillator.

THE IF SYSTEM

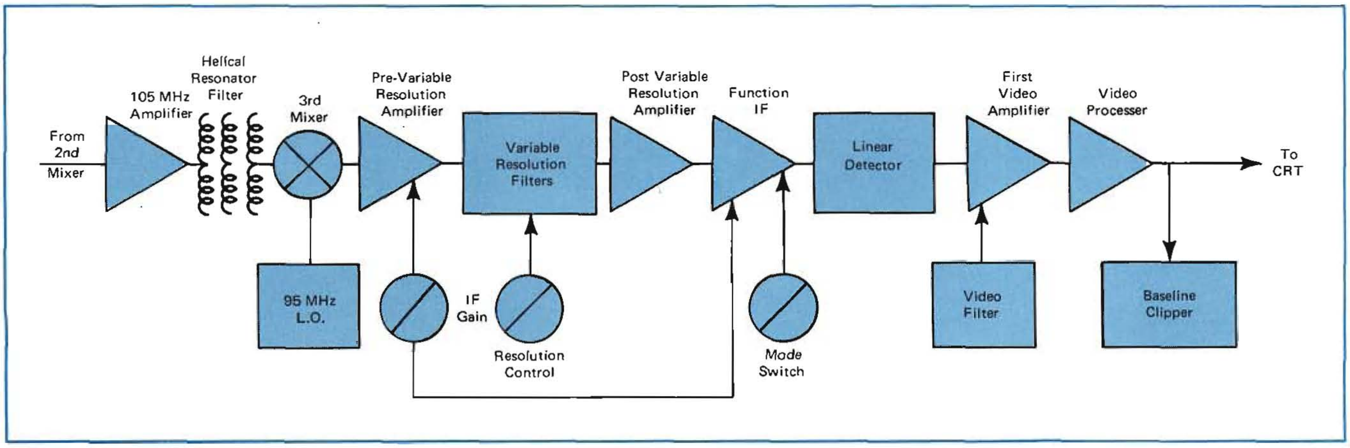
The high frequency IF System in the 7L12 is a low noise, wide dynamic range system incorporating advanced features. The block diagram depicts the design of the IF System. It consists of a first IF at 105 MHz, followed by a second IF and amplifier chain at 10 MHz.

The 105-MHz IF

The 105-MHz IF provides the first gain in the system, the microwave components ahead of this IF having no gain. It is important, therefore, for sensitivity considerations, that the 105-MHz IF have a good noise figure. Since low intermodulation is also important, a dual gate MOS-FET is used as the first amplifier stage.

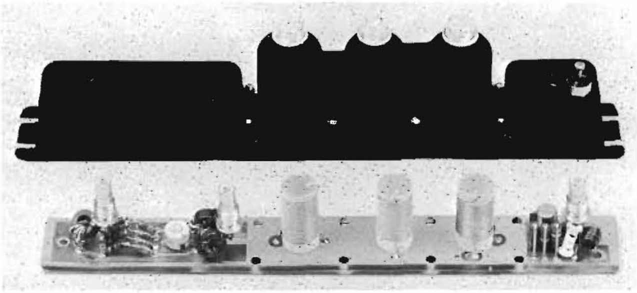
The MOS-FET amplifier is followed with a three-cavity helical resonator filter. A helical resonator is similar in concept to a quarter-wave transmission line filter, except that the center conductor of the transmission line is spirally wound inside the outer conductor. The spiral winding foreshortens the transmission line, making a quarter wavelength of line very compact. A quarter wave resonator at 105 MHz made of air line would be about 2.5-feet long. Because of this foreshortening, the 105-MHz helical resonator is only ¾-inches long! This makes the volume of the three-resonator filter very small.

The housing of the IF must provide the outer conductor of the helical resonator cavities. It is quite important that the cavities be uniform from unit to unit. To achieve uniformity and ease of production, it was



Block diagram of the 7L12 IF system and Video Amplifier and Processor.

decided to electroform the housing. The electroformed housing has a small compartment for the amplifier, three cavities to house the helical resonator filter, and a larger rear compartment to house the doubly balanced mixer that converts the 105-MHz signal to 10 MHz.



The 105-MHz three-cavity helical resonator filter and electroformed housing.

The 10-MHz IF

The 10-MHz IF is composed of four circuit blocks. The first block is the pre-variable resolution amplifier, followed by the second block containing the variable resolution filters. The third block is the post-variable resolution amplifier and noise filter. The final block is a function IF that generates logarithmic display functions at 10 dB/div and at 2 dB/div, as well as a linear display function.

Variable Resolution Filters

The bandwidths of the resolution filters in the 7L12 are in decade steps from 3-MHz to 300-Hz. A special feature of the 7L12 is that all of these filters have a narrow (4:1) 60 dB/6 dB aspect ratio.

The three narrowest bandwidths are obtained with crystal filters, while the 300-kHz position uses an L-C filter. The 3-MHz bandwidth is that of the 105-MHz helical filter, so in the maximum resolution postion, the 10-MHz IF is operated without a filter. After the variable resolution filters, the signal passes through another amplifier to raise its level before entering the function IF.

The Function IF

The function IF is designed to process the signal and feed the resulting video to the plug-in/mainframe interface for display on the CRT. In the 10-dB/div and 2-dB/div display modes, the function IF operates as a logarithmic amplifier. In the 2-dB/div and the Lin display modes, the funtion IF provides 40 dB of post-variable resolution gain as well.

The amplifier is followed by a detector utilizing feedback to attain a high degree of linearity and wide bandwidth. A 3-MHz low pass filter following the detector limits the video bandwidth to the maximum resolution bandwidth of the system.

Video Amplifier and Processor

The first video amplifier is also an active filter and baseline clamp. When the video filter switch is depressed, one of two video filters is turned on dependent on the position of the resolution switch. For resolutions of 300-kHz or greater, a 15-kHz video filter is chosen. For resolutions of 30-kHz and smaller a 30-Hz filter is selected. The concept of automatic selection of internal video filters simplifies the front panel and minimizes operator confusion.

Following the first video amplifier is the video processor. It was found that when viewing the spectrum of narrow RF pulses, the 3-MHz bandwidth of the 7L12 taxes the visual writing rate capabilities of even reasonably fast oscilloscopes. When looking at narrow RF pulses with a low repetition rate, the sweep speed may be as low as 1 sec/div. Normally all that would be seen on the display would be the baseline noise and a line representing the peak amplitude vs frequency of the pulses. The rise and fall times of the pulses would be invisible. The video processor slows the fall time of the beam so that the display shows a filled-in spectrum. The time constant of the display is short enough that under other conditions the display will be unaffected.

The Baseline Clipper

An adjustable baseline clipper is also provided. This circuit dims the trace when it is in the vicinity of the baseline. An added feature of the 7L12 is that the contrast between the clipped and unclipped areas of the screen is adjustable. This is particularly useful when one wishes to photograph the display, since one may overcome the baseline absence associated with conventional clippers.

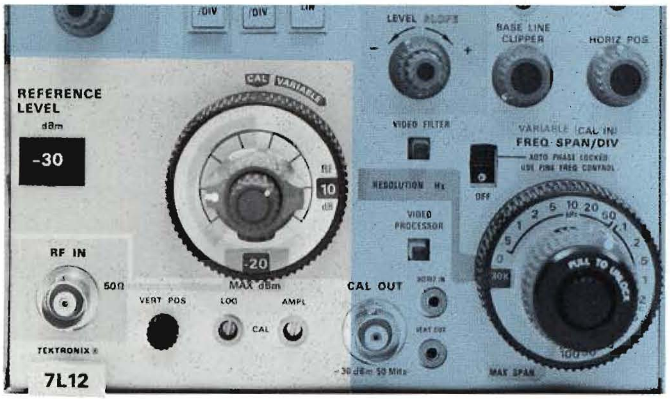
The design of the IF system was optimized for low intermodulation distortion and wide dynamic range. This, coupled with the low loss microwave front end of the 7L12, results in an instrument that typically achieves 70-dB dynamic range at 300-kHz resolution bandwidth. This permits the operator to sweep wide frequency spans at a high rate and still have 70-dB performance.

THE 7L12 MECHANICAL PACKAGE

Mechanical Design Objective

The goal was to provide a microwave spectrum analyzer in a two-plug-in width package offering all of the functions usually found in larger, stand-alone analyzers. Easy access to all active components and calibration adjustments for ease in servicing was a must. The efforts of many groups working in diverse disciplines combined to meet these challenging design goals.

Mechanically, the 7L12 is divided into three main sections: the front panel, designed for functionality and ease of operation; the RF section located directly behind the front panel; and the circuit board section containing the bulk of the active components.



Chance of measurement error is greatly reduced by automatic readout for various combinations of RF and IF gain and/or attenuation.

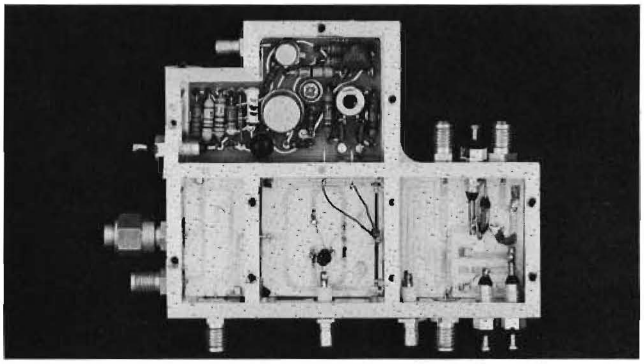
The Front Panel:

Use of lighted push buttons, color-coded grouping of associated controls, multifunction controls and easy-operating cam switches result in a control panel that is easy to understand and use.

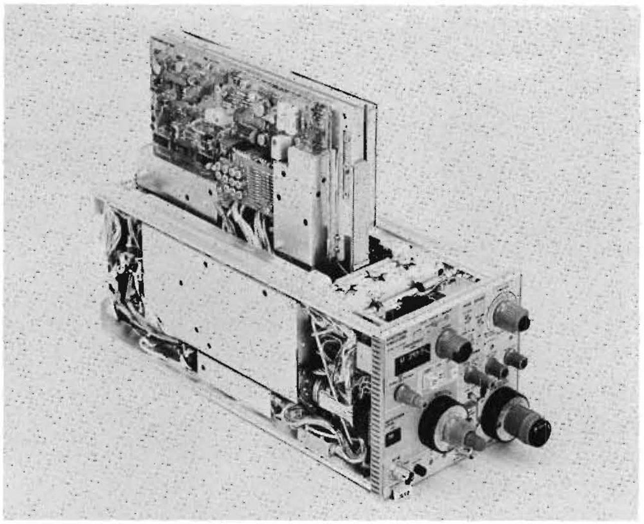
Switching of RF and IF attenuators and gain is accomplished by concentric controls. A unique summing arrangement provides direct readout of top-of-screen reference level, RF attenuation and maximum power input for linear operation.

Behind the Front Panel:

Immediately behind the front panel is the section containing the RF and IF attenuators, filters, and some of the oscillator and phase lock circuitry. Semi-rigid cables are used through this area to interconnect the various modules. These cables consist of a silver-plated solid center conductor, solid TFE fluorocarbon dielectric and tin-plated copper jacket. Using reasonable care the cables can be hand bent to aid in removing components. A multiple compartment enclosure houses the RF coupler, phase gate and 2.2 GHz oscillator hybrid circuits. Interconnection and shielding between sections is simplified and the space occupied by these components greatly reduced.



Multiple compartment enclosure housing the RF coupler, phase lock gate and 2.2 GHz hybrid circuits.



The two center circuit boards extend for easy servicing. The instrument can be operated with boards in the extended position.

The Circuit Board Section

This section contains four major etched circuit boards. The two center boards placed back-to-back, are mounted on miniature slides. The instrument can be operated with the slides locked in the extended position for ease in servicing.

Removal of the etched circuit boards and other components is simplified through extensive use of harmonica connectors.

The design objectives for the 7L12 posed a tremendous challenge from the mechanical standpoint. This challenge has been met with a unit that offers new operating ease and good serviceability, yet occupies only 5¼" of rack space when operated in a TEKTRONIX R7403 Oscilloscope.

ACKNOWLEDGEMENTS

Many talented people contributed to the successful completion of the 7L12—more than one can enumerate. Certainly a major portion of the credit belongs to the electrical, mechanical and integrated circuits design teams.

Here are some of the folks making up those teams: Electrical Engineering—Morris Engelson, Linley Gumm, Gene Kauffman, Larry Lockwood, Gordon Long, Steve Morton, Paul Parks, Fred Telewski.

Mechanical Engineering—Neal Broadbent, Jack Doyle, Al Huegli, Steve Skidmore, Leighton Whitsett.

Integrated Circuits—Judy Hanson, Robert Holmes, Carolyn Moore, Rena Randle.

Frequency Stabilization Techniques

by F. Telewski

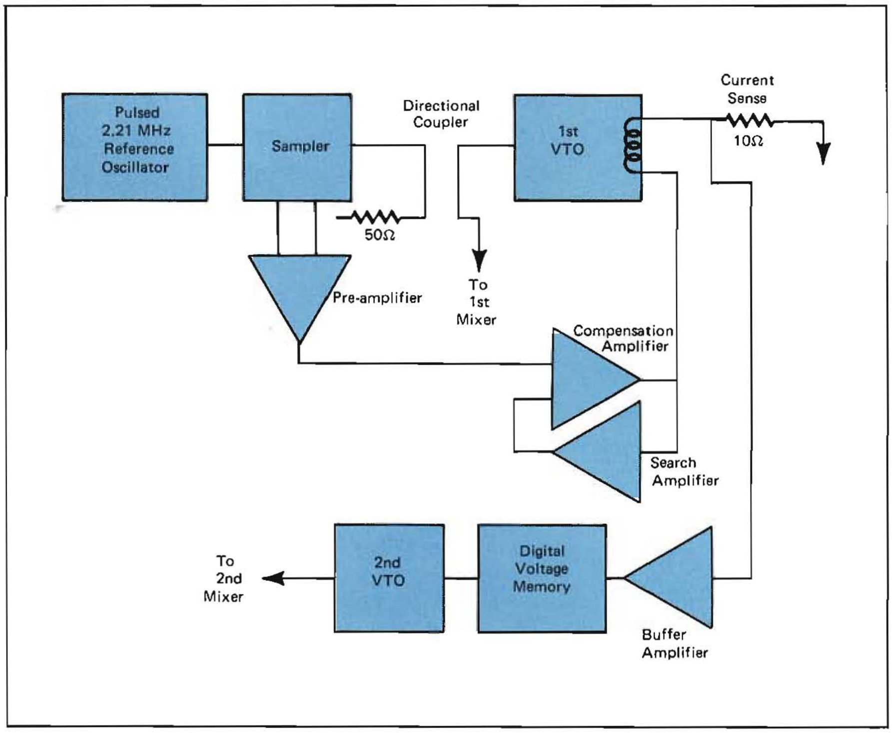
When spectrum analyzers were first conceived, designers soon became aware of the necessity of a circuit block referred to as the phase lock. The necessity for phase lock is determined by two parameters: the sensitivity of the first voltage tunable oscillator (VTO) and the narrowest span width which the instrument is to possess.

Let us assume that a VTO will respond with 100% integrity to its tuning command. Consider what stability may be achieved with good power supply regulation in today's swept front end spectrum analyzers. Typical VTOs have tuning sensitivities of 200 MHz/volt, or equivalently 200 Hz/μV. Since one normally does not like to live with a spec of less than 100 μV of noise on the sweep voltage, the oscillator will jitter 20 kHz at zero sweep. In modern analyzers with display spans of less than 20 kHz, this amount of instability is unacceptable.

This problem can be eliminated by stabilizing the first VTO with phase lock circuitry and sweeping the signal with a second VTO whose sensitivity is in the order of 1 MHz/volt, thereby providing stabilities in the order of 100 Hz.

Another advantage of the phase lock technique of oscillator stabilization is that the first VTO may be made as essentially pure as the reference which is used for the stabilization. This is important in reducing the phase noise on VTOs which use low Q resonators.

In general, the concept of phase lock involves the comparison of an oscillator (known as the locked oscillator) to a reference oscillator via a phase detector. The output of the phase detector is a voltage proportional to the phase difference ($\Delta\phi$) between the oscillators. This voltage is amplified, filtered, and fed back in a manner so as to tune the locked oscillator (first VTO) and maintain a constant $\Delta\phi$. As the gain increases, the $\Delta\phi$ becomes smaller and vice versa. It is important to note here that while we have mentioned a phase difference ($\Delta\phi$), there is no frequency error (ΔF). When the first VTO is locked, its long-term frequency stability is as good as that of the reference oscillator.



Block diagram of the 7L12 phase lock system.

PHASE LOCK SYSTEMS

Phase detection is classically accomplished in two manners. IF mixing is a technique in which two signals (reference and locked oscillator) are fed into a mixer which yields a voltage related to the phase difference between them. This, of course, requires that we have a reference tone at each frequency at which we desire a lock. Circuitry for this type of system is somewhat more complex than the alternative.

Alternatively, a DC sampler may also be used as a phase detector. The sampler is a fast switch driven by a pulse generator which acts as the reference oscillator. The pulse generator supplies a short (typically $<$ 100 ps) pulse which activates the switch, allowing a small portion of the locked oscillator waveform to pass through. These "samples" are integrated and form the voltage proportional to the phase difference between the generator and the locked oscillator. This system has an advantage in that it will yield outputs at discrete multiples of the pulse generator frequency.

Generally speaking, the DC sampler circuitry is less complex than the IF mixer system and therefore leads to a smaller and more economical package.

To date, the principal disadvantage of the sampling system was the very high output impedance of the sampling gate (typically 1 MΩ). This weakness has been overcome with development of a low impedance

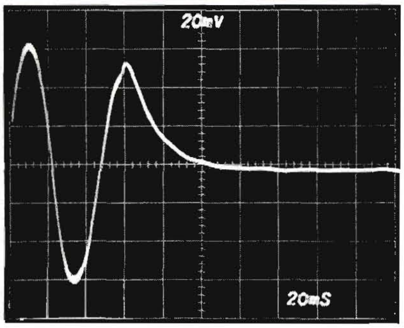
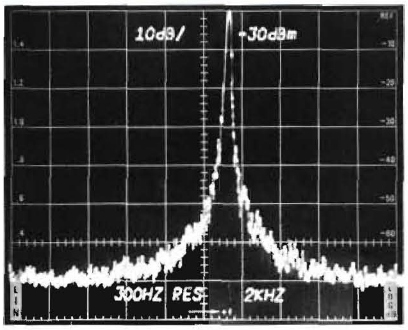
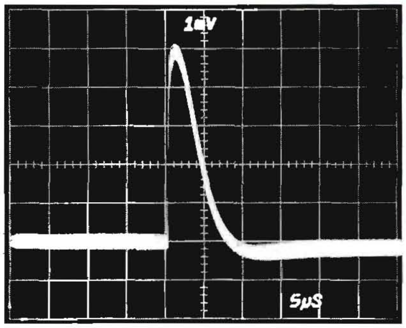


Photo above depicts the search and acquisition waveform in the 7L12 phase lock system. For the purpose of illustration, the loop was closed 20 ms after the start of the trace, thus the loop required 40 ms to acquire.



This photo demonstrates the spectral purity of the 7L12 phase lock system. The source is a 50-MHz crystal oscillator.



This photo of the impulse response of the 7L12 phase lock system depicts the wide band nature as well as the damping factor. These parameters contribute to the 7L12's spectral purity and resistance to shock.

(≈100 kΩ) balanced sampling gate. The balanced property also results in simplification of the phase lock circuitry.

ACQUISITION

When the frequency span is reduced, at some point the phase lock system must be engaged. When this happens, the locked oscillator (first VTO) must acquire on one of the harmonics of the pulse generator which, in the 7L12, operates at ≈2 MHz. The second VTO must be offset by an amount equal to, and opposite in direction to, the shift which the first VTO underwent during its acquisition, in order to keep the signal of interest on center screen.

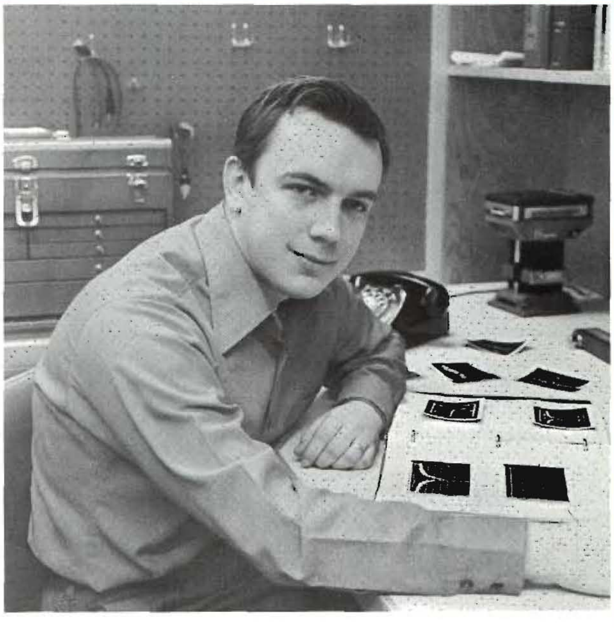
The acquisition is usually accomplished by adding a phase lock indicator which is used to turn off a search oscillator. The 7L12 eliminates this extra hardware through the use of a conditionally stable phase lock loop. The loop will oscillate at a 20-Hz rate until it intercepts a lock point. When this occurs, the oscillation ceases and the loop is locked.

While this takes place, a digital system measures the offset voltage on the first VTO before and after lock. It now generates a highly stable potential equal to this change, but of opposite polarity, for application to the second VTO.

PERFORMANCE CHARACTERISTICS AND FEATURES

The phase lock system of the 7L12 has been human engineered to operate automatically as a function of the frequency span control setting. This leaves the operator free to concentrate on his primary objective, spectrum analysis. Specifically, the 7L12 phase lock is energized automatically at frequency spans of 100 kHz or less without operator intervention. In order to provide versatility for other types of measurement, the operator may opt to disable this automatic feature with the phase lock on-off switch.

In addition to ease of use, the 7L12 provides excellent spectral purity and lock stability. The phase lock system incorporates a ≈40-kHz closed loop bandwidth damped to greater than 0.6. This damping factor yields a flat noise floor devoid of noise rises often seen in systems which are less damped. The wide loop bandwidth gives the 7L12 outstanding immunity to shock and vibration. It also permits the use of a 20-Hz search rate resulting in less than 50-ms acquisition time for the phase lock system. The 2-MHz reference generator typically reduces the phase noise ≈6 dB as compared to a 1-MHz reference generator used in previous instruments.



Fred Telewski*—Fred is a newcomer to Tek and brings a good background in spectrum analyzer circuit design to the group. He received his BSEE in 1967 and his Master's in '69 from Newark College of Engineering in Newark, N.J. Fred is a cat fancier, has three Siamese, and also dabbles in photography and amateur radio.*

TEKNIQUE:

OPTIMIZING MIXER PERFORMANCE USING THE 7L12 SPECTRUM ANALYZER

by Gene Kauffman

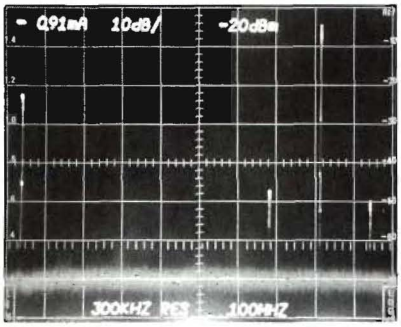


Fig. 1. *Signals observed from IF port of mixer are from left to right: Signal feedthrough at 130 MHz, (LO-Signal) conversion at 770 MHz, LO feedthrough at 900 MHz and (LO + Signal) conversion at 1030 MHz.*

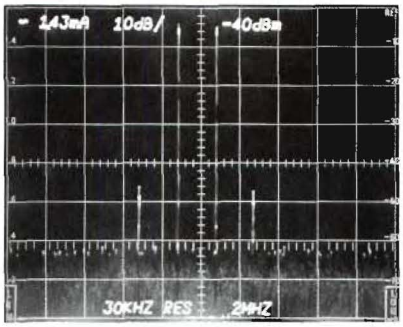


Fig. 2. *Third order intermodulation products before mixer bias optimization.*

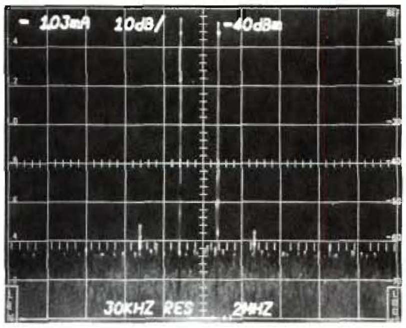


Fig. 3. *Third order intermodulation is reduced by optimizing mixer bias. 7D13 readout of bias is at upper left corner of display.*

"What can a spectrum analyzer do?", or, "What is an oscilloscope used for?" These questions are frequently asked by those outside of the electronics community. These are difficult questions to answer in a concise manner. Likewise, space here does not permit description of the broad domain of challenging RF measurement needs that the 7L12 is capable of fulfilling. However, one typical example will be outlined, showing a new facet of the TEKTRONIX 7000-Series measurement capability.

Here the 7L12 is combined with the 7D13 Digital Multimeter in a 7000-Series mainframe with readout (as shown in Figure 4). The following major parameters of an RF mixer can be determined using this setup:

1. Mixer conversion loss
2. Local oscillator feedthrough
3. Signal feedthrough
4. Mixer intermodulation products
5. Mixer bias

Figure 1 is a single exposure photograph showing, from left to right, the input signal feedthrough at 130 MHz. Next, we see displayed the mixer conversion (L.O. — signal), then the local oscillator feedthrough is observed at 900 MHz, and finally the (L.O. + signal) conversion. Thus, on one convenient setup, we can characterize or optimize the performance of this device.

Figure 2 shows the frequency span expanded around the (L.O. — signal) conversion; the center frequency on the spectrum analyzer is set at 770 MHz. Two signals 2 MHz apart are now applied to the input of the same mixer; third order intermodulation products[1] are displayed 42 dB below the converted signals. Figure 3 now shows that reducing the mixer bias current from 1.43 mA to 1.03 mA, reduces the intermodulation products by 10 dB while not substantially affecting the desired conversion efficiency.

To repeat, "What can a spectrum analyzer do?", perhaps you will be finding new and unique answers to that question as you discover the ease with which RF measurements can be made over the wide frequency range of 100 kHz to 1800 MHz, using the 7L12 Spectrum Analyzer along with the complementary 7000-Series Oscilloscope Systems.

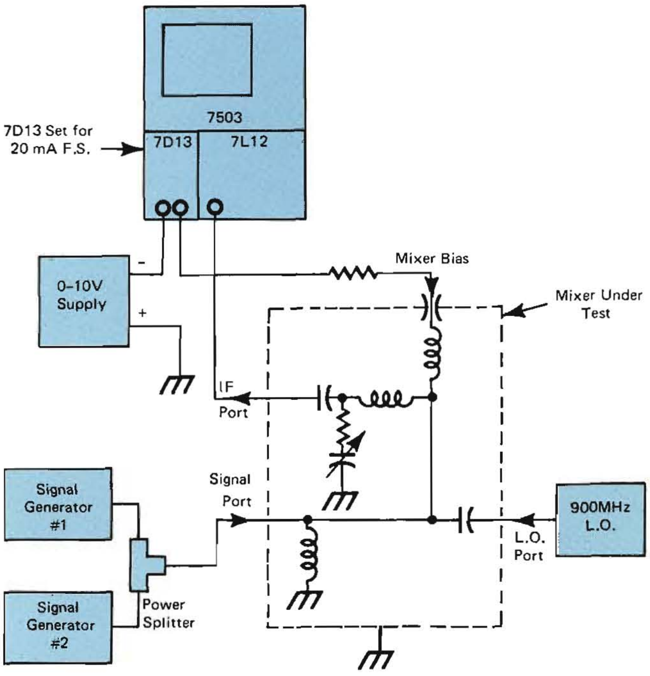


Fig. 4. *Block diagram of test set up using 7L12 and 7D13 to measure RF mixer parameters.*

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[1] Engelson, M.; "Spectrum Analyzer Circuits;" Tektronix Circuit Concept Series.

***Gene Kauffman**—Gene is an old-timer at Tek (11 years) and an old-timer with the spectrum analyzer group. He has contributed to the development of most of our analyzer products and was project engineer for the popular 491 portable spectrum analyzer. Gene's offwork hours are filled with his family, church activities, ham radio and photography.*

INSTRUMENTS FOR SALE:

564B/3B3/3A6 w/probes $1800. John Clarke, 1531 Edinborough, Ann Arobr, Mi. 48104 (313) 971-7377

543/L $1500. Robert Healy. PO Box 2028, Dublin, Ca. 94566 (415) 828-6044

545B/1A6/53-54D/CA w/cart, 7 probes & acc. $1800. Dave Eppley, 988 Kingston Dr., Cherry Hill, NJ 08034 (609) 429-5957

321 exc. cond. $350. R. J. Jarnutowski, 1909 Forest Dr., Mount Propect, Il. 60056

585A/81. Marty Sperber, One Jake Brown Road, Old Bridge, NJ 08857 (201) 679-4000

502A; 2021; P6023 (2) Dr. Jane Denton or Ron Calvanio, Mass. Gen. Hosp. Fruit St., Anesthesia Rsch., Boston, Ma. 02114 (617) 726-3851

661/4S1/5T3 & Acc. Mr. Mawson, Scientific Measurement Sys., 351 New Albany Rd., Moorestown, NJ 08057 (609) 234-0200

531A/B $650. Robt. A. Stevens, 960 Hastings Ranch Dr., Pasadena, Ca. 91107 351-9141 or 246-6761, ext. 474

555. $895. L. A. Electronics, 23044 Crenshaw, Torrance, Ca. (714) 534-4456

3B4 $400. Craig Brougher, Hallmark Cards, Photo Res. Dept., 25th & McGee, Kansas City, Mo. 64141 (816) 274-4404

585A/82. $1870. Jim Leiby, Southwestern Industries, Inc., 5880 Centinela Av., Los Angeles, Ca. 90045 (213) 776-1125

532/53B $675. Dave Loder, 19511 N.E. Halsey St., Portland, Or. 97230 (503) 666-3440

D54, P6006, P6011 (2). $550. Richard Campbell, 766 Washington St., Marina del Rey, Ca. 90291 (213) 821-4958

310, 310A, 502. John Staples, University Computing Co. (214) 241-0551

3C66 Plug-in, 2 years old. $340. G. Rayber, Harrisburg Hospital. (717) 782-3152

134 Amp. Never used. Best offer. V. F. Meyers, P.O. Box 929, Minneapolis, Mn. 55440 (612) 377-8480, ext. 23

S54A, $425. Damien Appert, 1610 L St., Davis, Ca. 95616 (916) 756-4462 eves only

585A/82 $1000; 454, $1700; 422, $900; 567/6R1A/3S76/3T77, $2500; 561A/3S76/3T77, $1350. Brian Yamrone, LeCroy Rsch. Labs, 126 N. Route 303, West Nyack, NY 10994 (914) 358-7900

P6015. Never used. Best offer. John Zielinski, Spitz Labs, Chaddsford, Pa. 19317 (215) 459-5200, ext. 43

2A63, 502A. Elliot Geophysical Co., 4653 E. Pima, Tucson, Arizona 85712 (602) 793-2421

Will trade 162A for functional 126 Power Supply. Roger Pick, P.O. Box 1190, Berkeley, Ca. 94701

310. Jack Kidd, Honeywell, Inc., 275 Wyman St., Waltham, Ma. 02154 (617) 237-4150, ext, 441

561A, $300; 2A63, $100; Mod. D Scope Cart, $75; 1A5, $300; C-12, $250. Ron Jenkins, Scientific Advances, Inc., 4041 Roberts Rd., Columbus, Oh. 43228 (614) 876-2461

535A, 561A, 545B, 661, 545, 545A, 531A, 585A, 561. Wayne Coe, Univ. of Kansas, Center for Rsch., Lawrence, Ks. 66044

310A, Make offer. Interstate Business Equipment, Inc., 8264 Hascall, Omaha, Neb. 68124

502 w/electromyography machine attached. Mrs. Marie Spang, French Hosp., 4131 Geary Blvd., San Francisco, Ca. 94120 (415) 387-1400, Ext. 507

567/3S76/3T77/6R1, 262. Mr. Endean, Westinghouse Electric Corp., Computer & Instrument Div., 200 Beta Dr., Pittsburgh, Pa. 15238 (412) 782-1730, ext. 319

514D, $195 plus freight. Comm-well Sales & Engrg. Inc., RR 5, Box 761, Golden, Co. (303) 277-0807

561A/2A63/2B67 (5) $350 ea. Tom Coulter, Dept. of Physiology, Baylor College of Medicine, 1200 Moursund Av., Houston, Tx. 77025 (713) 529-4951, ext. 471

564B/2B67/3A6, C12. Best offer. George E. Leger, Dela Enterprises, Inc., P.O. Box 1407, Coolidge, Az. 85228 (602) 723-5491

P6046 w/acc. $500. Ed Paul, 4 Carlson Circle, Natick, Ma. 01760. (617) 653-4777

INSTRUMENTS WANTED:

P6032. Mr. McGaffy, Polara Engineering, 11208 Greenstone Av., Santa Fe Springs, Ca. 90670

Any scope of 500-Series accepting letter plug-ins, preferably defective or not serviceable. B. Kalab, 4712 Exeter St., Annandale, Va. 22003 (703) 941-4843

321A, D67, D54, S54A or S54U. Chuck J. Kolar, 5461 Vallecito Dr., Westminster, Ca. 92603 (714) 897-5874

T Plug-in for 536 Scope. Joe Konieczny, Jr., 5725 Edgepark Rd., Baltimore, Md. 21239 (301) 435-2529

611. Terry Keesey, P.O. Box 1008, State College, Pa. 16801

453. Charles Wallace, 3025 Palos Verdes, Dr. No., Palos Verdes, Ca. 90274 (213) 378-7002

516 Scope. Leonard Oursler, Ch. Engr., Staten-Oursler Broadcasting, 840 E. State St., Princeton, In. 47670

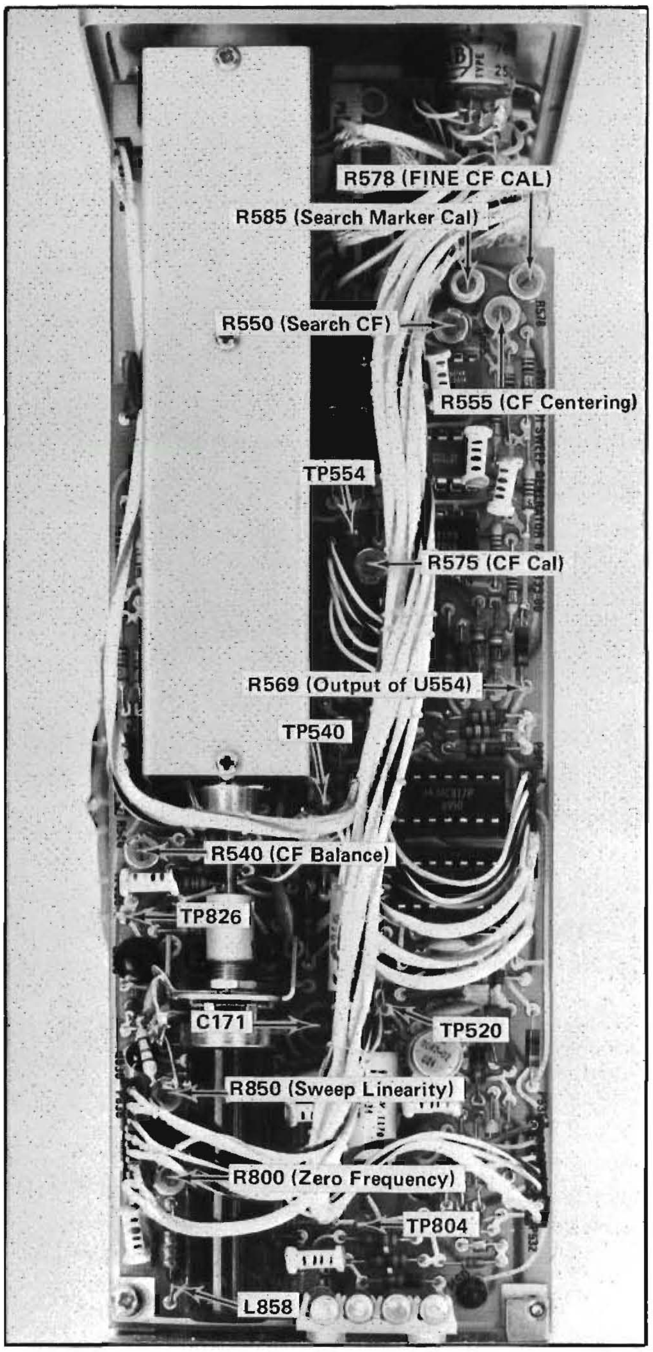
3B3. Fred Stuebner, Kuchler Dr., LaGrangeville, NY 12540 (914) 463-6092

P6021, P6013A, P6015. Richard Gilman, Box 3582, Hollywood Sta., Ruidoso, NM 88345

SERVICE SCOPE

Calibration and Troubleshooting Aids for the 1401A

by Bob Williams and John Ross, Production Test



Location of test points and adjustments on the 1401A Sweep Board.

Calibrating and troubleshooting the compact portable 1401A Spectrum Analyzer Module is a relatively easy job despite its small size. However, there are some aids that will help speed the job. Here are some items we've found helpful:

THE POWER REGULATOR

It is often difficult to determine which section of the power supply is faulty because of the feedback to the pre-regulator. The feedback can be disabled by removing Q708 and inserting a 100-KΩ, 1/8 watt carbon resistor in the socket between the emitter and collector terminals. This should permit the multivibrator in the pre-regulator to run and you can proceed from there.

Another area that sometimes causes concern is checking ripple on the supplies. A lead connected from the ground post on the side of the 1401A, to the test scope ground will reduce the apparent ripple.

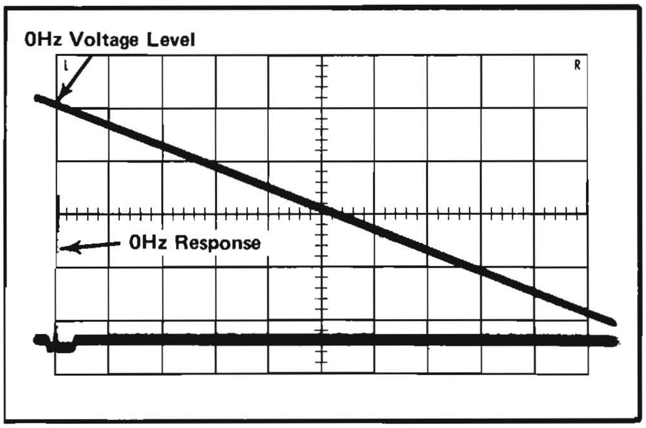
THE RF SECTION

If you are experiencing low sensitivity, the first step is to make sure the RF attenuator is switched out of the circuit. You can bypass the attenuator by feeding the signal directly into J141. If the sensitivity is quite low, check mixer diode CR167 in the second converter. It is physically located between two sections of the RF module and is easily broken if installed with leads that are too short. Failure of Q184 in the second converter will cause total loss of signal. If it is replaced you should check the 720-MHz oscillator adjustments as outlined in the manual.

Note that care should be taken when soldering parts or leads on the RF module printed circuit board. The board is made of material having low dielectric loss and is subject to damage from prolonged or excessive heat.

It is a characteristic of microwave RF components that they require special techniques and tools to properly service them. If you have problems in the RF attenuator, low-pass filter, voltage tuned oscillator or the wideband mixer, we suggest you return the unit to Tektronix for service.

If you have occasion to align the RF section of the analyzer, you will encounter a spurious that occurs at about 12.5 MHz. This can be tuned down by inserting an RF signal close to it in frequency. With both the signal and spurious displayed on screen, set the RF module adjustments for optimum signal response and minimum spurious amplitude. The spurious may be twice the noise in amplitude if the input of the 1401A is not properly terminated (50 Ω for the 1401A and 75 Ω for the 1401A-1).



Test scope display when setting R550, center frequency adjustment.

THE IF SECTION

While we're discussing alignment, you will find that T208 and T210 have considerable effect on sensitivity. These should be set for peak signal. Low amplitude when in the 3-kHz resolution position indicates that the 100-kHz filter is not aligned over the 3-kHz filter. If you have removed the power regulator board for servicing and inadvertently reversed the connector on P711 or P712 you will have a similar symptom.

IF gain is contributed by Q208, U240 and U260. Q208 is the most likely suspect if gain through the IF section is low.

The IF section also contains the circuitry for gated operation of the 1401A. If trouble is suspected in this area, you can bypass the gate by placing a jumper between Pin 1 and 4 of P208.

THE SWEEP CIRCUIT

Because the sweep adjustments interact, more difficulty with calibration has been experienced in this area than in any other. The following procedure will help set the sweep adjustments properly:

1. Set up the 1401A and test scope as detailed in step 5 of the manual calibration/adjustment procedure.
2. Set R575 (CF Cal) on the sweep circuit board about 1/3 turn from full CCW.
3. Connect the test scope probe to TP554 and adjust the test oscilloscope EXT HORIZONTAL GAIN for about 10.5 divisions centered horizontally.
4. Adjust R555 (CF Centering) for 0 V at TP554.
5. Switch FREQ SPAN MHz/div to 20 and adjust R540 (CF Balance) for 0 V at the center of the sweep.
6. Switch FREQ SPAN MHz/div to SEARCH and adjust R550 (Search CF) for 0 V at the left graticule line.
7. Continue as shown in the manual for the remaining sweep adjustment, commencing with step 8.

When adjusting the sweep shaper the following points may be noted:

a. Step 12 of the procedure calls for measuring the voltage across R108. This cannot be done without removing the gate-calibrator board. An alternate method is to measure the voltage at L858 on the sweep board. It should be approximately 1 V more negative than at TP826.

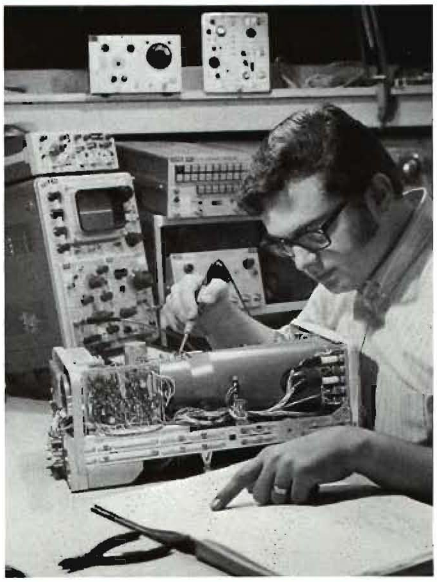
b. If the 0-Hz response moves appreciably ($\approx$0.5 cm) when adjusting R415 it usually indicates R800 will have to be set to a different voltage level and R850 readjusted.

c. It is not always necessary to adjust R410 to R415 from their preset positions to achieve proper sweep shaper adjustment.

Using these service hints and the calibration and maintenance procedures outlined in the manual you should be able to keep your 1401A in good working order. If you have difficulty, don't hesitate to call your TEKTRONIX Field Engineer.

Bob Williams, *pictured at left, is a staff engineer in Production Test. Bob has been with Tek six years, working primarily with spectrum analyzer products. He started his electronics career in the Navy as an Electronic Technician. Bob's leisure time is largely filled with his wife and three children; he does admit to an occasional stint at the bowling lanes.*

Co-author ***John Ross,*** *at right, also works in Production Test. He joined Tektronix nearly six years ago upon graduation from Spokane Community College. He, too, likes to bowl; however, electronics is John's main hobby as well as vocation. He has a charming wife and year-and-a-half old daughter.*



TEKSCOPE

Volume 4 Number 1 January 1972
Customer Information from Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97005
Editor: Gordon Allison Graphic Designer: Jim McGill For regular receipt of TEKSCOPE contact your local field engineer.

The 1401A/324 Portable Spectrum Analyzer System

Spectrum analysis from 1 MHz to 500 MHz with 60 dB dynamic range and absolute calibration.

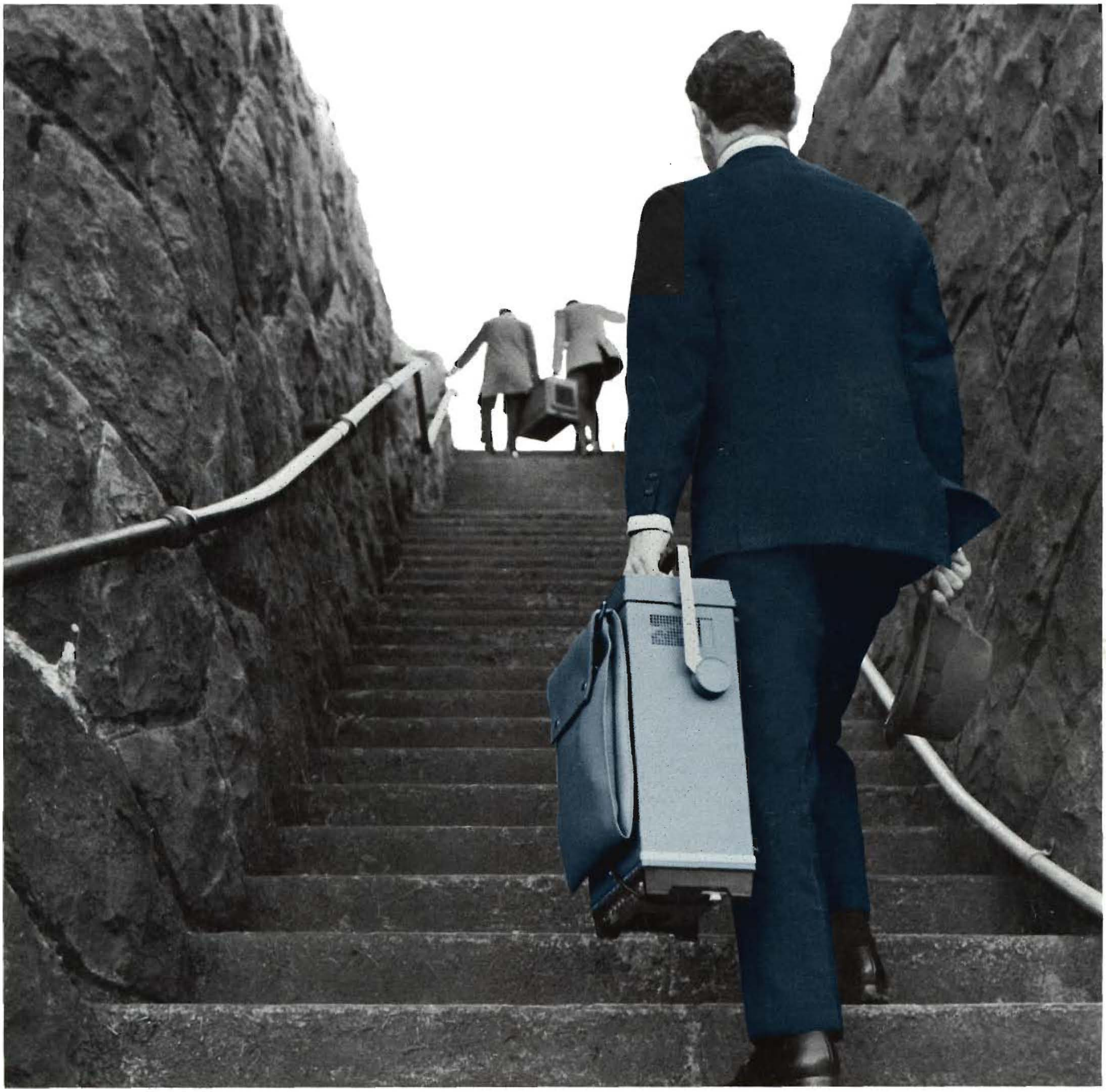
Oscilloscope measurements from DC to 10 MHz at 10 mV/div and to 8 MHz at 2 mV/div.

System weight including batteries is less than 15 pounds.

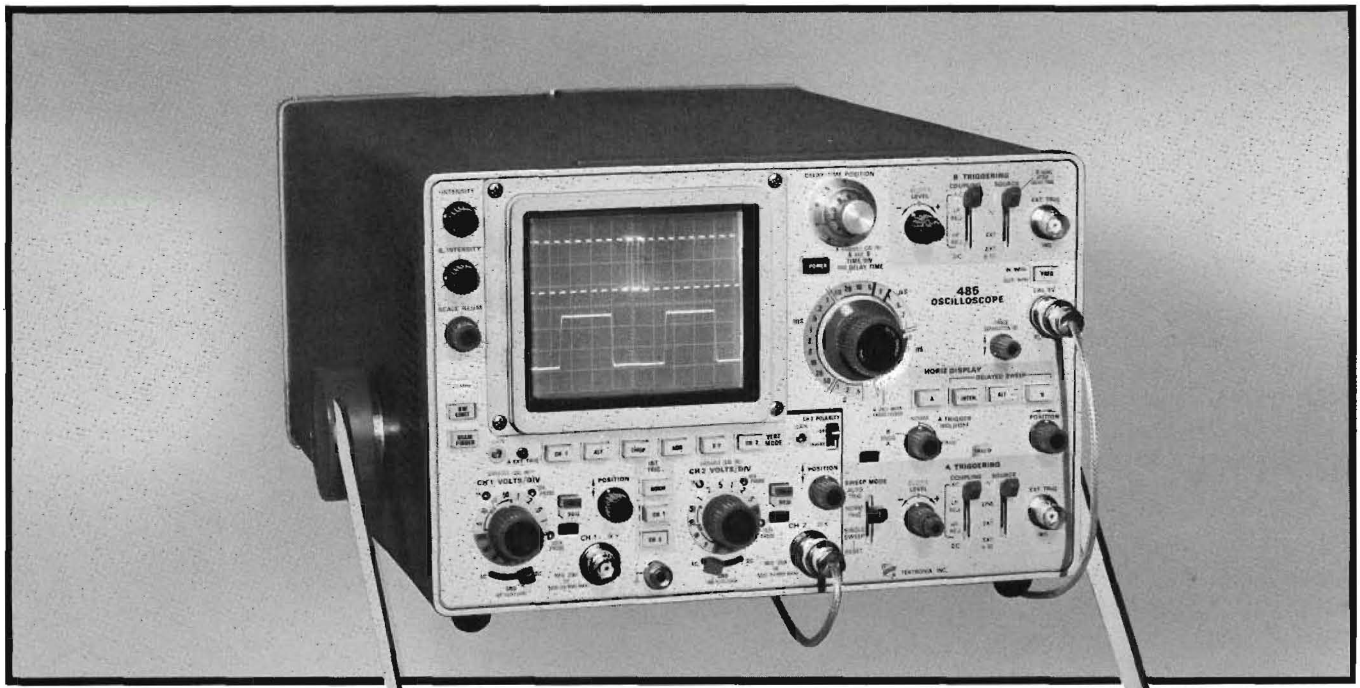
The 1401A is tailored for use with the SONY/TEKTRONIX 323, 324 and 326 Oscilloscopes. It is compatible with any oscilloscope having 0.5 V/div horizontal deflection factor and 1.2 volt full-screen vertical deflection.

TEKSCOPE

MARCH 1972



A Nanosecond Portable Oscilloscope
A Review of Basic Counter Principles
A Potpourri of Servicing Aids



A Nanosecond Portable Oscilloscope

By Gene Andrews,
Engineering Project Manager

Nanosecond signals, limited to the laboratory environment yesterday, are appearing with increasing frequency in equipment delivered to customers today. The need to view and measure these signals in a "field" environment is upon us.

Responding to this need, the 485 offers greater bandwidth/sensitivity than any other real time oscilloscope available today, and in a portable package.

Weighing only 20½ pounds the 485 boasts 350-MHz bandwidth at 5 mV/div with a 50-ohm input impedance. Selectable input impedance permits you to easily switch to the traditional 1-megohm input for measuring power supplies and other high level signals. Bandwidth in the 1-megohm position is 250 MHz.

The wide bandwidth is complemented by a top sweep rate of 1 nanosecond/div with stable triggering to full bandwidth. A variable holdoff control permits viewing of complex waveforms such as digital words without multiple triggering.

Smaller and lighter than the world's most widely travelled oscilloscopes, the TEKTRONIX 453A and 454A, the 485 possesses all of the capability you have come to expect in portables, plus several new features. Dependability, dual trace, delaying sweep, automatic triggering, bright trace, X-Y . . . they're all there. In addition, you have an alternate sweep presentation that lets you view repetitive signals on both delaying and delayed sweeps at the same time. Automatic focusing keeps both traces sharp even though the individual intensity settings differ widely. Because of the infrequent need for adjustment, the focus and astigmatism controls have been relegated to the rear panel.

COVER—The new 485 Portable Oscilloscope makes the going easier whether the problem is a steep flight of stairs or a difficult measurement.

Much has been done to reduce operator error and speed measurement time. For example, light emitting diodes indicate the vertical deflection factor at the probe tip, automatically switching to accommodate X1, X10 or X100 probes. Push-away variable controls prevent measurement error caused by inadvertently leaving the control in an uncalibrated position.

Operation is simplified by single-function pushbuttons; just pressing one pushbutton switches you from Y-T operation to X-Y operation. And there is no need to reach frantically for the Intensity control. CRT beam current is automatically limited to prevent damage to the screen in every display mode.

A unique feature on the 485 is the ability to view the signal applied to the external trigger input, by means of a front panel pushbutton. This is a real time-saver when the external trigger signal is frequently used as a timing reference.

State-of-the-art performance at the front panel can only be achieved by state-of-the-art components and circuit design, coupled with the latest in manufacturing techniques. Let's look at each of these areas.

The CRT Circuit

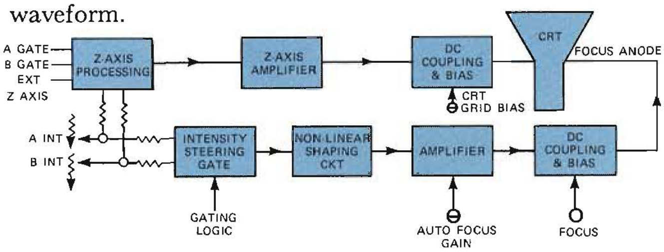
The CRT circuit produces the high voltage potentials and provides the control circuits necessary for the operation of the cathode ray tube. This section contains several innovations in circuitry that enhance the operation of the scope. Two examples are auto-focusing and beam current limiting.

Auto-Focus

Auto-focus is especially useful when viewing the delaying and delayed sweeps in the alternate mode. The focus voltage required is a function of the CRT control grid voltage or intensity setting. Since the two sweeps are normally set to different sweep rates, their respective intensity controls are set to different levels. The objective is to keep both traces in focus despite the difference in intensity settings.

In single-shot photography it is often necessary to take several trial shots to obtain the correct intensity for a good picture. With auto-focus the job is made easier because it is unnecessary to change the focus with each intensity setting.

A block diagram of the auto-focus circuit is shown below. The DC levels from both the main and B intensity controls are fed into a steering gate. Also fed into the steering gate is a gating waveform from the horizontal logic. During the blanking interval, when sweep switching takes place, the intensity levels are switched by the gating waveform.



Block diagram of the 485 auto-focus circuit.

From the steering gate the selected intensity level passes through a nonlinear shaping circuit. This circuit converts the linear intensity (CRT grid) voltage function to the nonlinear focus voltage required by the CRT. From the shaper it passes through an amplifier where the amplitude is set to match the focus function to the particular CRT. The final block before reaching the focus anode is the DC restorer circuit containing the FOCUS control located on the rear panel.

It is well to keep in mind that the purpose of the auto-focus circuit is to automatically change the focus voltage as the intensity level changes. It does not correct for defocusing caused by the geometry of the CRT and the deflection plates.[1]

CRT Beam Current Limiter

Most scope users have, at one time or another, unwittingly switched to an operating mode in which the beam was either stationary or moving slowly, with the intensity setting very high. The result was often a spot or line burned in the phosphor screen, accompanied by a sick feeling in the pit of the stomach.

Now we have a circuit in the 485 to prevent this happening. The CRT beam current is sensed at the low-potential end of the high-voltage multiplier. When the average beam current exceeds the level set by the maximum intensity adjustment (about 20 μA), a signal is fed to the Z-axis processing IC which limits the maximum Z-axis drive signal. For sweeps of 50 ms/div and slower and in the X-Y mode, average beam current is limited to 5 μA. Normal CRT operation includes instantaneous beam currents as high as 150 μA but a continuous value of 20 μA is adequate for applications such as a full-screen bright raster.

In the event there is a failure in the Z-axis system that causes the average beam current to exceed 30 μA, a back-up system automatically shuts down the power supply. After 100 to 300 ms the supply attempts to restart. If the overload is still present, the supply will cycle off and on until the trouble is cleared or the scope is turned off.

The CRT

The 485 CRT was developed concurrently with the 500-MHz 7904 CRT and uses a similar gun structure. The 8 x 10 division scan (0.8 cm/div) is accomplished by the unique construction of the vertical deflection plate structure. Each plate is a photo-etched box-like structure about 2.5 inches long. The design permits bending the structure to gradually increase the spacing between plates at the screen end. The structure is tuned by means of adjustable compensator plates to maintain a Z_0 of 364 Ω within 1%. A dome-shaped mesh shields the deflection plate area from the high accelerating-anode potential and contributes a two-times deflection magnification.

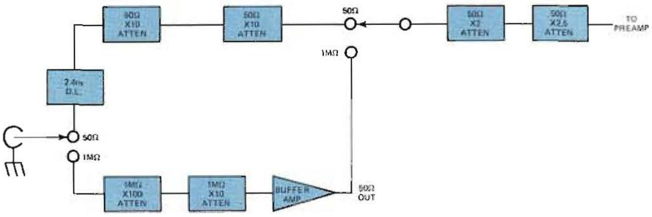
The 21 kV accelerating potential yields a writing speed in excess of 6 div/ns using a P11 phosphor and C-31 Camera with 10,000 speed film.

THE VERTICAL AMPLIFIER

Access to the vertical amplifier is through a single front panel BNC connector. Separate 50-ohm and 1-megohm signal paths are selected by a front panel push-button.

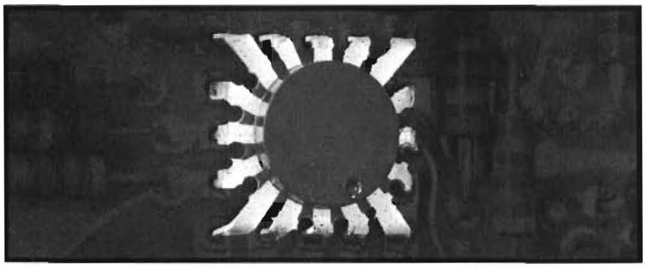
Note 1 Reference TEKTRONIX Circuit Concepts Book entitled "Cathode Ray Tubes".

The input switching relay also provides protection for the 50-ohm input by automatically disconnecting the input whenever a continuous signal exceeds 5 V RMS, or a pulse above 5 V exceeds 0.1 watt-second. A RESET light indicates overload has occurred. The input is easily reset by pressing the 50 Ω/1 MΩ input selector pushbutton.



Separate input paths for the 50 Ω and 1 MΩ inputs yield a low 1:1.2 VSWR.

The vertical amplifier uses nine IC's, all of the same type with the exception of the output stage. Both types are Tek-designed and manufactured. Innovation in packaging as well as circuit design contributes to the outstanding performance of these devices. The square lead arrangement of the M84AC package minimizes bondwire lengths and provides the optimum configuration for interfacing with the printed circuit board.



The M84AC is a multifunction device. It serves as an amplifier, polarity inversion switch and variable gain control. Basically it is a cascode amplifier. Connection to the base of the input amplifier is through a "T" coil arrangement partially formed by the bondwires of the device. This technique results in the input appearing as a 50-ohm load at all frequencies and a considerable increase in the bandwidth of the device is effected.

Two pairs of transistors form the output portion of the cascode amplifier. The DC voltage on the bases determines which pair conducts and, hence, the polarity of the output signal relative to the input. Variable gain control is achieved by allowing both pairs to conduct by a selected amount.

Bandwidth limiting in the stage driving the output amplifier is achieved using a similar technique. With the BW LIMIT switch in the FULL bandwidth position, one pair of output transistors passes the signal through a 50-ohm environment to the output stage. In the 20-MHz position, the signal is routed through the other pair of output transistors into a 2-pole, 12 dB/octave filter for signals above 20 MHz.

The output stage is a hybrid IC consisting of an "f_T doubler"[2] stage driving discrete transistors mounted on separate silicon chips. The output stage is housed in a TO-8 stud-mounted package with the integrated circuit chip mounted right on the stud for maximum heat transfer.

THE HORIZONTAL SYSTEM

Flexibility is the word best describing the horizontal system in the 485. Some of the features we've already mentioned briefly, such as stable triggering to full bandwidth and viewing of both delaying and delayed sweeps in an alternate sweep presentation. A single pushbutton puts the 485 in a calibrated X-Y mode with less than 3° phase shift to 5 MHz.

The top sweep rate of 1 ns/div is achieved without the use of the usual 10X magnifier. This results in improved linearity and timing accuracy for the fastest sweeps since the horizontal amplifier operates over a relatively small dynamic range. The amplifier circuitry is greatly simplified as the limiters and circuitry normally associated with the use of a magnifier are not needed.

Further simplification of the horizontal circuitry is effected through a unique scheme that uses a single time base generator to generate the 1, 2, 5 ns/div sweeps for both the main and delayed sweep functions.

Usually the main (delaying) sweep operates over the broadest range of sweep rates since this is the sweep used in the majority of applications. The delayed sweep normally does not include the slower sweep rates; however, the faster sweeps are needed for many applications. This means the horizontal system usually contains two time base generators capable of generating these fast sweeps.

In the 485 only the delayed sweep generator is used for the 1, 2 and 5 ns/div sweep rates. When operating in the Main Sweep Mode at these sweep rates, both Time/Div controls are locked together. The delayed sweep generator is automatically placed in a "zero delay" condition and starts immediately upon receiving a gate from the Main Trigger logic. In essence, it is being triggered by the Main Trigger and it is not apparent to the user that the displayed sweep is actually being generated by the delayed sweep generator.

Requiring only one time base to generate the fast sweeps results in an appreciable reduction in instrument cost. Maintenance expense is also reduced accordingly.

Another important feature of the horizontal system is the capability of operating at up to 2-MHz rep rates on

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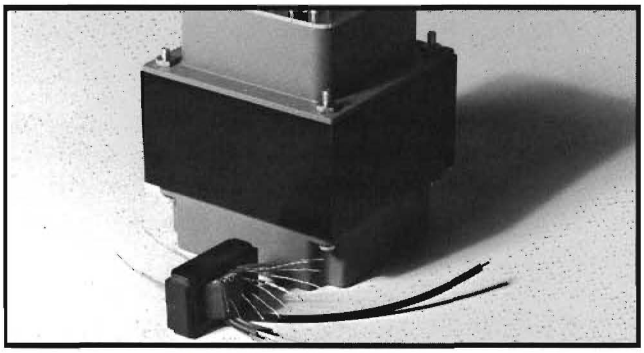
Note 2 See July TEKSCOPE "A Subnanosecond Realtime Oscilloscope".

the faster sweeps. This provides minimal loss of signal information and maximum display brightness.

THE POWER SUPPLY

The 485 uses a high-efficiency power supply; the type first used in the 7704 Oscilloscope[3]. Great strides have been made in reducing the complexity and physical size of such supplies. In the 485, total weight of the unit supplying both low and high voltages is only 2.8 pounds. Overall efficiency from line to regulated DC is 80%.

A single transformer weighing only 4 ounces and dissipating less than 2 watts powers the unit. The photo below shows its size in comparison to the power transformer used in the TEKTRONIX 547 Oscilloscope.



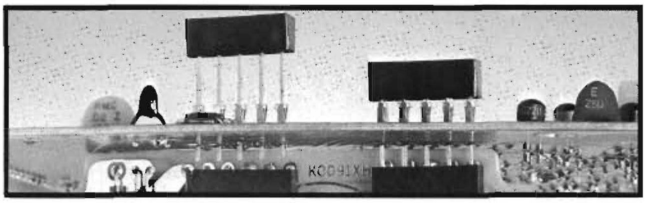
MECHANICAL CONSIDERATIONS

Mechanical design goals for the 485 were to produce a smaller, lighter package than the 453/454, with improved operating ease and serviceability. Close cooperation between the electrical and mechanical design groups resulted in significant achievement in each of these areas.

Some of the improvements in operating ease have already been noted, such as function changing by means of a single pushbutton, elimination of front panel controls through automatic focusing, and front panel indication of the deflection factor at the probe tip. Tektronix-developed cam switches provide smooth, easy operation for changing of sweep rates and vertical deflection factors.

The low 20½ pound weight is achieved by unitized construction which takes maximum structural advantage of all components. Overall dimensions of 20-5/8 x 12 x 6-9/16 inches make the 485 both narrower and shorter than other portables. It requires less bench space and is easier to carry.

Serviceability is a prime feature of the 485 design. A minimum number of printed circuit boards are used and a unique circuit board interconnection system practically eliminates cabling between boards.



Since the 485 is expected to operate in widely differing environments, the cooling system employs a temperature sensing circuit which varies the air flow according to the ambient temperature. This insures minimum drift and maximum reliability.

Designed to meet the need for nanosecond measurements in a field environment, the truly remarkable capabilities of the 485 will undoubtedly find many applications in the laboratory and production areas as well.

ACKNOWLEDGEMENTS

A project of the magnitude of the 485 naturally involves many people. Here are some of the members of the talented team responsible for the 485. John Addis was project leader for the vertical section, assisted by Winthrop Gross. Glenn Bateman, Ron Peltola and Bob Firth designed the low and high impedance attenuators. Murlan Kaufman was project leader for the horizontal and logic systems and designed the trigger generator. Bob White designed the trigger amplifier and external trigger view circuits. Keith Taylor did the work on the fast sweeps, the horizontal and the Z-axis amplifiers. The excellent mechanical design was done by Tom Baker, Mark Anderson and Dave Curtis under the direction of Dick Duggan. Dick Troberg designed the high efficiency power supply system, contributing much to the low power and weight of the instrument. Vaughn Weidel, project coordinator, provided much valuable assistance including the unique board-interconnect design. Conrad Odenthal designed the high-performance 485 CRT. A great many other groups also made valuable contributions to the 485 project.

Note 3 See March, 1971 TEKSCOPE.

Gene Andrews—During his ten years at Tek, Gene has made many fine contributions to the product line. He began by working on the 10A2 amplifier, and was then responsible for the vertical amplifier design of the 453 Portable. He later was project engineer on the 647A/10A2A to bring this up to a 100-MHz instrument. When the 7000-Series was conceived he worked out the horizontal amplifier for the 7704 and designed the high-efficiency power supply for the unit; the first used in a TEKTRONIX laboratory oscilloscope.

Gene received his BSEE from Oregon State in 1954 and completed his M.S. at Stanford in 1956. For recreation he enjoys hiking with his wife and two teenagers in this great Northwest country.

a review of basic Counter Principles

By Ray Herzog, Assistant Program Supervisor

With the introduction of the 7D14 Digital Counter plug-in, Tektronix opened the door to the world of counter measurements for oscilloscope users. The convenience of having a digital counter as an integral part of the oscilloscope meant that, for the first time, many of you would be using this valuable tool to help solve your measurement problems.

As with any instrument, the more familiar one is with the basic operating principles of the counter, the better he can put it to use. To this end, we've prepared a review of basic counting principles and the common types of counters in use today.

BASIC COUNTER FUNCTIONS

Although there are many types of counters, all are basically designed to measure an unknown frequency or time by comparing it with a known frequency or time. Design differences account for variations in such areas as price, accuracy, and number of measurement modes. We will use the direct counting type of counter as a basis for our discussion of basic counter functions. Other types of counters will be mentioned later in the article.

In addition to a power supply and necessary switching circuitry, five main functions are essential to any counter. As shown in Figure 1 these are:

(1) Signal input conditioner
(2) Gate
(3) Gate control/Time base
(4) Decimal counting units (DCU's)
(5) Readout

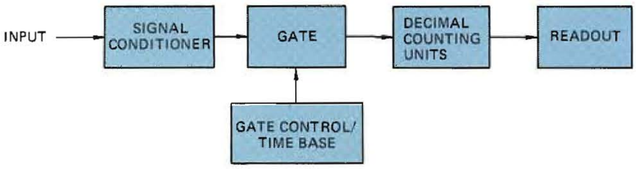


Fig. 1. Five main functions of an electronic counter.

The incoming signal to be counted, in going through the signal conditioner stage, receives the normal conditioning typical with any input stage: attenuation for large signals, amplification for weak signals, selection of coupling, impedance matching and so forth. But in addition to normal signal processing, the counter signal conditioner has another purpose; to transform the measured signal's waveform into a precisely shaped signal suitable for further counter functions. The conditioner, therefore, may also be referred to as a "shaper". The need for signal shaping arises from the fact that input signals, with varying shapes and amplitudes, are not suitable to drive the counting circuits.

Signal shaping is usually done with a Schmitt trigger circuit. Inherent with this Schmitt is a LEVEL/SLOPE control that selects the amplitude and slope on the signal where the counter is triggered. This control is much like that found on the conventional scope.

The conditioned signal is next passed through a gate for a time interval determined by another function—the Gate Control/Time Base. The gate is a "go/no go" device. How it is turned on and off via the control stage is basically determined by the operating mode. More will be said about the gate and its control later in the operating mode discussion.

Signal pulses from the gate, having been determined by the counting mode, are fed to the decimal counting units (DCU's). Here they are converted into a signal suitable to drive the readout. DCU's are usually flip-flops arranged to divide their input by 10; they drive the readout in binary coded decimal (BCD) form. The first DCU gives the "units" count, the second DCU, the "tens" count and so forth. And, as would be expected, the number of DCU's, as well as readout capacity, determines the magnitude of the displayed count. For example, eight DCU's and a corresponding number of readout units would give an 8-digit readout.

Readout, the last of the counter stages, provides a visual indication of the count. Typical readout devices include neon lamps, incandescent lamps, light emitting diodes, gas ionization tubes, and multi-segment/bar indicators. With the 7D14, readout is provided by the unique oscilloscope CRT readout. CRT readout gives an alphanumeric display of information on the CRT on a time-shared basis along with the analog waveform.

MODES OF OPERATION

The electronic counter is most often thought of as a device that totalizes (counts) input events. But this operation, in the totalize mode, is only one of seven common modes. A counter can also indicate an input signal's frequency or period, in frequency and period modes. It can compare two signals in the ratio mode. It can indicate the time between any two points on a waveform; when they represent an input signal's pulse width, the counter would be in a width mode. And finally, in the averaging mode, a counter can average the measurement reading over a number of periods or time intervals to give better resolution.

It should be noted that not all counters are capable of seven modes. The main factors that limit the total number of modes are price and type of counter. For some applications, all modes are not needed. The 7D14, for instance, has the totalize, frequency and ratio modes.

Totalize Mode

The discussion of counting modes will start with the simplest one, the totalize mode shown in Figure 2. When compared with Figure 1, it may readily be seen that the gate control/time base function is no more than a simple switch that turns the gate on and off in performing the totalize operation. Indeed, in totalizing an input signal, all that's necessary is to let the signal accumulate in the readout register. Thus, the gate is permitted to pass the signal for whatever time the totalizing is to occur.

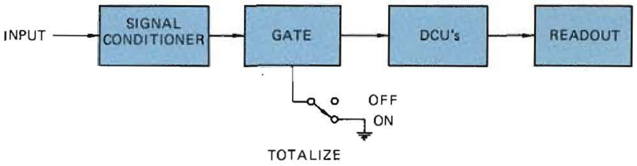


Fig. 2. In totalize mode, the gate is turned on for the time that the input signal is to be accumulated.

In its simplest form, the gate's "on" time is controlled manually. In the 7D14 this switching is done with a double push-button, self-cancelling switch called MANUAL GATE/ON OFF. A count is started when the "ON" switch is pushed "in", and is ended when the "OFF" switch is pushed "in". Figure 3 shows this function, along with one other totalizing gating method; external control.

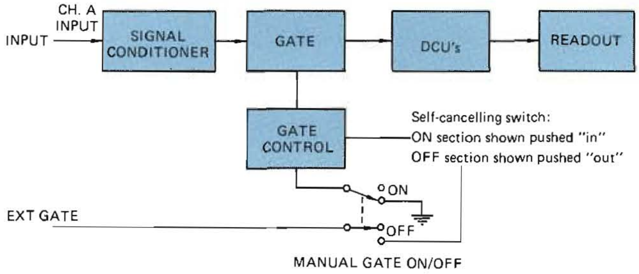


Fig. 3. Two methods for totalize mode gate control: Internal (manual) and external.

Remote control of the gate may be obtained from an external control signal. When the MANUAL GATE "OFF" switch is pushed "in", the EXT GATE input is connected to the gate control circuitry, and this signal establishes the gate "on/off" time. When the external control signal is an accurate time base, precise gate control may be established.

In both of the above totalizing operations, the input signal will be totalized (counted) for as long as the gate is conducting.

Frequency Mode

When the gate is controlled by an accurate time interval, the counter is in the frequency mode. This is diagramed in Figure 4. In a way, the frequency mode is like the totalize mode in that the input signal is counted for the period of time that the gate is open. In fact, a comparison of the totalize mode in Figure 3 with the frequency mode in Figure 4 reveals that the only difference is the way in which the gate control is operated.

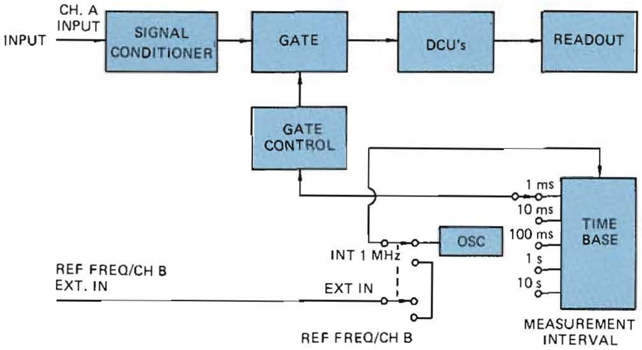


Fig. 4. Two methods for frequency mode gate control: internal time base and external.

For frequency measurements, the counting time interval must be very accurate. Usually a reference oscillator in the counter provides the time interval. The 7D14 oscillator frequency of 5 MHz is divided down to a 1-MHz signal before being fed to the time base. The time base further divides the 1 MHz and from it derives time base intervals.

As Figure 4 shows, an external oscillator may also serve as the time base reference. For this operation, the external oscillator is applied to the REF FREQ/CH B EXT IN connector; from there it is routed via the EXT IN switch to the time base.

Ratio Mode

A third mode of operation is shown in Figure 5, in which the ratio of two input signals is displayed on the counter readout. The higher frequency signal is fed to the CH A INPUT connector and goes to the gate. The lower frequency signal is fed to the REF FREQ/CH B EXT IN connector. With the EXT IN switch pushed in, this signal is then routed to the time base. Here it is divided down and serves as the gate control signal.

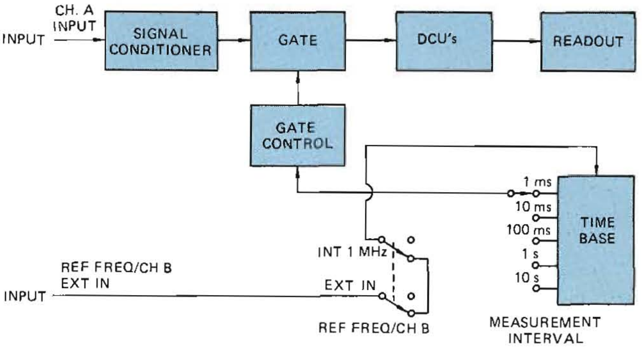


Fig. 5. Ratio mode gives the ratio of two input signals.

In effect, what happens is that the lower frequency signal determines how long the gate is open, and thus, how long the gate passes the higher frequency signal from the CH A INPUT. The gate output, therefore, is the ratio of the two signals.

An example will serve to illustrate this. For convenience in understanding ratio action, both signals will be assumed to be equal. And the influence of the time base will be ignored for the moment. Let's say a 1 kHz signal is fed to the CH A INPUT and another 1 kHz signal is fed to the REF FREQ/CH B EXT IN connector. The gate would then be open for 1 ms (period of the 1 kHz signal). In this 1 ms time, the gate would pass 1 pulse of the CH A INPUT signal. Or, in other words, the ratio of the two signals, each 1 kHz, would be 1/1. This ratio would be displayed on the counter as 1. (The ratio denominator "1" is assumed in the readout.)

Now let's consider the effect of the time base on the above example. With the MEASUREMENT INTERVAL switch in the 1 ms position, the REF FREQ/CH B EXT IN signal would be divided by 1000. The gate would thus be open for a longer time than in the previous example. The result of the longer counting time is better resolution of the ratio measurement. This is shown on the readout in the form of significant decimal digits. The 1/1 ratio in our example would be displayed as 1.000 with the MEASUREMENT INTERVAL switch in the 1 ms position. In the 10 ms position, the displayed readout would be 1.0000, and for a 100 ms time interval, the readout would be 1.00000.

Period Mode

The period of a signal is the reciprocal of its frequency. As such, the measure of signal period might be expected to have a similar inverse relationship with its frequency measurement. And as shown in Figure 6, the period mode circuit is similar to that of the frequency mode (Figure 4)—with the exception of a reversal of the gate inputs.

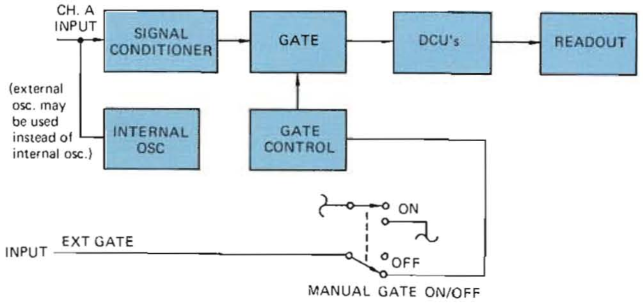


Fig. 6. *In period mode, counter counts a reference oscillator signal during an input signal's period.*

In the period mode, the signal to be measured is fed to the gate control where it determines how long the gate is open. To the gate is also fed an accurate oscillator signal. The gate output, therefore, consists of pulses from the oscillator that represent the measured signal's period. For example, say the signal to be measured is 100 kHz (10 μs) and the reference oscillator is 1 MHz (1 μs). The gate would be open for 10 μs, and in this time would pass 10 pulses from the oscillator. These 10 pulses are then processed by the counter to provide a readout indicating a period of 10 μs.

Time-Interval Mode

The time-interval mode permits the counting of any number of events occuring between any two points on a waveform. This variable interval of measurement time is possible with a more elaborate gate than with other modes previously discussed. As evidenced in Figure 7, the gate has three inputs: one from the gate control, and two from the signal conditioner stages—"start" and "stop" inputs.

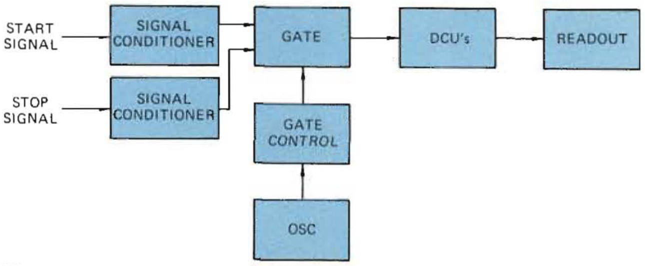


Fig. 7. *"Start" and "stop" signals open and close the gate in the time-interval mode.*

The gate control feeds an accurate oscillator frequency to the gate where it then gets counted for a time determined by the "start" and "stop" input. The "start" and "stop" points are selected by triggering levels on the input waveform.

In a way, the time-interval mode is like the period mode, i.e., counting is done during a given time. But with the selectable "start" and "stop" points, the time-interval mode can count for not only the signal's period, but less than or more than a given period.

Width Mode

The width mode is a type of time-interval mode wherein the measurement is that of the signal's width. Compared with the time-interval mode, the width mode would have a preset trigger and other circuitry to function on the signal slopes so that the effective "start" and "stop" points are those of the successive rising and falling slopes of the measured signal.

Averaging Mode

It is often desirable when making period, time-interval, or width measurements to be able to average the reading over a number of periods or time intervals to achieve better resolution and accuracy. This is done with the averaging mode.

Consider the period mode given in Figure 6: if the input signal fed to the EXT GATE connector were to be divided by 1000, then the count of the reference oscillator applied to CH A INPUT would be averaged for 1000 periods. As long as the total count does not exceed the capacity of the readouts, the resolution would effectively be increased 1000 times.

In a ratio measurement, averaging is done when the signal fed to CH B EXT IN is routed through the time base to the gate control. In the ratio mode example, the 1 kHz input to the time base would be extended 1000 times with the MEASUREMENT INTERVAL switch in the 1 ms position. (1 ms being 1/1000th of a second.)

TRIGGERING

Part of the signal conditioner function in Figure 1 is a trigger circuit that selects the signal level at which counting is to occur. You'll recall that the signal conditioner output is a series of shaped pulses, and this output is affected by a trigger LEVEL/SLOPE control.

Let's examine this more closely. Consider a Schmitt trigger circuit receiving a sinewave input signal as in Figure 8(a). Each time the signal level rises above and drops below the circuit's hysteresis window, a rectangular pulse is produced. This properly shaped pulse becomes the signal that eventually gets counted.

Why, it may be asked, convert the input signal to a pulse? Or, what is the purpose of the level control? It would appear from Figure 8(a) that the signal's peak could serve as a point to be counted; moreover, the hysteresis window, centered at the input zero level, seems to give a good output reference. So why the variable trigger and conversion?

Basically this—conversion provides a uniform signal suitable to drive the counting circuits; and a variable trigger permits errorless, noise free counting. Indeed, an important criterion for a counter is its accuracy. No discussion of counters would be complete without its mention. And so, let's see how counting accuracy is affected by triggering and other factors.

COUNTER ACCURACY

Three major factors affect the accuracy of counter measurements: (1) trigger errors; (2) time base stability; and (3) inherent count ambiguity. Trigger errors are a main source of inaccuracy in totalize, ratio, period, width, or time-interval measurements. Time base stability primarily affects frequency measurements, but is important for all others. And count ambiguity can affect all counter measurements.

Trigger Errors

As depicted in Figure 8, trigger errors can cause the shaped pulses out of the Schmitt circuit to be either: (1) too wide; or (2) too many. For instance, the first cycle in Figure 8(b) is noise free, and it produces a normal output pulse. However, noise on the second and third cycles triggers the Schmitt too soon, producing a wider output pulse; this too-wide-a pulse would cause an error in the ratio, period, width, or time-interval modes, but not in the totalize or frequency modes. Noise on the fourth cycle goes through the hysteresis window and produces an output pulse. This extra pulse would show up as an error in all modes except frequency.

But notice what happens when the hystersis level is adjusted to be above the noise level as in Figure 8(c). Now the noise pulses don't go through the window and therefore cannot cause any erroneous trigger output!

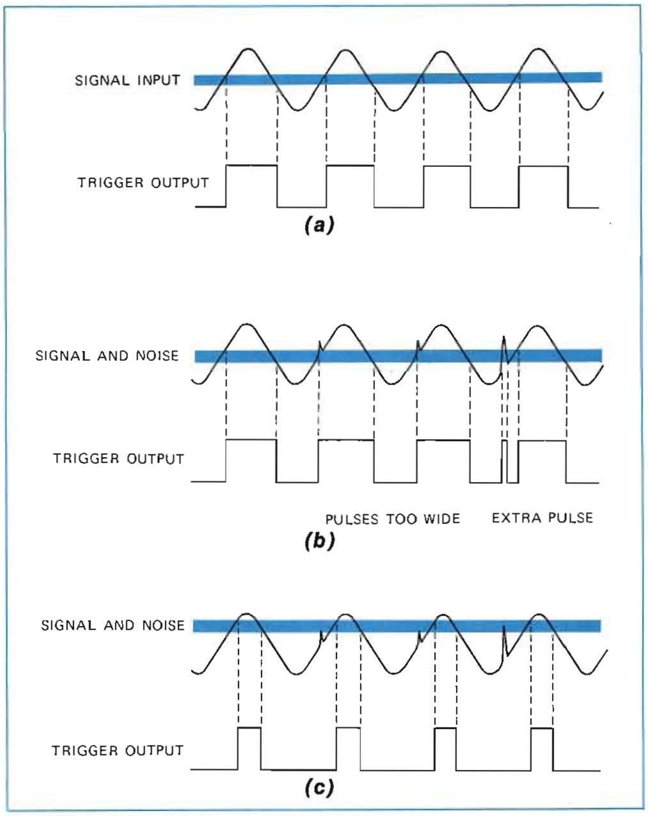


Fig. 8(a). *Whenever input signal crosses hysteresis window (shaded area), an output pulse is produced.* ***(b)*** *Noise in input signal produces errors in output count.* ***(c)*** *Hysteresis level moved above noise level for noise-free count.*

There is a compromise, however. Best operation comes with a trigger recognition point on the portion of the signal with the greatest slope (fastest rate of change in signal) and with as large an effective hysteresis window as possible.

Trigger error can be stated in two ways: (1) as a function of time; or (2) as a percent.

$$t \propto \frac{Vn}{Ss}$$

where t = time in which an error could occur, in seconds

Vn = peak-to-peak noise, in volts

Ss = slope of input signal at trigger point, in volts/second

This error time can be visualized as in Figure 9. When the trigger point is at the maximum slope, the time for possible error is the smallest. As the trigger level moves nearer to the top of the signal (where the slope is smallest), the time for any possible error increases. Trigger error expressed as a percent is:

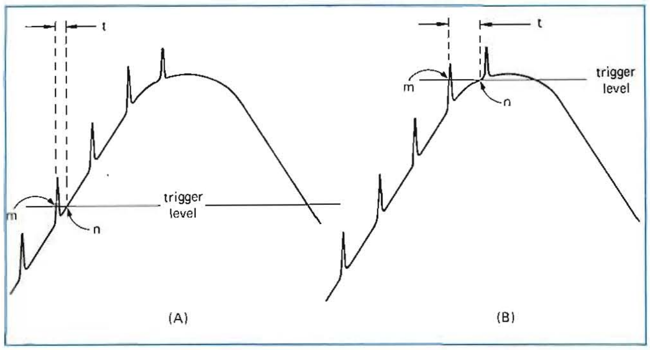


Fig. 9. Trigger error, t, is smallest when triggering occurs on maximum slope.

where % error = trigger error, figure of merit
t = error time, in seconds
T = time gate is open, in seconds

Quite often trigger error is specified as <0.3% divided by the number of periods taken (averaged). This percentage assumes certain conditions: sinewave input, signal amplitude equal to counter's sensitivity limit (usually 100 mV P-P), and signal-to-noise ratio of 40 dB.

In summarizing these two trigger error formulae it is clear that minimum error comes when—

- a count is made over a long time
- signal-to-noise ratio is high
- trigger point is on greatest signal slope

Time-Base Stability

The second major accuracy factor is time base stability. It primarily affects the frequency mode with both short-term and long-term stability contributing factors.

Long-term stability of the time base is affected by vibration, temperature, power supply voltage, and the oscillator crystal aging rate. Of these factors, the first three should be self-explanatory. Crystal aging, however, warrants further discussion.

Crystals have a slow variation in their resonant frequency with respect to time. This change or drift is predictable, with the greatest change taking place during the first 30 days. Specifications for crystal drift are usually given in parts per million per month; the 7D14, for instance, has a long term stability of 1 part in 10^7 per month.

Short-term stability is also affected by vibration, temperature, and power supply voltage; moreover, it is affected by crystal defects and inherent thermal noise of the oscillator. Short-term stability is usually specified as the frequency deviation for periods of seconds, or fractions of seconds. When longer periods are specified, the error is primarily a function of thermal noise.

Plus or Minus One-Count Ambiguity

The final accuracy factor to be discussed is the plus or minus one-count ambiguity. If the input signal is not synchronized with the gate operation, the resultant time difference can cause the total count to be either one count too great or one count too few.

Consider first the case where the input signal applied to the gate is synchronized with the gate control signal, as in Figure 10(a). The gate output will have the same number of pulses as its input, and thus there will be no error. But, as in Figure 10(b), when the two signals are not synchronized, the gate output could be either of two possible counts for a given input signal.

In accuracy specifications for a counter, the count ambiguity error may be given as $\frac{1}{\text{total no. of counts}}$.

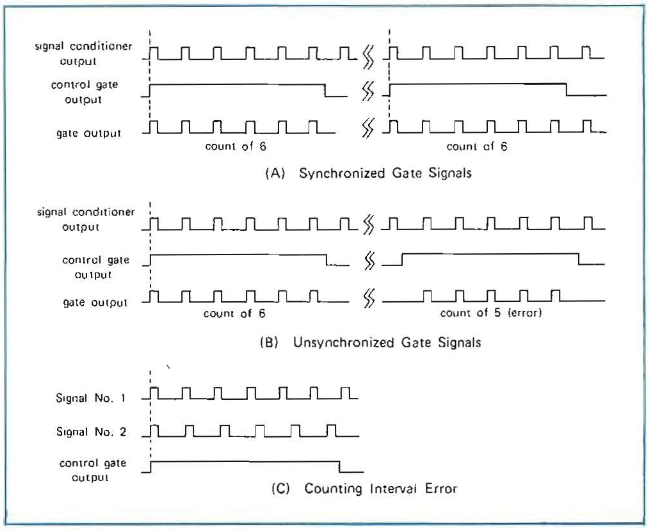


*Fig. 10. ±1 count ambiguity gives **(a)** and **(b)** different counts for same input signal; or **(c)** same count for different input signals.*

Figure 10(c) depicts yet another ambiguous count situation where a change in the input test signal frequency would not be indicated in the gate output. Although signal number 2 has a slight frequency shift with respect to signal number 1, the gate output would still be six pulses for both signals. This undesirable effect can be minimized by using as long a counting interval as possible; or, in period or time-related measurements, by averaging. (If 100 counts were averaged, the ± count error will be only 1% as large as for a single period).

Count ambiguity for period or time-related modes can also be reduced by increasing the time base reference oscillator frequency. This effectively improves resolution and the ability to determine changes. If the oscillator frequency were increased, say, ten times, the count ambiguity would be decreased by a factor of ten.

REVIEW OF COUNTER TYPES

For consistency in presenting basic counter principles, this article has used one type of counter design throughout the discussion. To complete our study, let's now take a look at some other types of counters.

Prescaling Counter

The prescaling counter (shown in Figure 11) divides the input signal before it goes to the gate for subsequent counting. This design is economical. And with a frequency range from DC to 1 GHz, this type of counter is popular.

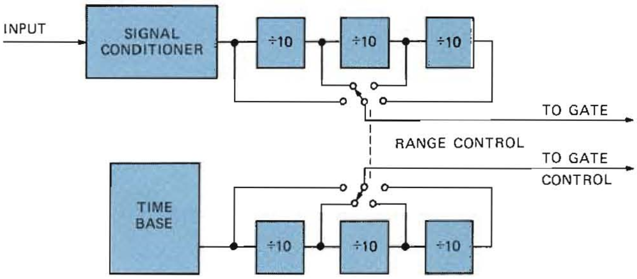


Fig. 11. Prescaling counter divides input signal and time base before further processing and counting.

On the other side of the pro's and con's for prescalers are such things as not being able to count a number smaller than the divider ratio, reduced resolution, and longer time to make as measurement. These three disadvantages arise from the necessity to divide the measurement interval by the same amount that the input is divided.

Heterodyne Converter Counter

The heterodyne converter counter mixes the input signal with a second frequency, and the difference frequency is then counted. The second frequency is usually derived from the counter reference oscillator, which drives a harmonic generator. The desired harmonic is then selected by a tuned filter or cavity, as shown in Figure 12.

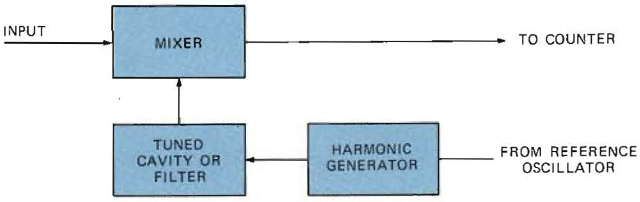


Fig. 12. Heterodyne converter converts a high input frequency to a lower frequency more suitable for counting.

Heterodyne counters provide a resolution of 1 Hz, and operate from DC up to 18 GHz. Their drawback comes from the operator having to use a conversion chart to determine the true input frequency from the readout frequency. And for accurate operation, the heterodyne counter works best with a sinewave input.

Manual Transfer Oscillator Counter (TO)

The manual transfer oscillator counter (TO) is somewhat like the heterodyne converter counter in that two signals are compared. But unlike the heterodyne unit with its fixed reference frequency, the transfer oscillator counter uses a variable frequency oscillator (VFO). The VFO frequency is harmonically related to the input signal being measured. In operation, the counter VFO frequency is counted, rather than the input signal's frequency. The correct VFO harmonic is determined by tuning the VFO and noting a zero beat in the meter stage shown in Figure 13. The counter readout is multiplied by the correct harmonic number to indicate the input signal frequency.

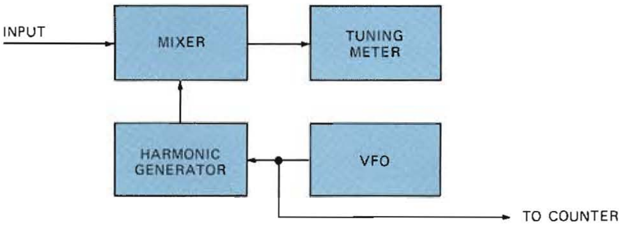


Fig. 13. Manual transfer oscillator counter measures its own oscillator frequency which Is harmonically related to the input signal.

Two advantages of the transfer oscillator counter are: a very wide frequency range of 20 Hz to 40 GHz, and ability to measure pulsed signals as well as CW. Disadvantages include loss of resolution, longer measurement time, and the need for operator skill in the complex computation necessary for the harmonic calculation.

Preset Counter

The preset counter incorporates one or more dividers that can be used to preset limits for go/no go tests or to divide either the input or time base so that the readout is in engineering units (e.g., Feet/second, Parts/million.

Reversible Counter

The reversible counter permits the accumulation of a count which is proportional to two separate inputs or a single bipolar input.

Summary

Counters come in many sizes, shapes and capabilities; some perform many functions, some few. The basic principles of operation, however, are pretty much the same. Advances in components and packaging have dramatically reduced the physical size of counters. The TEKTRONIX 7D14 Digital Counter plug-in is an outstanding example of utilizing this reduction in size to expand the measurement horizon for both the oscilloscope and the counter.

NOTE: 7000-Series Application Notes on the 7D14 are available from Tektronix, Inc.

Editor's note: We have preempted the space normally devoted to TEKNIQUE to present this article in its entirety in this issue.

SERVICE SCOPE

A POTPOURRI OF SERVICING AIDS

By Charles Phillips
Factory Service Technician

Having the right tool for the job often makes the difference between a time-consuming frustrating task and a job quickly and expertly done. We would like to share with you some of the tools and other aids we find especially useful in our factory service center.

Thermal Shock Tools

In a previous issue we discussed using circuit cooler and a hair dryer as aids in locating intermittent or temperature sensitive components and connections. These tools will usually get you to the general area of the trouble, but the heat or coolant is applied over too large an area to identify the specific component. You can cool individual components by spraying a cotton swab with coolant and applying the tip of the swab to the suspect component. Conversely, you can heat individual components by applying the tip of a small (15 watt) soldering iron directly to the component. The soldering iron should be unplugged to prevent damage to the component caused by leakage voltage from the iron.

Incidentally, in selecting a spray coolant, choose one with a temperature rating of −50°C such as Miller-Stephenson MS-240. Coolants going down to −70°C may cause stress cracks to occur in the Polyphenylene Oxide (PPO) boards used in the vertical attenuator area. These boards are translucent in appearance and were selected for their extremely low dielectric loss.

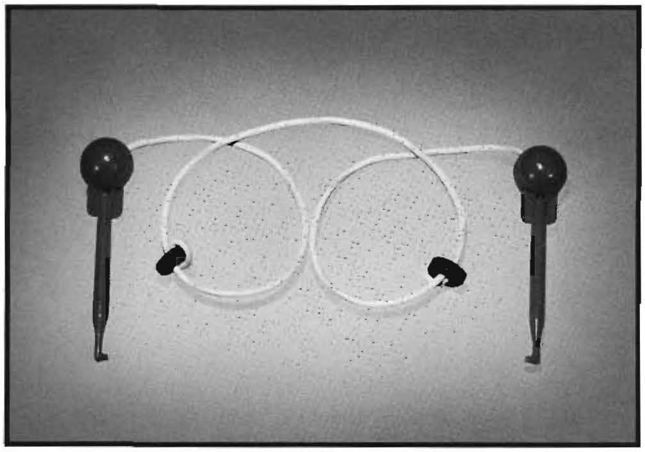
Test Leads and Cables

Test leads are like neckties in some respects. We usually have a lot of them hanging on the hook but find ourselves using a select few time after time while the rest just hang there in some degree of disarray. Here are some leads we've found to be especially useful.

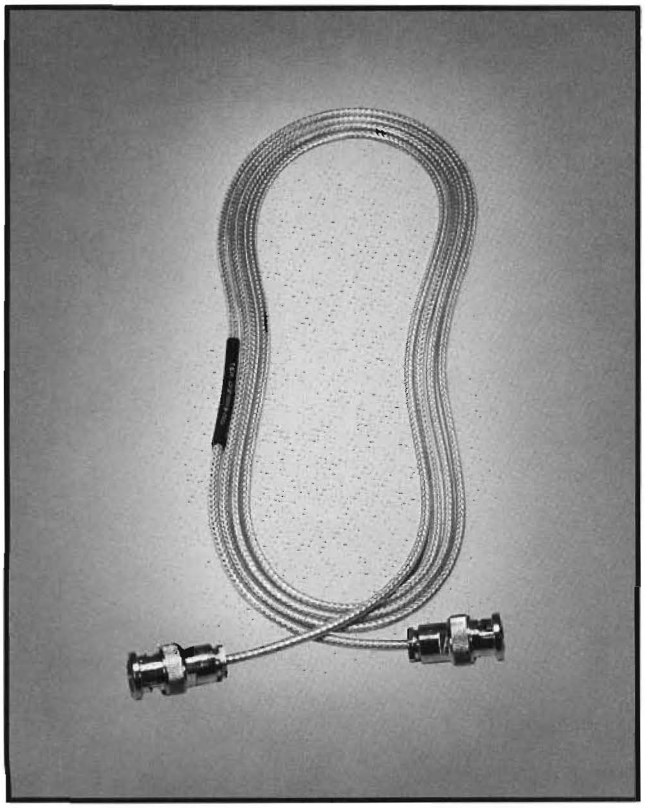
Pictured at upper right is a hybrid set of test leads consisting of Triplett or (Simpson) meter leads with Tektronix probe tips installed on the probing end. These are handy to connect onto closely spaced components without shorting between them.

The photo at right shows what you will need, in addition to the basic meter leads, to build them. The small rubber grommet serves to hold the lead securely in the probe body when the rear set screw is tightened.

To facilitate fastening the stranded lead to the nose portion of the probe body, solder a short piece of solid wire to the lead (a straightened standard paper clip works well). This simplifies threading the lead through the probe body and provides a good solid contact against which to tighten the forward set screw. Clip off the excess solid wire protruding from the probe nose. All of the needed parts may be ordered from your Tektronix Field Office using the part numbers shown in the photo.



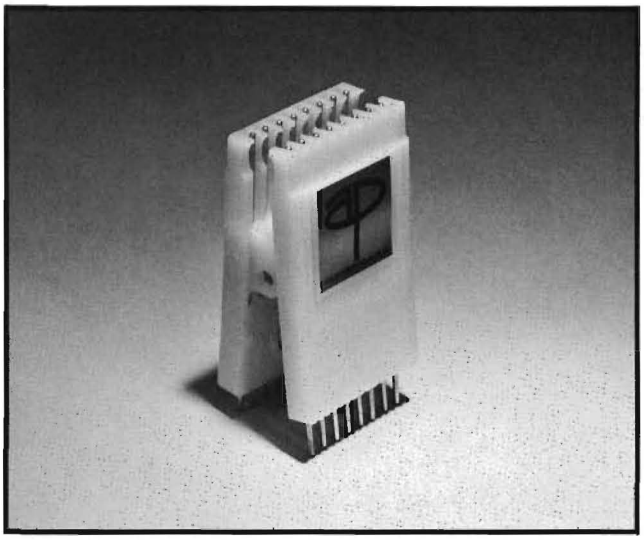
Another type of lead that is very useful is shown above. It's designed primarily for locating unbalanced stages in push-pull amplifiers but it is so convenient you'll find many occasions to use it. The small ferrite beads prevent the lead from causing oscillations when connected to high gain circuits. The assembly is available from Tektronix under part number 003-0507-00 or you can build your own leads to a length best suited to your purpose. The clips carry the designation X-100 and are manufactured by E-Z Hook, Division of Tektest, Inc., P. O. Box 1405, Arcadia, Calif. 91006.



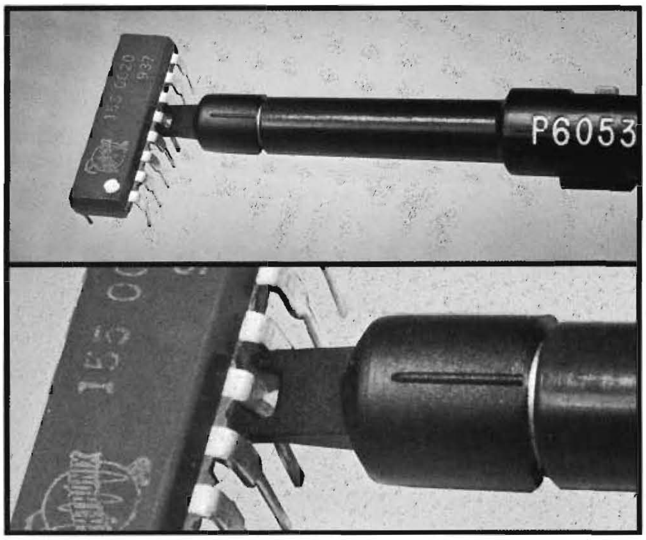
Pictured above is a six-foot 50-ohm cable that is much smaller in diameter and more flexible than RG-58 cable and, hence, easier to use. The Tektronix part number is 012-0113-00.

Other Miscellaneous Tools

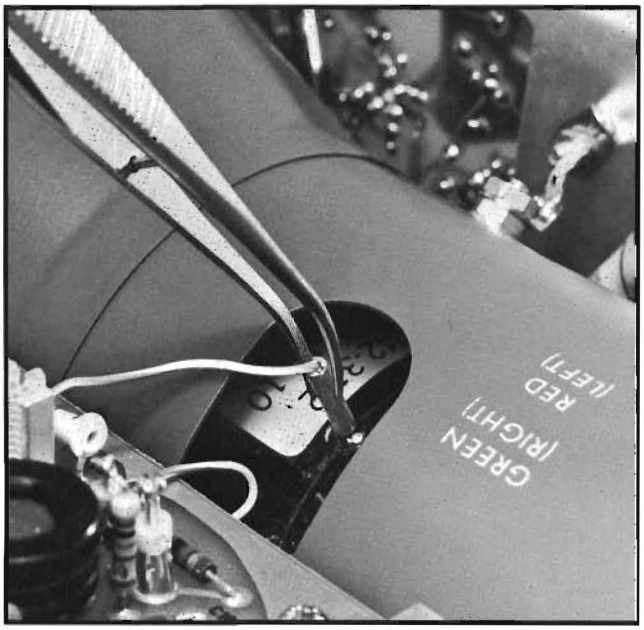
In the June 1970 issue of TEKSCOPE we introduced you to the integrated circuit test clip shown below but failed to give you adequate ordering information. The unit clips over a 16-pin dual-in-line package and provides accessible test points. It is also useful in removing the IC from sockets and boards. The 0.3-inch size (#923700) fits most IC's, with a 0.5-inch size (#923-702) available for wider packages. The clip is manufactured by AP Inc., 72 Corwin Dr., Painesville, Ohio 44077.

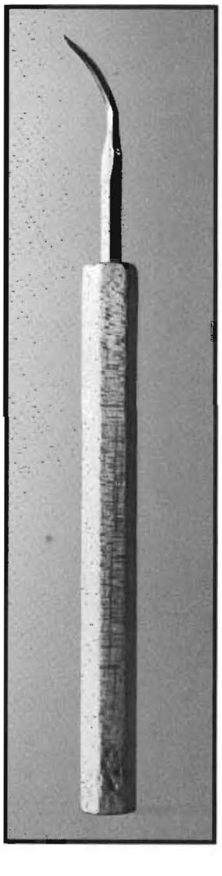


While we're discussing making readings on IC pins we should mention a new probe tip designed specifically for this function. It slips over the bayonet tip of TEKTRONIX miniature probes and covers the exposed ground sleeve. The tip guides itself squarely into firm contact with one pin of the IC at a time without danger of shorting to adjacent pins. You'll find it good for a variety of other probing jobs where leads are close together, as in much of the transistor circuitry. The Tektronix part number is 015-0201-00.



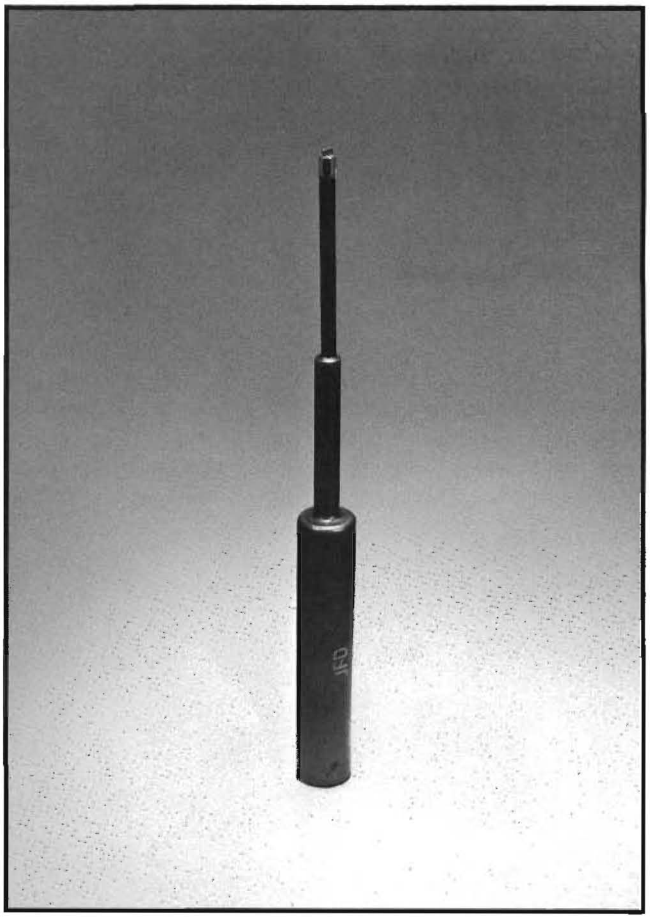
Another handy tool around the bench is the angle tweezers shown being used to remove leads from the CRT neck pins. Much less pressure is applied to the pin as compared to using long-nosed pliers for this function, thereby reducing the likelihood of damage. The tweezers also may be used to remove IC's from their sockets by placing the tips between the IC and the socket and using a gentle prying action.





Another convenient tool for removing IC's is a soldering aid such as the Hytron SH20A. It is slightly modified by filing down the sides of the flattened portion of the tip to extend the narrow portion. The tip is then curved to about a 45° angle so it can be used as a lever in the fashion described for the tweezers.

Almost as profuse as the test leads we collect are the trimmer tools in our tool box, most of them with damaged tips. We've found the J.F.D. production tool number 7104-5, while rather expensive (about five dollars), to be very durable. If you can't find it at your local supplier it can be ordered from Tektronix under part number 003-0666-00.



These are just a few of the tools and other items that we've found useful in doing the service job better and more efficiently. We trust you will find them as useful.

INSTRUMENTS FOR SALE

453, $1600. Used very little. FLM Industries, Maywood, Ill. (312) 345-6991, Mr. Lonberger.

545/CA/D/G/L/Scopecart, $1000. Wm. Erickson, 1273 Montevideo Ave., Placentia, Calif. 92670 (714) 524-2852.

502, $900. Used very little. Mergenthaler Linotype Co., 531 Plymouth Ct., Chicago, Ill. 60605. (312) 427-3121.

Sale or trade 453, $1100. Mr. L. R. Beam, 1705 Devonshire Rd., Sacramento, Calif. 95825. (915) 482-4321.

422, $1000. Exc cond. Mr. Frank Hayes, Red Hill Rd., Middletown, N. J. 07748. (201) 671-0271.

535A/B/Cart, $1000. Bill Vichiconti, Precision Multiple Controls, 231 Greenwood Ave., Midland Pk., N. J. (201) 444-8410.

524AD. Mr. Charles C. Yamamoto, C & E Radio of Hawaii, Inc., 1651 Ala Moana Blvd., Honolulu, Hi. 96813.

D54 w/2 Tek P6006 Probes, used less than 10 hrs. $550. (214) 348-6919.

545/CA/Scopemobile, access. $1200. D, $100. Dr. T. Perera, Barnard Coll. 76 Claremont, N. Y. C., N. Y. 10027.

453, 2-P6010, 2-P6028 Probes. Make offer. Barry Noll, FAMCO Machine Co., 3100 Sheridan Rd., Kenosha, Wi. 53140. (414) 654-3516.

Type 661, 4S1, 5T3, 109, 292, & 291. (617) 275-9200, Ext. 307.

502A, recond. 4/8/70 (New CRT) $700. Parko Electronics, 1540 S. Lyon, Santa Ana, Calif. 92705. (714) 547-0184.

RM529, $400. Stacey's Electronics, 1 Tibbett St., Natick, Mass. 01760. (617) 653-5822.

535A/CA. Bob Duke, 13526 Pyramid Dr., Dallas, Tex. 75234. (214) 241-2888.

547/1A4/Scope Cart & Access, $1800 or best offer. Metrology Inc., 126 No. Jackson Ave., Hopkins, Minn. (612) 935-4436.

545B/CA, best offer over $1500. Bates Aviation, Hawthorne, Calif. Jim Laver, (213) 675-4405.

CA, dual trace amp., $200. Univ. of Tenn. at Chattanooga. Dept. of Biology 37401. (615) 755-4221, Dr. Durham.

503. Mr. Daniel Baugh, 1835 Cutler Dr., Apt. A, Tempe, Ariz. 85281.

504, $275. Ron Stanley, Aero Devices, 2993 Los Feliz Dr., Thousand Oaks, Calif. 91360. (805) 495-1219.

543B/1A4 w/Scope Cart, $1800. Mr. Chas. Kroh (609) 424-3910.

535/C/E/L/N/P/T/Z, $1500 or best offer. Spare CRT & Scope cart. Harvey E. Smith, P. O. Box 2985D, Pasadena, Calif. 91106.

511AD with 121 Amplifier. Both for $250. Fred Chambers, 11 Locustwood Blvd., Elmont, N. Y. 11003.

For sale or trade for 2 or 3-series plug-ins: 3T2, 3S2, 2-S3's. Mr. John Forster, MIT Branch P. O. P. O. Box 48, Cambridge, Ma., 02139. (617) 876-1579.

561A/3A6/3B3, $1000. Ex. cond. Robert Harp, 166 Merrill Ave., Sierra Madre, Calif. 91024. (213) 355-4365.

531A/CA w/202-1. Joe Soltan, Dow Jones & Co., 1325 Lakeside Ave., Cleveland, Ohio, 4414. (216) 241-5183, Ext. 24.

Pulse Generator, Mod. 163, New, $95 postpaid. Bob Duke, 13526 Pyramid Dr., Dallas, Tex. 75234. (214) 241-2888.

Recond. type Z $225. Richard H. Cook II, Teletek Enterprises, P. O. Box 118, Carmichael, Calif. 95608. (916) 635-1773.

316 w/Scope cart, 10x and 2x probes, $600. I. R. Compton, Comptronics, 3220 16th Ave. West, Seattle, Wa. 98119. (206) AT 4-4842.

515A, $425. Mr. Israeley, JSH Electronics Co., 8549 Higuera St., Culver City, Calif. 90230. (213) 870-4616.

545A/CA, $400 for comb. Merle Smith, General Electric, 212 N. Vignes St., Los Angeles, Calif. 90051. (213) 625-7381.

661/5T1A/2-4S1's, $1800 or trade for 453 or 2-422's. Salient Electronics, Inc., Rexford, N.Y. 12148. (518) 393-4590.

53/54B, $50. Scott Howell, Mobilscope, Inc., 17734 1/2 Sherman Way, Reseda, Calif. 91335. (213) 342-5111.

561A/3A6/2B67/2A63. Used very little, $995. Mr. Bill Wiernsing, 125 Northview Rd., Ithaca, N. Y. 14850. (607) 272-3723.

B plug-in $40; 107 $60. Walt Sonnenstuhl, Energy Systems, 3180 Hanover, Palo Alto, Calif. 94303. (415) 493-3900, Ext. 222.

422, 20 hrs. use, $1200. Scope Cart $60. Ed Jevec, Canton, Ohio (216) 456-2851.

TLS53, 524AD, R527. Ken Durkee, Lafayette School Dist. (415) 284-7011.

575 Mod 122C Curve Tracer, 4 yrs. old—best offer. Joe Bookee, Rancho Los Amigos Hosp., 7601 Imperial Hwy., Downey, Calif. 90242. (213) 869-4521, Ext. 2122.

545A/H/L/M/Scopemobile, $850. Jim Underwood, 3615 Wilbur Ave., Huntsville, Ala. 35810, (205) 852-6153.

162 Waveform Gen. Layton Industries, Inc., 542 E. Squantum St., N. Quincy, Mass. 02171. (617) 773-9790.

516; Dustcover; Polaroid Viewer; 2/P6006 Probes, $800. Mr. Krandel Jr., (516) 825-6436.

564/3A72/2B67 w/probes $950. Mike Breen Univ. of Calif. LBL, Bldg. 14, Berkeley, Calif. 94720. (415) 525-3033.

(8) 519's from $1800 to $3000. 561B/3S2/3T2 & (2) S-2 Heads (never used) $2500. (4) C-27 Cameras from $250 to $400. C-40 Camera $275. Plug-ins; S $50, 82 $325, 80 $42. Mr. Henry W. McLarey (617) 271-6181.

543, 53/54K. Exc. cond. A. Blanck, Box 162 Rutherford, N. J. 07070. (201) 933-2091.

422. Allen Hahn, 3144 Black Swan Dr., Shawnee, Kan. 66216. (913) 362-5300, X 133.

611 Mod 162C. Syntex Medical Instr. 3401 Hillview Rd., Palo Alto, Calif. 94304.

INSTRUMENTS WANTED

Used 202-1 or 202-2 scope cart. Ronald B. Tipton, Testronic Dev. Lab., P. O. Drawer H, Las Cruces, N. M. 88001. (505) 382-5574.

1S1, Optitron, Inc., 1645 Sepulveda Blvd., Torrance, Calif. 90501. (213) 530-2811.

Real Time Tek scope with 15 to 30 MHz BW. Will trade 575 curve tracer. Bill McCarthy, 47 Tor Rd., Wappingers Falls, N.Y. 12590. (914) 297-7738.

5T3, 4S1, 4S2A, 4S3 in any condition. Bill Cordaro, 5 Rich Dr., Wappingers Falls, N. Y. 12590. (914) 297-7895.

Type L Plug-in, Gordon A. Hammers, Muir Industries Inc., 24 Thing Road, Tecate, Calif. 92080. (714) 478-5694.

P170CF Probe & B170A Attenuator for 517. Dr. Marshall Siegel, 211 Liberty St., Bloomfield, N. J. 07003. (201) 748-9000 Ext. 838.

TEKSCOPE

Volume 4 Number 2 March 1972

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Editor: Gordon Allison Graphic Designer: Tom Jones For regular receipt of TEKSCOPE contact your local field engineer.

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TEKSCOPE

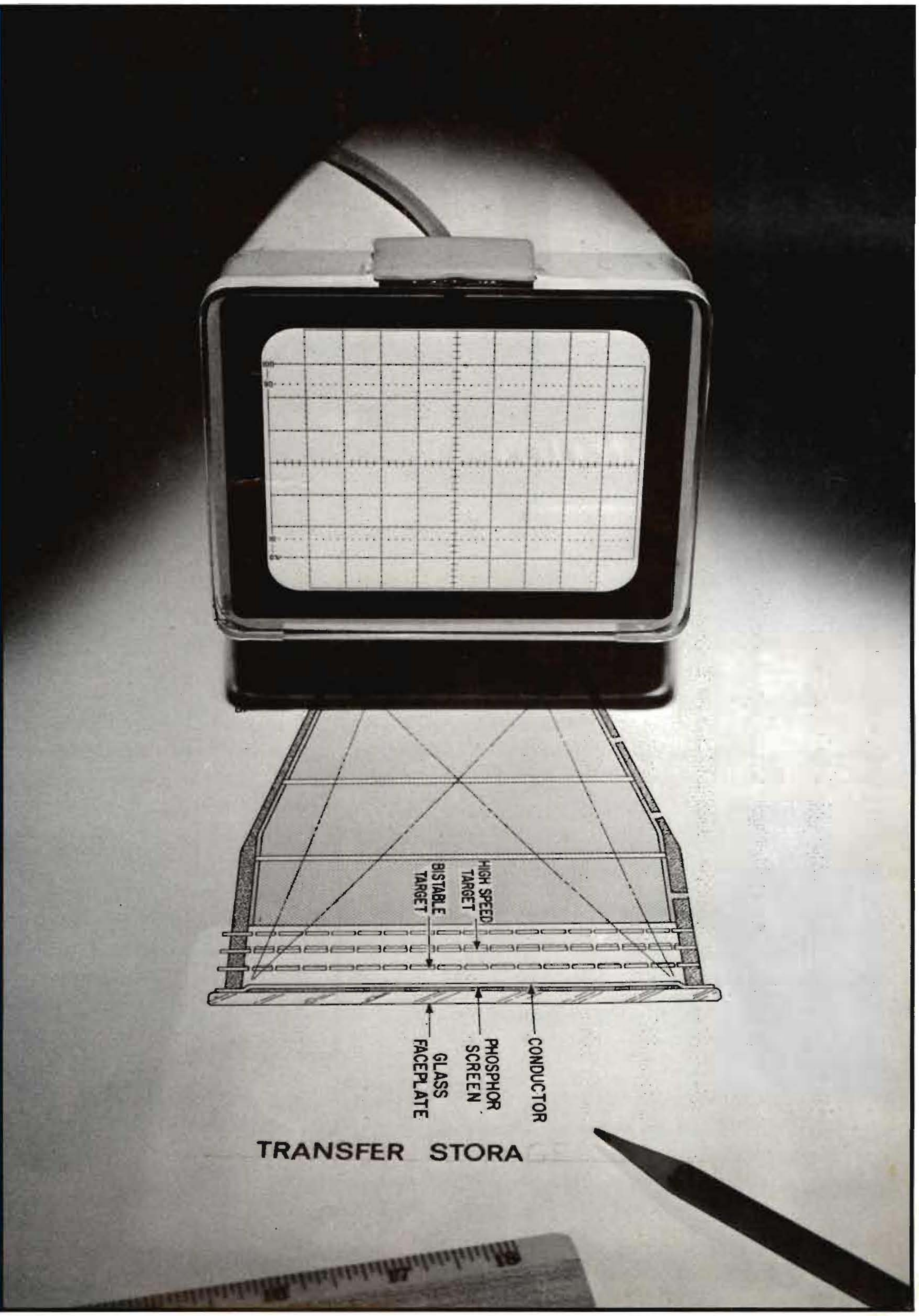
JULY 1972

THREE NEW INSTRUMENTS THREE KINDS of STORAGE

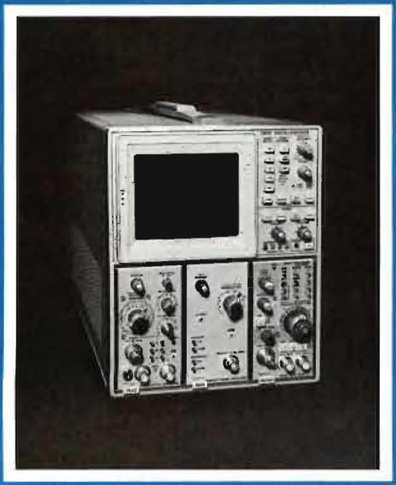
TEKTRONIX LOOKS AT LIGHT

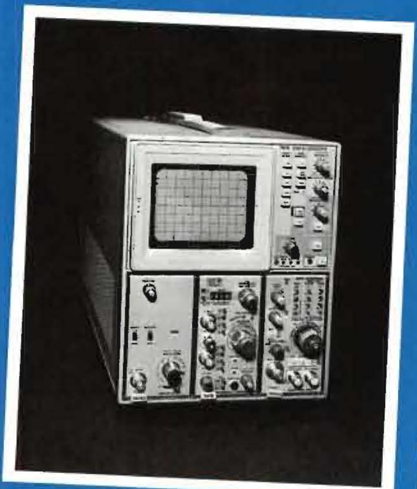
IN CIRCUIT TESTING OF TUNNEL DIODES

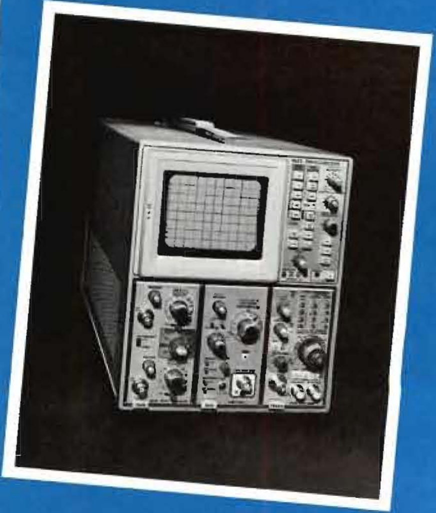
WASHING YOUR TEKTRONIX INSTRUMENTS



COVER: The transfer storage CRT yields a phenomenal 200 cm/μs stored writing speed.







New Instruments 3 Kinds of Storage

WHAT IS STORAGE?

Storage, in an oscilloscope, is the ability to retain the image of an electrical event on the cathode-ray tube (CRT) for further analysis after that event ceases to exist. This image retention may be for only a few seconds with variable persistence storage, or it may be for hours with bistable storage. And now Tektronix, Inc. introduces a new ultra-fast storage concept which essentially combines the advantages of variable persistence and bistable storage while providing the fastest stored writing speed yet achieved. This article explains the basic principles of each kind of storage and describes the three new instruments which use these storage concepts.

A CHOICE OF STORAGE

With the introduction of the 7313, 7613, and 7623, Tektronix, Inc. offers a choice of storage to match your measurement as well as your budgetary requirements. The 7313 provides the convenience and economy of split-screen, bistable storage in a new 25-MHz 7000-Series instrument. The 7613 introduces variable persistence storage to the TEKTRONIX product line, and the 7623 provides ultra-fast storage for stored writing speeds as fast as 200 cm/μs. In addition, the 7623 combines bistable and variable persistence storage into one versatile instrument.

A FAMILY RESEMBLANCE

These new instruments take their place in the 7000 Series of instruments from Tektronix, Inc. Also new to this family is the 7603, a large screen, non-storage oscilloscope. The vertical deflection system bandwidth of the 7603, 7613, and 7623 is 100 MHz.

All of these new instruments share a common mechanical design; each instrument accepts up to three of the more than 20 plug-ins from the constantly growing 7000-Series plug-in line. Each instrument is also available in a rackmount configuration which occupies only 5¼ inches of rack height.

A prominent feature of each instrument in this family is the exclusive TEKTRONIX CRT READOUT which provides an alphanumeric display of measurement parameters on the CRT along with the waveform. The CRT READOUT circuit used in these instruments includes an adjustment to determine the size of the displayed readout characters. Also included in the 7603, 7613, and 7623 is an autofocus circuit to maintain a well-defined CRT display irrespective of intensity level changes.

Primary functional differences between these three new instruments is in their storage operation and capabilities. A basic description of the storage principles for each kind of storage is given in the remainder of this article.

PRINCIPLES OF DIRECT-VIEW BISTABLE STORAGE

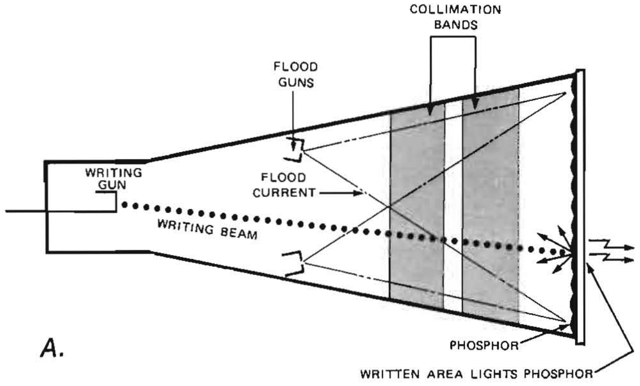
The 7313 uses a direct-view bistable storage CRT. The basic structure of a storage CRT is the same as a conventional (non-storage) tube. However, several elements are added to make storage operation possible. The most important of these additional elements are the flood guns which cover the entire viewing area with low-velocity electrons. The collimation bands serve as an electro-static lens to shape the flood gun electron beam for uniform coverage of the target area. The storage target consists of a phosphor screen with a thin transparent conductive coating in front of it which serves as the collector. The storage target is split into two sections which allows two signals to be stored, viewed, or erased independently.

Direct-view bistable storage is based on a secondary-emission principle. When a stream of primary electrons strikes a phosphor, secondary electrons are dislodged from the phosphor surface. As the accelerating potential of the primary electrons increases, more secondary electrons are displaced for each primary electron that arrives. The ratio between primary and secondary electrons is called the secondary-emission ratio. When this ratio is less than one, the target area gains electrons and charges negative; when greater than one, it charges positive. The storage target has two stable potentials (bistable) where the secondary emission ratio is one; the first is near the flood-gun cathode potential, and the other near the collector potential.

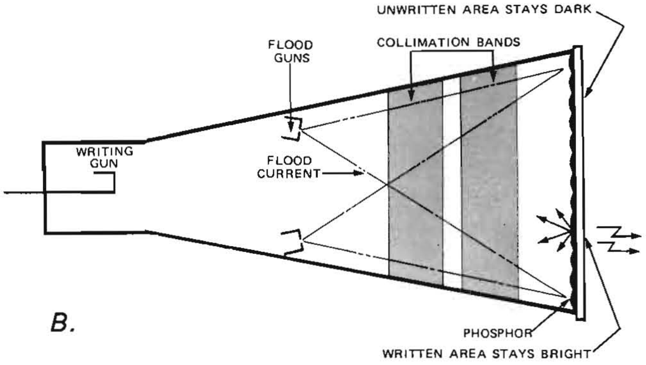
In the storage mode, the flood guns provide a continuous stream of low-velocity electrons which cover the entire target area. This results in a slight background glow over the entire phosphor area. However, these flood electrons do not have sufficient energy to dislodge many secondary electrons from the phosphor so the target charges negative and remains in the first stable state.

As the writing beam is scanned across the screen, it dislodges many secondary electrons (see Fig. 1A). The written area of the target shifts to the second stable state and the written area charges positive. Now, the flood electrons strike the written area with sufficient velocity to dislodge enough secondary electrons to keep the area charged positive and the written area remains visible (Fig. 1B).

Fig. 1. *Direct-view bistable storage.*



Writing beam dislodges many secondary electrons as it traces the waveform. The written area loses electrons and charges positive while the surrounding area remains negative.



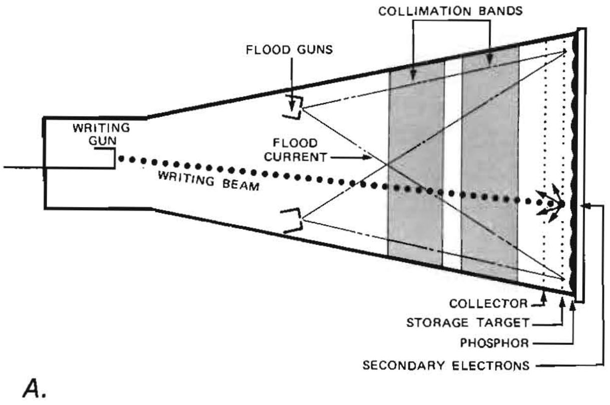
Flood gun electrons hit unwritten areas too slowly to light phosphor and the target charges negative. The positively charged written area attracts electrons at higher speed, keeping the phosphor lit and dislodging enough secondary electrons to hold the area positive.

As the sweep rate of the writing beam increases, a maximum limit is reached where it is difficult to store a display. This limit is specified as stored writing speed. There are two techniques which can increase the stored writing speed limit. For repetitive sweeps, integration can be used. In this technique, the flood guns are momentarily turned off and repetitive sweeps are allowed to build up the charge on the target. If the charge is allowed to build up sufficiently, the written area of the target shifts to the stored state. Then, the flood-gun beam is turned on again to view the display. The second method of increasing the writing speed is called enhancement. This method is intended for use with fast, single-sweep displays only. Again, the writing beam may not shift the target area positive enough to store the trace. To aid in storing the partially written trace, an enhance pulse is applied to the target area during the sweep time. This pulse raises the target positive enough to shift the partially written trace into the stored state.

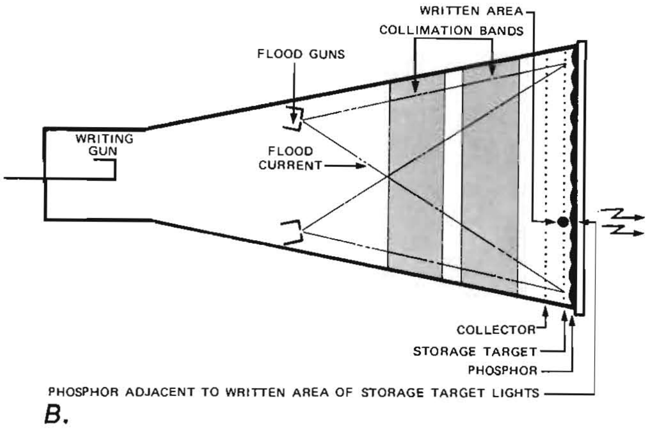
A stored display can be erased by first raising the collector positive so the entire screen is fully written. Then it is dropped negative to about the potential of the flood-gun cathodes and slowly returned positive to the ready-to-write level.

To operate either half of the screen in the conventional (non-store) mode, the collector is dropped to a level close to the flood-gun cathodes. This prevents the target from being held in the stored state by the flood-gun electrons.

Fig. 2. Halftone transmission storage.



Writing beam dislodges secondary electrons from storage target. The written area charges positive while the surrounding area of storage target remains negative.



Flood gun electrons pass through written area of storage target and strike phosphor. Remainder of storage target blocks flood electrons.

PRINCIPLES OF HALFTONE TRANSMISSION STORAGE
(VARIABLE PERSISTENCE)

The halftone transmission storage tube has a basic structure similar to the direct-view bistable tube. Two mesh-type elements are added in this tube near the faceplate to achieve transmission storage. The mesh nearest the electron-gun structure is a fairly coarse mesh which serves as the collector electrode to accelerate electrons toward the storage target and to collect secondary electrons emitted by the storage target. The second mesh is very fine (about 500 lines/inch) and serves as the storage target. A highly insulative dielectric layer is deposited on this mesh using thin-film techniques. It is on this dielectric layer that storage occurs.

In the storage mode, the flood guns cover the entire storage target with a continuous stream of low-velocity electrons. However, these electrons are prevented from reaching the phosphor screen unless a display has been written on the storage target. As the writing beam is scanned across the storage target, it dislodges secondary electrons from the dielectric (see Fig. 2A). These written areas charge positive while the unwritten areas remain negative.

An accelerating potential of approximately 7 kV exists between the storage target and an aluminized layer which is deposited over the phosphor. This potential attracts flood electrons through the written area of the storage target, to the phosphor screen (Fig. 2B). The flood electrons are blocked by the unwritten areas of the storage target so these areas of the phosphor remain dark. The result is a bright, high contrast display of the image originally written on the storage target.

The density of the writing beam striking the storage target determines the amount of positive charge on the dielectric. This positive charge, in turn, determines the amount of flood electrons reaching the phosphor and thereby determines the brightness of the stored trace. It is this ability to store and display changes in intensity that leads to the name halftone transmission storage.

The entire stored image can be erased by applying a positive pulse of about 10 volts to the storage target mesh. Although the dielectric is insulated from the storage target mesh, it goes positive also by capacitive coupling. However, the dielectric immediately begins to discharge back to about zero volts due to the flood gun electrons which are striking it. After about one-half second, the positive erase pulse is removed and the storage target mesh drops back to a quiescent level near zero volts. Again by capacitive action, the dielectric follows negative to about −10 volts. The storage target is now in a ready-to-write state.

A characteristic of the halftone transmission storage tube is that unwritten areas of the storage target begin to fade positive due to positive ion generation in the flood electron system of the tube. As a result, the entire screen reaches a stored condition after only a few minutes and the desired image is no longer visible. To prevent this from occurring and to provide for optimum viewing of the stored image, the entire screen is slowly erased during operation. This is done by applying variable-width erase pulses to the storage target every 10 ms. Each time a pulse is received, the storage target is partially erased. As the width of these pulses is increased, the display is erased more. Varying the setting of the front-panel PERSISTENCE control changes the width of the erase pulses and, hence, the time that a stored image can be viewed. The few flood electrons collected by the dielectric during each erase pulse cancel the effect of the ions, producing long term stability of the target.

A display can be retained for longer viewing by pressing the SAVE button. This interrupts the variable-persistence pulses and disables the ERASE button. Maximum retention is provided with the SAVE TIME control set to MAX. This removes the display completely from the screen. The display can be viewed by turning the SAVE TIME control clockwise until the trace is displayed at the desired brightness. The display will begin to fade positive after a short time due to positive ions. The viewing time in the SAVE mode is a function of the displayed intensity.

TRANSFER STORAGE

Principles of Transfer Storage

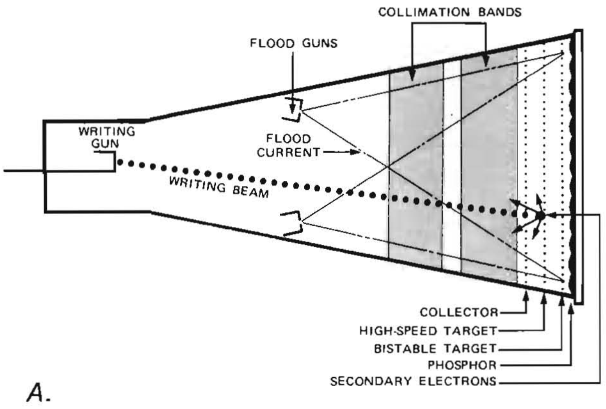
Recent developments in storage at Tektronix, Inc. yield the fastest stored writing speed yet achieved by a storage instrument—a phenomenal 200 cm/μs (222 div/μs at 0.9 cm/div) with the 7623 Option 12. Based on a transfer storage concept, the 7623 combines many of the advantages of both halftone transmission and bistable storage to produce this ultra-fast storage. Although similar types of storage have been used before to store relatively slow signals, Tektronix, Inc. has refined the techniques to make them applicable to storage of high-speed oscilloscope displays.

The transfer storage tube uses a third mesh in addition to the two used in the halftone transmission tube. The mesh closest to the electron gun serves as a collector. The second mesh is the high-speed target and is similar to the storage target in the halftone tube. The additional mesh is a bistable target which is constructed in a manner similar to the high-speed target but differs in the operating potentials applied.

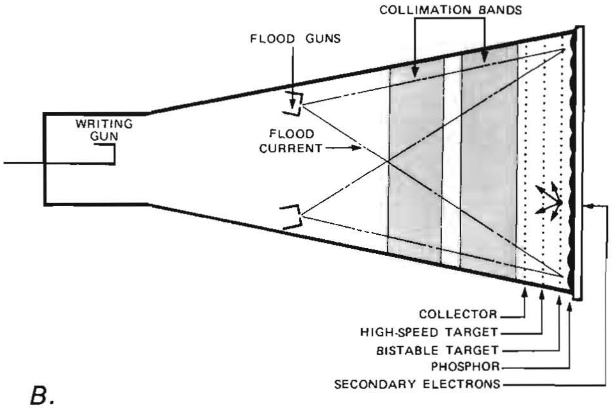
Storage of a trace on the high-speed target is basically the same as in the halftone transmission tube (see Fig. 3A). This target is very sensitive so that even slight levels of writing beam current affect its charge level.

After the trace is stored on the high-speed target, it is transferred to the bistable mesh (Fig. 3B). If it were not transferred, it could be viewed for only a few seconds before the display would begin to fade positive. To transfer the stored image, a very high-level positive pulse is applied to the bistable target. In a normal bistable tube, this action would completely write the bistable target. However, since the high-speed target

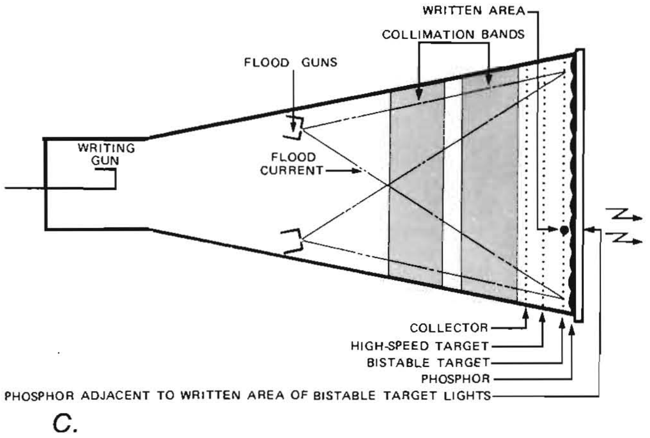
Fig. 3. Transfer storage.



Writing beam dislodges secondary electrons from high-speed target. The written area charges positive while the surrounding area of high-speed target remains negative.



Flood gun electrons pass through written area of high-speed target and strike bistable target dislodging secondary electrons. Remainder of high-speed target blocks flood electrons.



High-speed target is raised positive to allow all flood electrons to pass. Written areas of bistable target pass more electrons than unwritten areas, producing a trace on the phosphor.

passes flood electrons only where the trace has been written, this is the only area that stores on the bistable target. The high-level transfer pulse insures that all written areas of the high-speed target, even those with a very slight positive charge, result in a transferred trace on the bistable target.

The final step in transfer storage is to lower the potential on the bistable target to a normal viewing level while increasing the potential on the high-speed target. The high-speed target now allows all of the flood electrons to pass. However, the written areas of the bistable target allow more flood electrons to pass than the unwritten areas, producing a trace on the phosphor (Fig. 3C). Note that bistable storage takes place on a mesh and that a transmission process is used to display the stored trace on the phosphor. Therefore the action taking place is bistable transmission storage.

Since the final image is stored on a bistable storage target, it can be viewed for as long as desired without deterioration in image quality. A 7 kV accelerating potential between the bistable target and the aluminized phosphor results in a bright display.

The intensity of the stored image can be varied with the front panel STORED INTEN control. When the trace is no longer desired, it can be erased. Erase sequence for the high-speed target is essentially the same as for the halftone transmission tube, while the bistable target is erased in a manner similar to the direct-view bistable tube.

Storage Display Modes

The 7623 offers several storage display modes to accommodate a wide range of storage measurements. The fast storage mode always operates in a single sweep manner where a trace is stored on the high-speed target, transferred to the bistable target, and then viewed as long as desired before manual or automatic erase. During view time, the time-base unit is locked out so further traces cannot be stored; it is "armed" so it can produce another trace after the erase cycle is complete.

Normally, pressing the ERASE button erases both the fast and bistable storage targets. Pressing the MULTI FAST button changes the erase cycle so only the high speed target is erased each time the ERASE button is pressed. After a trace is stored on the high-speed target and transfer is complete, further traces can be stored by pressing the ERASE button; the bistable target is not erased. This permits multiple traces to be stored on the bistable target and displayed on the phosphor screen.

Another change in the operating cycle is effected by pressing the INTEGRATE button. This action turns off the flood guns and interrupts the transfer pulse, allowing several traces to build up the charge on the high-speed target before being transferred to the bistable target. Integrate time is limited to only a few seconds in the fast mode.

In addition to the fast storage modes the 7623 provides bistable and halftone storage. In these modes the high-speed storage target is held at about the same potential as the collector and has essentially no effect on operation. The operating potentials on the second storage target determine whether the tube operates in a bistable or halftone storage mode.

SUMMARY

Each type of storage has application areas for which it is best suited. Direct-view bistable storage offers low-cost, long viewing time and split-screen operation. Halftone storage offers bright, high-contrast displays with variable persistence and the ability to store changes in intensity levels. Transfer storage provides both bistable and halftone storage, plus fast storage to store and display traces as fast as 200 cm/μs for as long as desired. With these three types of storage, in six new 7000 Series instruments, Tektronix, Inc. offers you the best in storage, no matter what your application.

ACKNOWLEDGEMENTS

Three concurrent design projects such as the 7313, 7613, and 7623 involve a lot of people. Although we cannot list all of the people involved in these projects, we would like to give credit to the following:

The new CRT for the 7623 was developed by Gary Siewell, Chris Curtin, and Wes Hayward. Wes also contributed much of the technical information for this article. Larry Virgin designed the 7613 CRT. Electrical and mechanical design of the 7623 and 7613 was as follows: Project Engineer was Bill DeVey under the direction of Oliver Dalton. John Durecka did the electrical design. Doug Giesbers, Ed Wolf, and Chuck Davis provided the mechanical design. Aiding the overall design effort were Dave McCullough and Dick Anderson.

John McCormick served as Project Engineer for the 7313. Tim Boege did the electrical design while Cathy Weinstein worked on the mechanical design. Paul Jordan also assisted in this project.

TEKTRONIX LOOKS at LIGHT

by **JON FESSLER** *and*
PETE KELLER

Almost since time began, man has been trying to identify and characterize the world around him. Among the first phenomena which drew his interest, and yet one which even today we do not fully understand, was light. At first, light could only be characterized as too bright or too dim, but as scientific knowledge increased, methods of measuring and specifying the quantity of light were developed. This study of light, when it deals with electromagnetic radiation which is visible to the human eye, is called photometry. If the study is broadened to also include the infrared and ultraviolet portions of the spectrum, it is called radiometry.

The study of photometry and radiometry is not confined to the laboratory. In fact, many uses require that the measuring instruments be taken to the light source. In addition, the instruments should be easily adaptable to a wide variety of applications while providing accurate measurements.

It is into this field that Tektronix, Inc., a leader in the manufacture of precision oscilloscopes and related products, enters with the J16 Digital Photometer/Radiometer. The J16 offers small size and light weight with rechargeable battery operation for maximum portability. Measurement results are displayed on a bright 2½-digit LED (light-emitting diode) display to facilitate measurements under low-light conditions and to reduce the errors associated with meter-type displays.

Interchangeable light-sensor probes allow the J16 to be adapted to the measurement requirement. Four calibrated probes are available for precise measurement of illuminance, irradiance, luminance, and LED light output. Since each probe is independently calibrated, the J16 does not need to be recalibrated when the probe is changed. A fifth probe is available to provide uncalibrated measurements where the only interest is the relative light output of the devices under test. The interchangeable probe concept also allows for future expansion of the system. An optional probe-extension cable allows the probe to be positioned independently of the J16.

A Simple Design

The circuitry used in the J16 is relatively simple as represented by the block diagram of Fig. 1. A silicon photo-diode is used as the light sensor in each probe. The different spectral response obtained from each probe is the result of a computer-designed, multilayer glass filter mounted in front of the sensor (except in the uncorrected J6504 Probe). A calibration adjustment in each probe allows the probe output to be normalized for easy interchangeability of probes without system recalibration or loss of measurement accuracy. Each probe also contains coding circuitry to light the correct units of measurement indicator on the front panel.

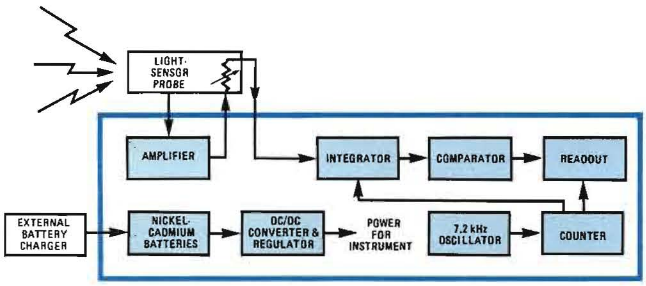


Fig. 1. *Block diagram of the J16 Digital Photometer/Radiometer.*

The silicon photo-diode used in the probes provide long-term stability, good linearity, and are rugged enough to stand up to typical portable usage. In addition, they cannot be damaged by extreme light levels, even when pointed directly at the sun. All probes include a READOUT HOLD switch which allows the user to store the display for as long as desired. This is particularly convenient when making measurements in situations which make immediate reading of the display difficult.

The photo-diode generates a current proportional to the intensity of the applied light. This current is amplified and converted to a voltage output by the amplifier. Also included in this circuit is the range-selection circuitry which determines the sensitivity of the unit. The output of the amplifier is connected to the integrator through the calibration potentiometer in the probe. This adjustment allows precalibration of the probes.

The remaining circuitry of the J16 comprises a digital voltmeter (DVM). The integrator produces a ramp signal which varies in amplitude in response to the voltage output of the amplifier. This ramp is applied to the comparator where it is compared against a fixed reference level. The output pulse from the comparator triggers the readout.

The 7.2-kHz oscillator free-runs continuously to provide a clock signal for the DVM. This signal is counted to provide a binary-coded-decimal drive signal to the readout. It also provides control signals for other circuits in the instrument.

BASICS OF PHOTOMETRY AND RADIOMETRY

Photometry refers to the measurement of visible light, usually with a sensor having a spectral sensitivity curve similar to the average human eye. Photometry is used to describe lighting conditions where the eye is the primary sensor such as illumination of work surfaces, television screens, etc.

The spectral sensitivity curve of the average human eye at typical light levels is called the CIE Photopic Curve. As can be seen from Fig. 3, the eye responds differently to light of different colors and has maximum sensitivity to yellow and green. In order to make accurate photometric measurements of light of various colors or from differing types of light sources, a photometer's spectral sensitivity must match the CIE Photopic Curve very closely.

The following are the most commonly used photometric units (see the drawing below for their relationship).

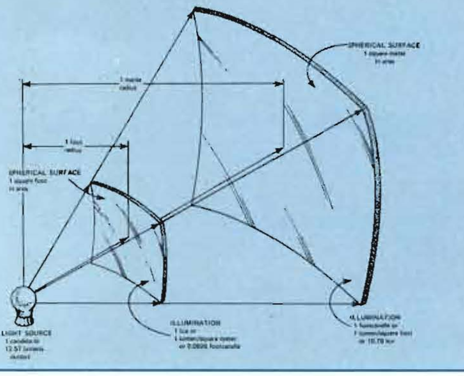
Illuminance is the amount of luminous flux received by a unit of surface area. Usually measured in foot candles (lumens/ft^2).

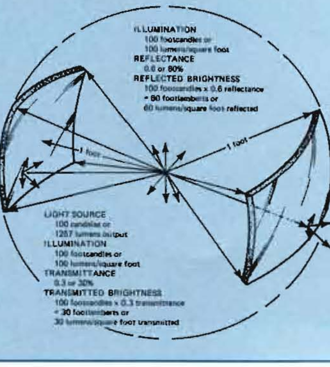
Luminance is the amount of light emitted or scattered by a surface and is usually measured in foot Lamberts. One foot candle falling upon a perfectly diffusing white surface with no loss would produce one foot Lambert.

Luminous Intensity is the luminous flux through a unit of solid angle and is usually measured in candelas (lumens/steradian).

Radiometry generally refers to the measurement of radiation in the infrared, visible, and ultraviolet portion of the spectrum. Devices used to make radiometric measurements should have equal response to light of various wavelengths in order to be versatile and easy to use without the need to correct data. This is similar to the necessity of having an oscilloscope vertical amplifier that has constant sensitivity from DC to the specified bandwidth.

Irradiance is the amount of radiant flux received by a unit of surface area and is usually measured in watts/cm^2. Other units of irradiance such as microwatts/cm^2 and watts/M^2 are also used extensively and are easily converted by shifting decimal places.)





When the readout is triggered by the comparator, it transfers the present count at its input to the LED display. The display is updated in this manner approximately every 80 milliseconds unless the READOUT switch on the probe has been set to HOLD. Under the latter condition, the readout retains the display present when the HOLD command was received.

Several convenience feaures are provided by the readout to facilitate accurate measurements. If the light intensity being measured is too great for the measurement range that has been selected, the display blinks at a 6-Hz rate to call the operator's attention. Another feature is the built-in battery check. When the BATT CHK button on the front panel is pressed, the battery potential is measured by the DVM and displayed on the readout.

Rechargeable nickel-cadmium batteries provide power for the instrument. A DC-DC converter with an electronic regulator provides stable voltages for accurate operation. Protection circuitry is included to interrupt instrument operation and prevent battery damage due to over-discharge. The batteries can be recharged in about 16 hours with the external battery charger. If desired, spare battery packs can be purchased so the J16 can be operated from one set while the spare is being recharged.

Packaging Performance

The mechanical design of the J16 results in a compact, self-contained instrument with mechanical performance to complement its electrical capabilities. The small size (2.4 x 4.6 x 8.0 inches) and low weight (3.25 pounds) result in a highly portable, easy-to-use instrument. The J16 can be hand-held while making measurements or the probe can be detached and used with the optional extender cable. Under the latter condition, the J16 can be placed in a fixed position or carried around the neck with the shoulder strap while the probe can be moved about freely to obtain the desired measurement. Also, both the J16 and the probes have ¼-20 mounts so they can be mounted on optical benches or used with standard photographic tripods or similar equipment.

Servicing Simplified

The J16 is a completely self-contained unit; discrete components are used throughout the instrument rather than sealed, non-repairable modules. The instrument is built on circuit boards for easy accessability to the components (see Fig. 2). As a result, the instrument is easy to service should repairs be necessary. In addition, the TEKTRONIX reputation for reliability and our world-wide service organization is available to back you up.

The J16 is totally solid-state, using a dependable integrated-circuit design. This results in a very reliable, stable instrument which requires recalibration only about once a year under normal operating conditions. Recalibration to insure accurate measurements requires only three adjustments. 1) Calibrate the DVM section against an accurate voltage source. 2) Set the front-panel ZERO adjust for a zero readout with no light striking the probe sensor (in dark room or with a photographic dark cloth covering the instrument). 3) The GAIN adjustment, located on the probe, should be made only under controlled conditions with an accurate light source. Tektronix, Inc. maintains complete recalibration facilities where the probes are adjusted with light sources traceable to the National Bureau of Standards. Since both the J16 and the sensor probe are precalibrated for normalized gain, only the probe needs to be returned to Tektronix, Inc. for recalibration.

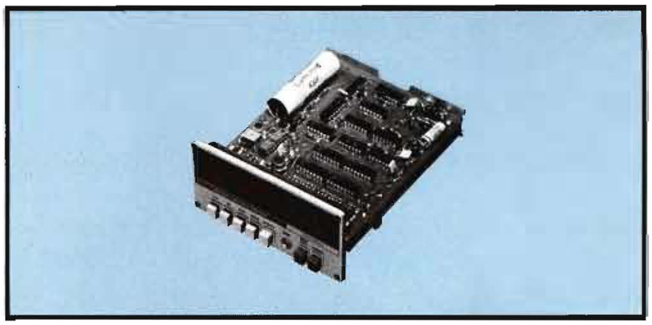


Fig. 2. *Simple construction of the J16 makes servicing easy.*

A Variety of Probes

The measurement flexibility of the J16 is greatly increased by the variety of plug-on light-sensor probes available. Measurement capabilities can be changed in a matter of minutes by simply changing probe units. A few of the typical application areas for the J16 system are:

- Outdoor lighting of highways, streets, airport runways, signs . . .
- Indoor lighting of offices, work areas, homes, movie and TV studios, hospital operating rooms . . .
- Manufacturing checks of lamps, light fixtures, auto headlamps, displays, photography equipment, light-dependent processes, light filters, industrial photo processing . . .
- Checks of TV picture tube brightness and uniformity, lasers, storage CRT brightness, readouts such as LED's and electroluminescent panels . . .
- And many, many more!

Following is a summary of the probes currently available along with some typical applications. Fig. 3 shows the spectral response of each probe.

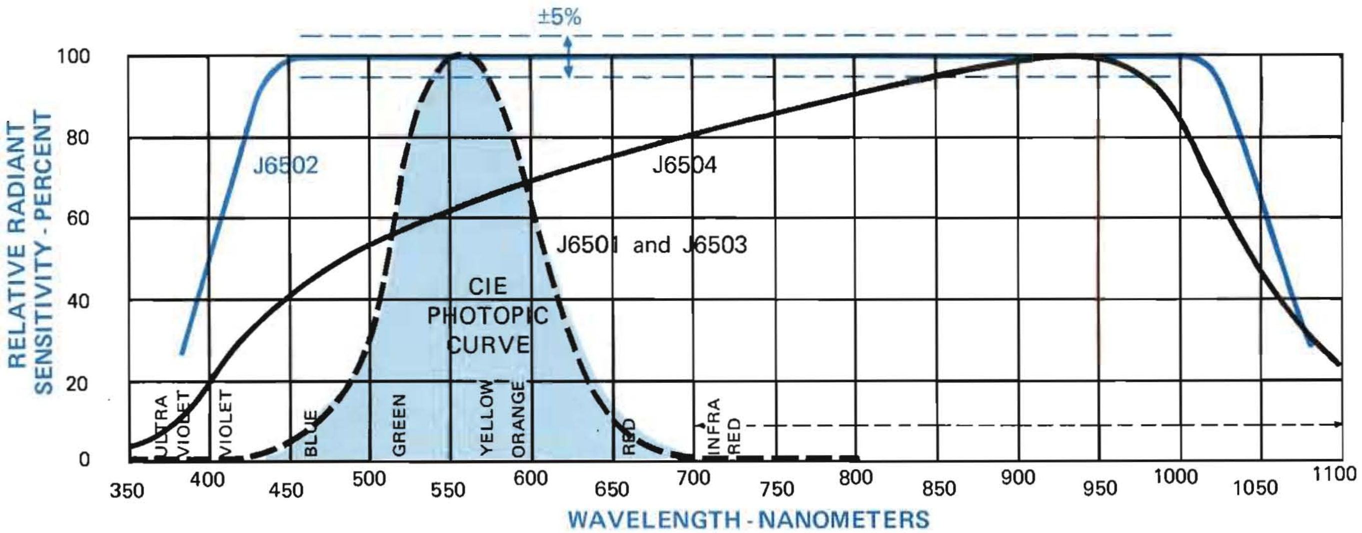


Fig. 3. *Spectral response of probes for J16.*

The J6501 Illuminance Probe is designed to measure light incident (falling) upon a surface. Measurements are made with the J6501 pointed at the light source. Response of this probe is very closely matched to the CIE Photopic Curve (see Fig. 3) to equal the spectral response of the average human eye. When this probe is installed, the front-panel FOOT CANDLES indicator is lit to indicate that measurements are in these units.

Typical applications for the J6501 are measurements of street lighting (see back cover), building lighting, television and movie scene illumination, and light levels falling on working surfaces.

The J6502 Irradiance Probe is corrected to provide a flat spectral response within 5% over the spectral range of 450 to 1000 nanometers (visible and near infrared). Measurements are made with the J6502 pointed at the light source. The front-panel μWATTS/SQ CM indicator is on when this probe is used.

Typical applications include measurement of radiant efficiencies and laser research experiments (see Fig. 4). For measurements of lasers exceeding about two milliwatts output, use neutral density filters to reduce the light intensity to the probe sensor.

The J6503 Luminance Probe measures light scattered, reflected, or emitted by a surface. Measurements are made with the J6503 pointed at the surface. Response of the probe is closely matched to the CIE Photopic Curve. Measurements with the J6503 are in FOOT LAMBERTS as shown by the front-panel indicator.

The J6503 can be used for typical applications such as measurement of television picture tube luminance and uniformity (see Fig. 5), storage CRT brightness, light reflected from work surfaces, and light output of electroluminescent devices.

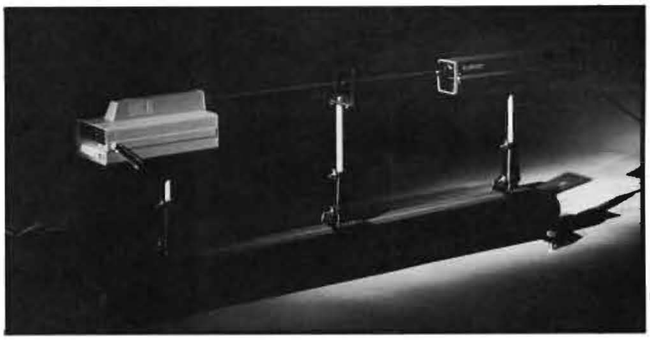


Fig. 4. *Measuring laser output power with the J6502 Irradiance Probe.*

Fig. 5. *Tek employee Marilyn Bonin monitors the new 7623 Transfer Storage Tube with the J6503 Luminance Probe.*

Fig. 6. *The J6505 LED Test Probe being used for incoming inspection of light-emitting diodes by Brenda Bryant.*

The J6504 Uncorrected Probe can be used where only the relative light level needs to be measured. No correction filters are used so the response is that of the silicon light sensor. However, an optional filter holder is available so you can add standard one-inch diameter filters in front of the sensor to match the response to your measurement requirements. Since measurements are relative, no units are indicated on the front panel when this probe is installed.

Typical uses of the J6504 are for standardizing light sources of photoresist and photoprocessing equipment or for matching light sources without regard to absolute units.

The J6505 LED Test Probe is designed to measure illuminance of light sources such as light-emitting diodes with spectral outputs in the range of 620 to 730 nanometers (red light). Measurements are made with the J6505 pointed at the light source. The front-panel FOOT CANDLES indicator is on when this probe is used. Measurements can be made in millicandelas by maintaining a predetermined probe-to-LED spacing.

The principal application of the J6505 is measurement of light-emitting diode output (see Fig. 6). However, it can also be used to measure any light source whose output falls in the 620 to 730 nanometer range.

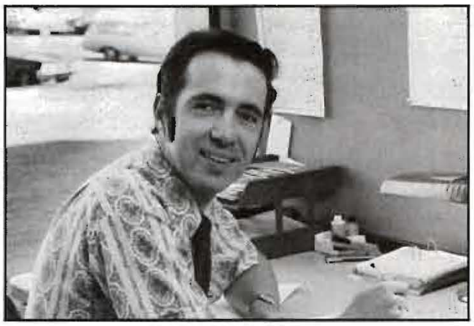
Summary

The TEKTRONIX J16 Digital Photometer/Radiometer can bring new capabilities and flexibility to your light-measurement applications. Just as interchangeable voltage and current probes greatly expanded oscilloscope measurements, the interchangeable light-sensor probe concept of the J16 will greatly expand your light measurement capabilities. Perhaps your job does not have requirements for an instrument such as the J16, but you know someone who could use it. If so, we would appreciate your passing this article on to them.

ACKNOWLEDGEMENTS

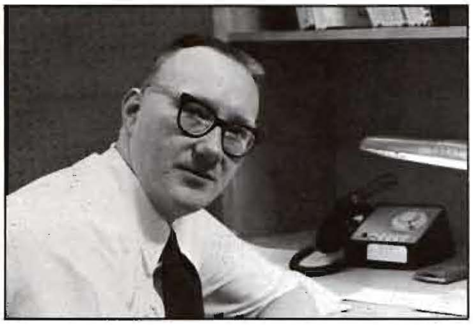
The J16 is the result of a joint effort by many people. Russ Anderson assisted Jon in the electrical design. The J16 was based on circuit concepts developed by Wendell Damm. Mechanical design was by John Benson and Larry Pearson and optical design by Pete Keller. Ron Phillips provided evaluation support while Millie Cantrall built the prototype units.

About our authors—



JON FESSLER

Jon started at Tek in 1965 as a Component Application Engineer and later worked as manager of the Prototype Engineering Group where he assisted in getting many new TEKTRONIX instruments into production. His present duties as Engineering Project Manager in the Optical Products group led to involvement on the J16. During his off-duty hours, Jon shares his hobbies of ghost-town exploring, rockhounding and photography with his wife Judy.



PETE KELLER

Pete has worked at Tek for 8½ years. Prior to his present duties as Marketing Staff Engineer for the Optical Products group, he worked in the CRT Development area. Pete has been involved with electro-optical measurements for many years and worked at Kitt Peak National Observatory before coming to Tek. Pete spends his spare time with his wife and four children, and enjoys pastimes of astronomy, classical music, and radio.

TEKNIQUE

TUNNEL DIODES:

In-Circuit Testing Using the 7D13 Digital Multimeter Plug-In.

A common practice in troubleshooting electronic circuitry is substitution of components as a quick analysis of the circuit malfunction. Often, however, a replacement is not readily available, especially if the part is expensive; and some components, such as semi-conductors, are extremely sensitive to heat and easily damaged during installation or removal.

Tunnel diodes frequently qualify in both of these categories. As such, it is best to test them in-circuit if possible. In past issues of Tekscope we have discussed various methods of checking tunnel diodes. One method described the use of the sawtooth output from your test scope as a current source for the TD with the resulting characteristic curve displayed on the test scope. Another method discussed using the TEKTRONIX 576 Curve Tracer for in-circuit testing of tunnel diodes.

For some applications a simpler, quicker test can be made using the ohmmeter section of the TEKTRONIX 7D13 Digital Multimeter plug-in. You may legitimately ask, "What's new about using an ohmmeter to check semiconductors? We've been doing that for years." The answer is that instead of getting just a high-low resistance indication you can take a resistance measurement accurate to within 0.5 percent ±1 count. Here is how this can be of importance to you in checking tunnel diodes and other devices.

When using the 7D13 on the 200-ohm scale, precisely 10 mA is caused to flow through the resistance being measured. The resultant voltage is then measured by the voltmeter circuits and read out as resistance, in digital form, on the CRT screen. In checking tunnel diodes, this 10 mA current switches the TD to its high state and a resistance reading is taken in the tunnel direction. The leads are then reversed and a reading is taken in the low resistance direction. We can thus establish a set of resistance "standards" for the device since precisely 10 mA is flowing through the device during each measurement. Readings for a given type of device are typically within one or two percent from one unit to another.

For tunnel diodes requiring more than 10 mA to switch, a 0.001-μf capacitor is placed across the 7D13 input terminals. This supplies the additional current needed for switching and the resistance reading is then taken with a constant 10 mA flowing through the device.

A note of caution is in order here. Some tunnel diodes, such as those with low-picosecond switching times, are easily damaged and should not be checked using this procedure. Typical of this class of device are the output tunnel diodes used in the TEKTRONIX 284 and S-50 pulse generators with switching times of less than 70 ps and 25 ps respectively.

The capability of making precise resistance measurements is particularly useful in production testing where several instruments of the same type are being processed. For example, a chart can be prepared showing the expected readings for each type of device to be checked. The chart need not be limited to tunnel diodes, of course. It may include signal diodes, Micro-T transistors and other devices easily damaged during installation.

When a reading is taken that does not correspond to the value shown in the chart it usually indicates a marginal or defective device, or as sometimes happens in production, a wrong component is installed.

The sample chart below shows typical readings for some of the tunnel diodes used in TEKTRONIX products. Several units of each part number were measured and the average reading listed. As we mentioned before, the readings for a given type were all within one or two percent of each other.

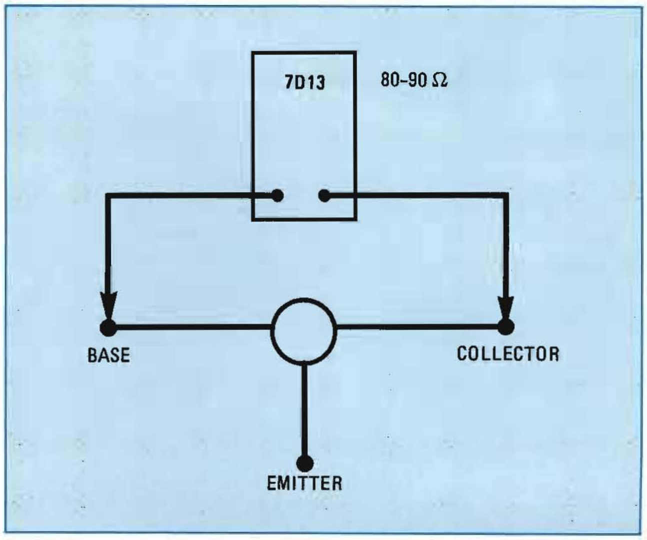
Tunnel Diode Resistance Readings Taken with the 7D13

Type No.	Part No.	Switching Current	Resistance Low-High
1N3712	152-0169-00	1.0 mA	10 - 60 Ω
1N3715	152-0330-00	2.2 mA	6 - 55 Ω
1N3713	152-0125-00	4.7 mA	5 - 55 Ω
1N3717	152-0381-00	5.0 mA	5 - 50 Ω
1N3718	152-0386-00	10.0 mA	3 - 53 Ω
TD253	152-0154-00	10.0 mA	5 - 60 Ω
TD253B	152-0177-00	10.0 mA	6 - 60 Ω
TD254	152-0380-00	20.0 mA*	3 - 53 Ω
TD274A	152-0387-00	20.0 mA*	3 - 53 Ω

**Install .001-µf cap across 7D13 Terminals*

Checking Micro-T Transistors

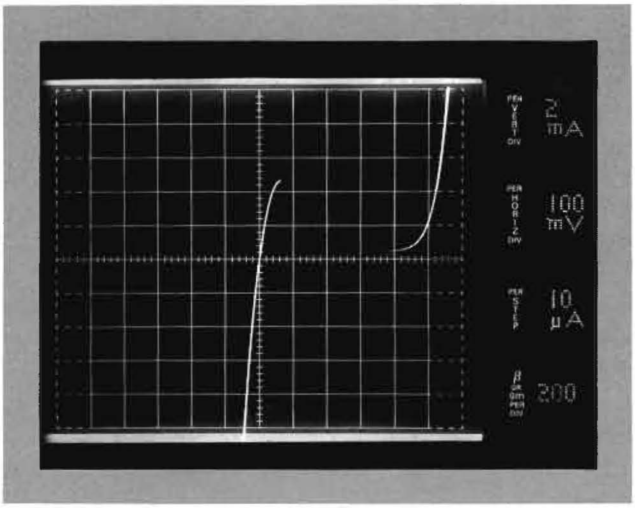
The Micro-T transistor is another device that is almost impossible to remove from the circuit for testing, without damage. This small, high-frequency package is usually soldered right onto the printed circuit board. The diagram shows the lead arrangement for the device. The layout is ideal for passing a signal through the device while maintaining a constant impedance environment in the printed circuit board layout. A resistance reading is usually taken across the base-to-collector junction and should typically read 80-90 ohms. Values outside of this range indicate a marginal or defective device.



Lead arrangement for Micro-T transistor. Resistance reading is taken across BASE/COLLECTOR junction.

Summary

Using the 7D13 Digital Multimeter plug-in for making accurate in-circuit measurements can substantially reduce the time spent in identifying marginal components that are causing trouble, or represent potential trouble spots. This technique is especially applicable to production testing where many units of the same type are being tested.



Pictured above is the characteristic curve for a 4.7-mA tunnel diode displayed on a TEKTRONIX 576 Curve Tracer. The device is being driven by the Collector AC supply. Zero current and zero voltage is at center screen. With 10 mA flowing in the forward direction there is 555 mV across the device. Forward resistance is thus 55.5 ohms. With 10 mA flowing in the reverse direction there is 45 mV across the device for a reverse resistance of 4.5 ohms.

The 576 is a convenient means of verifying what the forward and reverse resistance readings should be for a given type of device. The 7D13 provides a fast and accurate method of making these same readings for an "in-circuit" production test application.

SERVICE SCOPE

WASHING YOUR TEKTRONIX INSTRUMENT

By Charles Phillips, Product Service Technician

Have you ever noticed how much better your car seems to run when it has just been washed or polished? This is a psychological reaction of course, but the improved appearance does cause us to value our car more highly and take better care of it until the next rain storm messes it up again.

Test equipment gets dirty, too. Not as rapidly as our car, perhaps, but with a more detrimental effect on its operation. Thorough cleaning of a dirty instrument not only improves its appearance, but improves its performance and reliability as well.

Many of you are aware that Tektronix has, for many years, been washing instruments sent to our service centers for repair and calibration. Some customers with large numbers of instruments have installed their own wash facilities as an aid in keeping their instruments in top shape.

With the advent of printed circuit boards and solid state devices in instruments comes the question, "Is it still necessary to wash instruments and, if so, what precautions do I need to observe?" While it is true that solid state instruments do not usually get dirty as quickly as their vacuum tube counterparts, they too, can benefit from a periodic cleaning. We find they are easy to wash and no particular precautions, other than those applying to vacuum tube type instruments, need be observed.

Equipment Needed

Chuck Phillips is pictured at right washing a 7000-Series instrument in the wash booth of our factory service center. The booth includes an exhaust system to remove the dust and mist generated during cleaning and is typical of the wash booths used in our other centers.

There are several items you will need to do an effective job. They are as follows:

(a) Liquid silver cleaner used to remove tarnish from connectors.
(b) Brushes used to clean knobs and connectors.
(c) Paint brush used for dry method of cleaning, etc.
(d) Sponge for applying cleaner to remove marks on aluminum.
(e) Non-sterile cotton-tip applicators used for miscellaneous cleaning chores.
(f) Piece of plastic light filter or graticule used to remove labels and adhesive after soaking them with solvent.
(g) No-noise applied sparingly to pots and switches as needed.
(h) Kimwipes or equivalent for wiping off front panel, etc.
(i) WD-40 used for several applications.
(j) Spray paint used to touch up cabinets and side panels.
(k) Flux remover or any solvent that will soften adhesive used with calibration stickers and other labels.
(l) Ajax cleaner or equivalent used for removing marks on aluminum chassis, etc.
(m) Screwdriver for removing slotted screws.
(n) Screwdriver for removing Phillips screws.

The other items needed in the wash area are:

A source of compressed air with aproximately ten feet of hose.

A spray gun with eight feet of hose (Devilbiss Type GDV Series 510 or equivalent).

A rubber siphon hose three to four feet in length.

Hot and cold water.

Detergent (Kelite or equivalent, mixed approximately 1 part detergent to 20 parts water).

The drying oven is pictured at right. There are a number of commercially available ovens suitable for this purpose. The primary considerations in selecting one are size and the capability of providing circulating air at a temperature of 125°F to 150°F.

Steps Prior to Washing

Some early TEKTRONIX instruments used water soluble ink for chassis markings. The chassis have a shiny appearance as compared to those with permanent markings. If you suspect you are washing such an instrument use very little detergent and cold water.

Paper covers on electrolytic capacitor should be replaced with plastic covers or sprayed with a water repellent such as WD-40.

Leather handles should be sprayed with WD-40 or other type water repellent to prevent cracking.

Capacitors leaking oil should be tagged for replacement.

Labels and adhesive should be removed unless specified otherwise.

We no longer consider it necessary to remove the CRT, shields, vacuum tubes, etc. to do a thorough cleaning job. Experience has shown that warm water and detergent under pressure penetrates these areas adequately without completely exposing them.

The cabinet sides and bottom are removed and washed separately. They can be put back on the instrument before placing the instrument in the oven for drying, if desired. The 7000-Series plug-ins are washed with the side panels in place. This saves time and prevents a mix-up in panels.

Washing Procedure

After preparation, place the instrument in the wash booth and spray lightly with detergent and warm water. (Do not spray detergent directly on power transformers or paper items.)

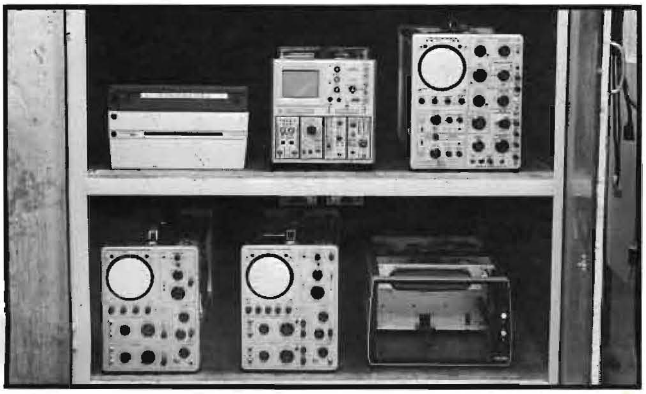
Clean connectors and knobs using appropriate brushes.

Rinse thoroughly with warm water.

Remove excess water from the instrument (especially the front panel) with air.

Place the instrument (with washed plug-ins installed) in the oven and dry for at least 24 hours.

The graticule and light filter are cleaned at the work bench using a glass or plastic cleaner.



After Washing and Drying

It is well to take a few minutes to apply lubricant to the switches, motors, etc., particularly on the older instruments. A lubrication kit designed specifically for this purpose is available under Tektronix Part No. 003-0342-01.

Switches—Lube detents with a light grease and contacts with No-noise.

Motors—Apply 1-2 drops of thin oil. (WD-40 is suitable).

Potentiometers—Apply 1-2 drops of No-noise to the shaft, contacts and open spots around the cover. Use a hypo and needle, or spray can with nozzle. Cover removal is neither necessary nor desirable.

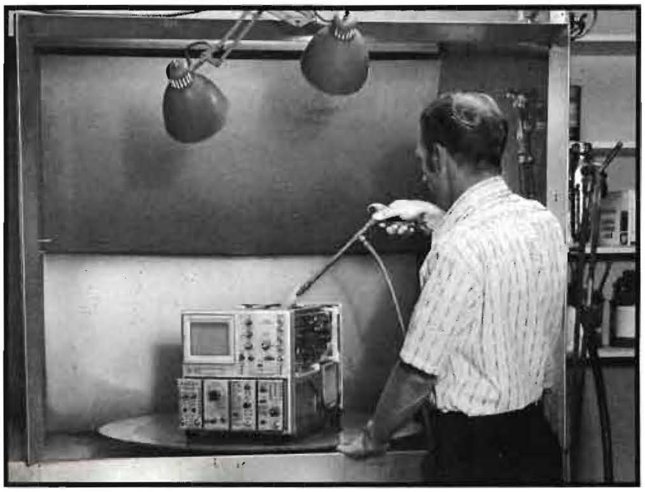
The appearance of the instrument can be enhanced by applying WD-40 or furniture polish to the front panel. The polish should be sprayed on an absorbent towel, not directly on the instrument panel. A small amount sprayed on the one-inch paint brush is handy to get around the knobs.

Summary

You will find that the time spent in properly cleaning an instrument will result in fewer calibration problems, a longer period between calibrations and greater operator satisfaction with both the instrument and the service center.

About our author

Charles Phillips—Chuck has just completed 10 years with TEK. His career at TEK has been devoted entirely to service center activities. After serving six years in field service centers he transferred to Factory Service where he has contributed much to improving servicing techniques and solving new instrument problems. Chuck's "off-work" hours are filled with Laymen for Christ activities, managing his own TV sales and service business, and his family.



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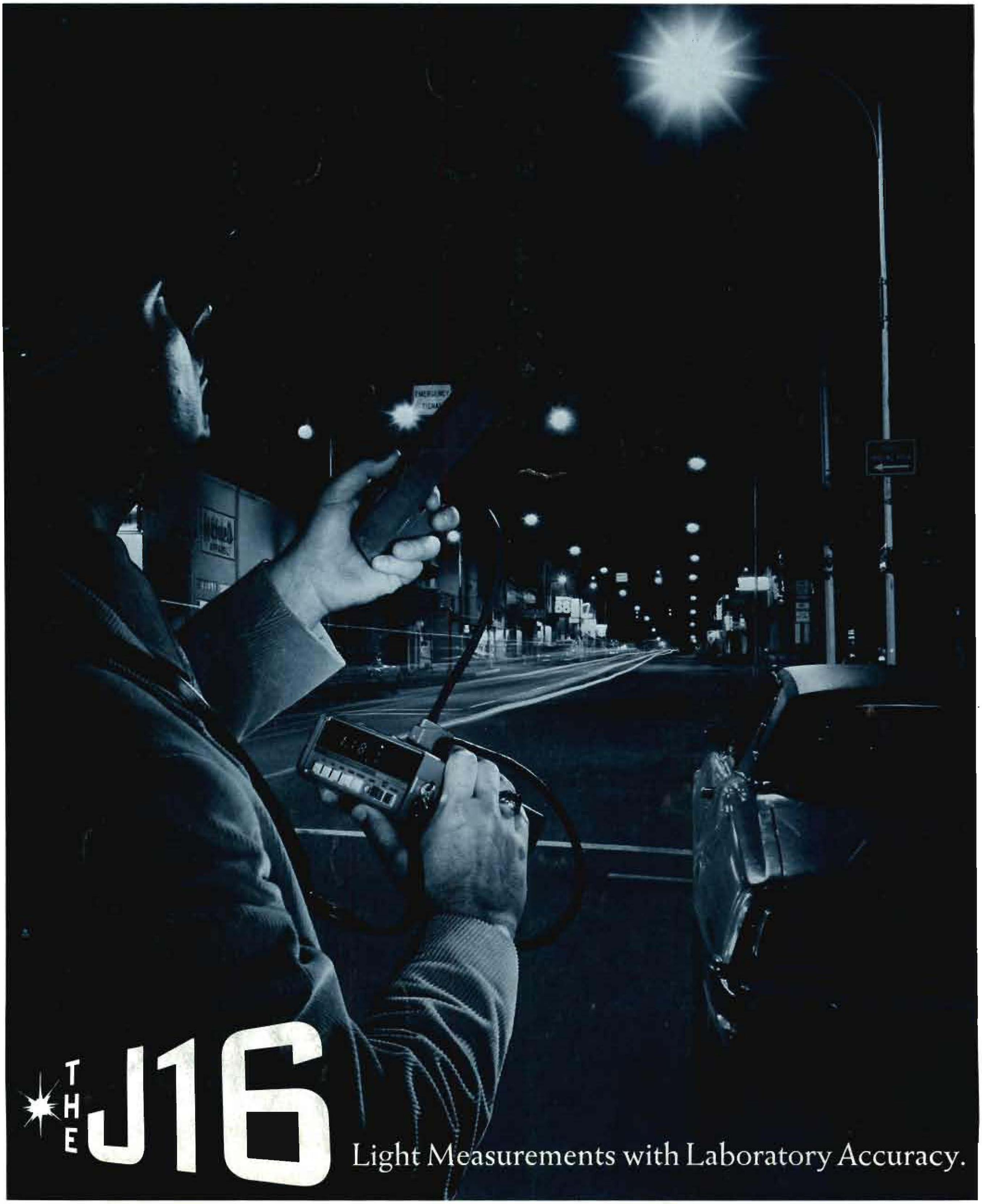

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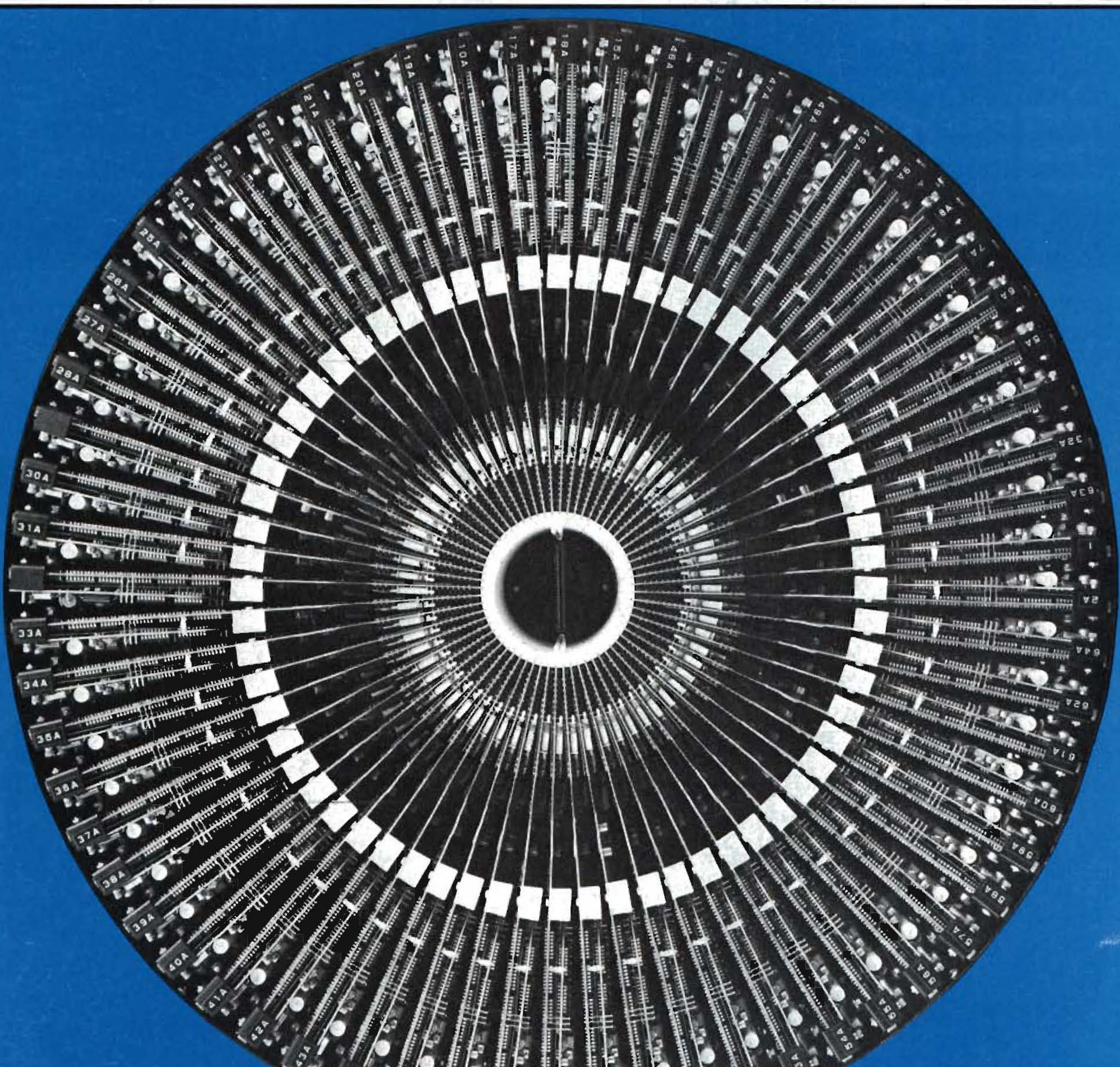


TESTS AND MEASUREMENTS WITH TEKTEST III

DIFFERENTIAL AMPLIFIERS AND MEASUREMENTS

REPAIRING OSCILLOSCOPE PROBES

TEKTEST™ III

AUTOMATED TEST SYSTEM CONTROL THROUGH SOFTWARE

by W. E. Kehret Automated Systems Engineering

TEKTRONIX AND AUTOMATED TEST SYSTEMS

A FAMILY HERITAGE: The S-3260 Automated Test System is the most recent addition to the TEKTRONIX family of test systems which began in 1964. The first system, and much of the later development was based on programmable sampling oscilloscopes and digital readouts. In contrast, the S-3260 is a real-time test system which uses single-shot measurement techniques to replace the sequential sampling techniques of the earlier systems. System operations are performed under software control of a dedicated computer. A graphic computer terminal handles communication with the system.

As is true of most technologies, automated test systems have made rather sweeping changes since their inception a little more than a decade ago. Although these early systems used all of the technologies available to them, their performance appears very limited as we look back from the vantage point of more than ten years of technological advancement. However limited they may appear in hindsight, these early systems adequately made the measurements required of them, and only development of more sophisticated devices to be tested placed the capabilities of these systems in question. Most tests were fixed by the original system design; if test parameters could be changed, it was usually through internal wiring changes or by front-panel switching.

As test systems advanced to include stored program control and the capability to test more complex components such as integrated circuits, the major criterion of system performance was still the hardware—what instruments were used and how they were physically connected together. Major changes in test characteristics often required reconfiguration of the system.

Implementation of large-scale-integration techniques by semiconductor manufacturers brought about the need for a much more flexible test system. The vast number of checks required on each device made testing with existing systems unfeasible, both in view of limitations of the equipment and limitations in the ability to physically program all of these tests. For relief the systems designers looked to the computer's ability to control many operations in real time (as they occur) and to ease the burden of programming.

***Cover:** Sixty-four Input/Output sector cards form the heart of the S-3260 Automated Test System. The Device Under Test mounts on a test board in the center of this array, placing it very close to the measurement subsystems.*

Addition of the computer to the test system shifted the focal point of system flexibility from the hardware configuration to the software operating system. In order to achieve a flexible system, the test language or software must also be flexible. Designers of the new TEKTRONIX S-3260 Automated Test System sought a test language which could be easily understood by engineers relatively untrained in computer programming methods, yet was powerful enough to control the full range of hardware capability in the system.

A New Language

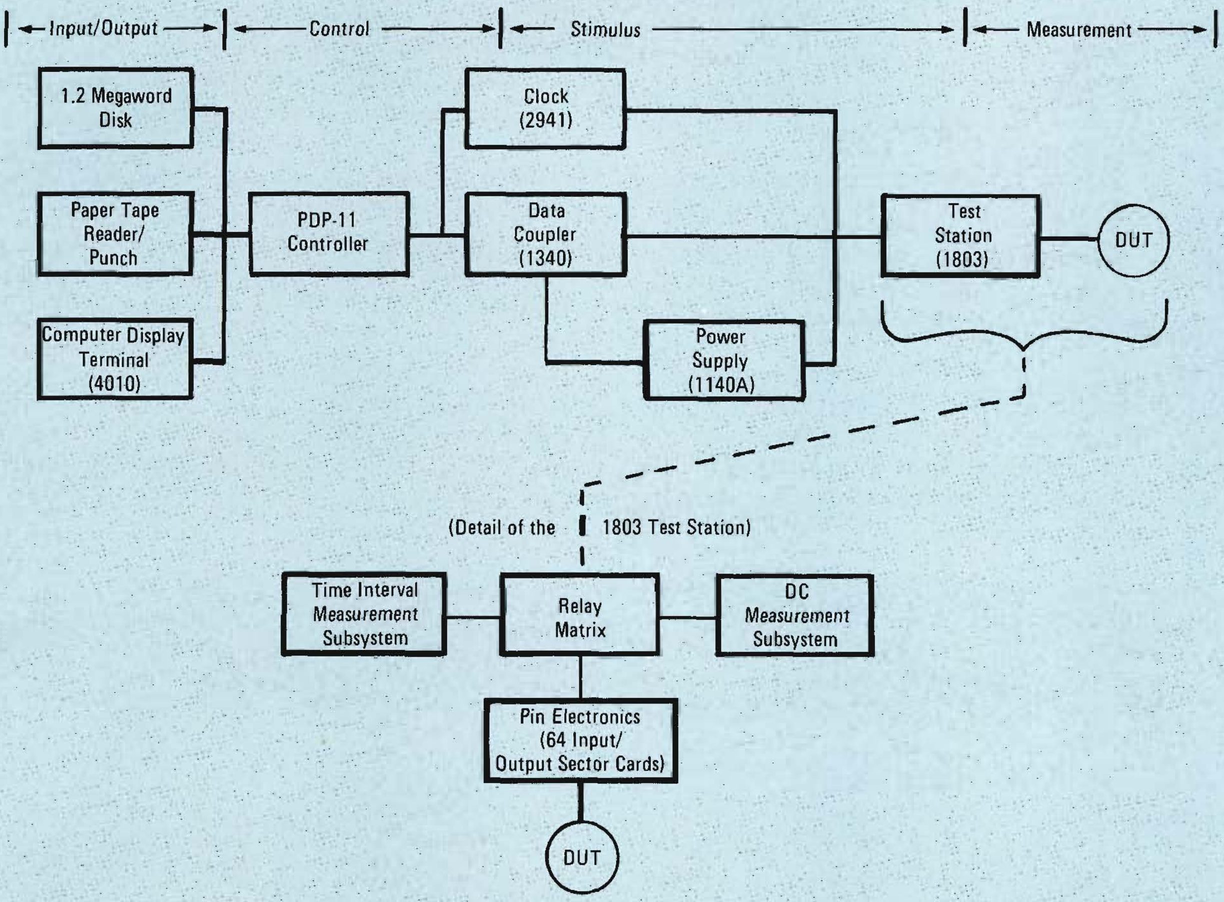
Existing test languages proved inadequate to meet the goals set forth for the S-3260 System. As a result, a totally new test language called TEKTEST III was developed.

For those familiar with computer operating systems, it is appropriate to distinguish TEKTEST III from existing compilers such as FORTRAN, ALGOL, or BASIC. While TEKTEST III is a higher level language with capabilities in some ways similar to the above mentioned compilers, this new software language for the S-3260 System is not equivalent to, or a subset of, any previously defined language. This is also true of other software components including the editors and the disk operating system. This totally new software system was developed to allow ease of operation for users other than systems specialists, and for speed of operation. Although it would appear that adaptation of existing software systems would be the easiest, this could not be done and still fully meet the objectives.

Software + Hardware = S-3260 System

While we will be dealing mainly with the Software Operating System, a basic understanding of the hardware used in the S-3260 Automated Test System is helpful. Please refer to the S-3260 System Hardware Organization discussion and Fig. 1 which accompanies this article.

S-3260 SYSTEM HARDWARE ORGANIZATION



The hardware which makes up the S-3260 System is shown in the block diagram of Fig. 1. Although a variety of options are available for this system, we will only look at those items which are a standard part of the system.

Input and output for the system is shown at the left side of the block diagram. The 1.2 Megaword Disk provides storage for the test program library, system programs, test results, files, etc. The disk system provides fast retrieval of stored material when addressed by the computer. Program material can be entered into the system through either the Paper Tape Reader Punch or the Computer Display Terminal. These devices can also be used for output. The computer display terminal is of particular importance when used to generate test programs in conjunction with the interactive programming capabilities of the Software Operating System. Since the terminal has both alphanumeric and graphic output capabilities, it can provide output in either form.

The entire system is under control of a dedicated computer referred to as the Controller. The Data Coupler interfaces between the Controller and other instruments in the system. Timing relationships for system operations are established by the Clock. Reference voltage levels are provided by the programmable Power Supply.

Interfacing for input or output to as many as 64 pins of the device under test (DUT) is provided by the Test Station. The Test Station contains 64 Input/Output Sector Cards which can be connected to the pins of the DUT through software control. Each card contains the forcing and sensing circuitry required for Functional measurements. Timing for these measurements is controlled by the Clock. The Sector Cards also contain a 1032-bit high-speed buffer memory. During functional tests, data is available from this buffer at Clock rates up to 20 MHz. Errors may also be stored in buffer memory at Clock rates.

In addition to measurements using the Sector Cards, the Relay Matrix allows each pin of the DUT to be connected to the parametric measurement subsystem. This subsystem consists of two separate measurement systems: the Time Interval Measurement Subsystem for timing measurements and the DC Measurement Subsystem for current or voltage measurements.

Fig. 1. *Basic block diagram showing hardware organization of the S-3260 System.*

Putting It All Together

To complement the very effective hardware organization, the S-3260 has an equally effective Software Operating System (see Fig. 2). This system can be broken down into three levels: Editor Level, Translator Level, and Machine Level. The Editor Level provides three separate editors to aid in the preparation of the test program (see The Editors for further information). This test program is not in the language most readily understood by the machine environment of the test system. The process of converting the source language to a machine language is called "translation" and is handled at the Translator Level. The translated code consists of macro-instructions which are processed under software control of a Digital Equipment Corporation PDP-11/40 and its floating-point hardware and software service routines. These macro-instructions relate to the S-3260 hardware functions at the Machine Level. These include clock generator instructions, power supply instructions, data coupler instructions, and parametric subsystem instructions.

System operations are classified by priority: background operations and foreground operations. Fig. 2 shows this breakdown. Foreground operations deal with the actual running of the test program. These operations occur at the Machine Level and are given priority by the Controller. Normally, pauses occur in the foreground operations as they are being run. These pauses are caused by reed switch settling time (normally 1 to 2 milliseconds), power supply slewing, etc. Rather than remaining idle during these pauses, the computer processes background operations if they have been scheduled by the operator. Background operations can consist of test program editing, data logging, graphing, etc. This relationship between foreground and background operations allows a form of time-sharing of the computers capabilities for more effective use of the total system. For example, a new program can be generated from the input terminal at the same time that devices are being tested. Even though the test receives priority scheduling, the programmer will probably not realize that he is not receiving the full attention of the computer.

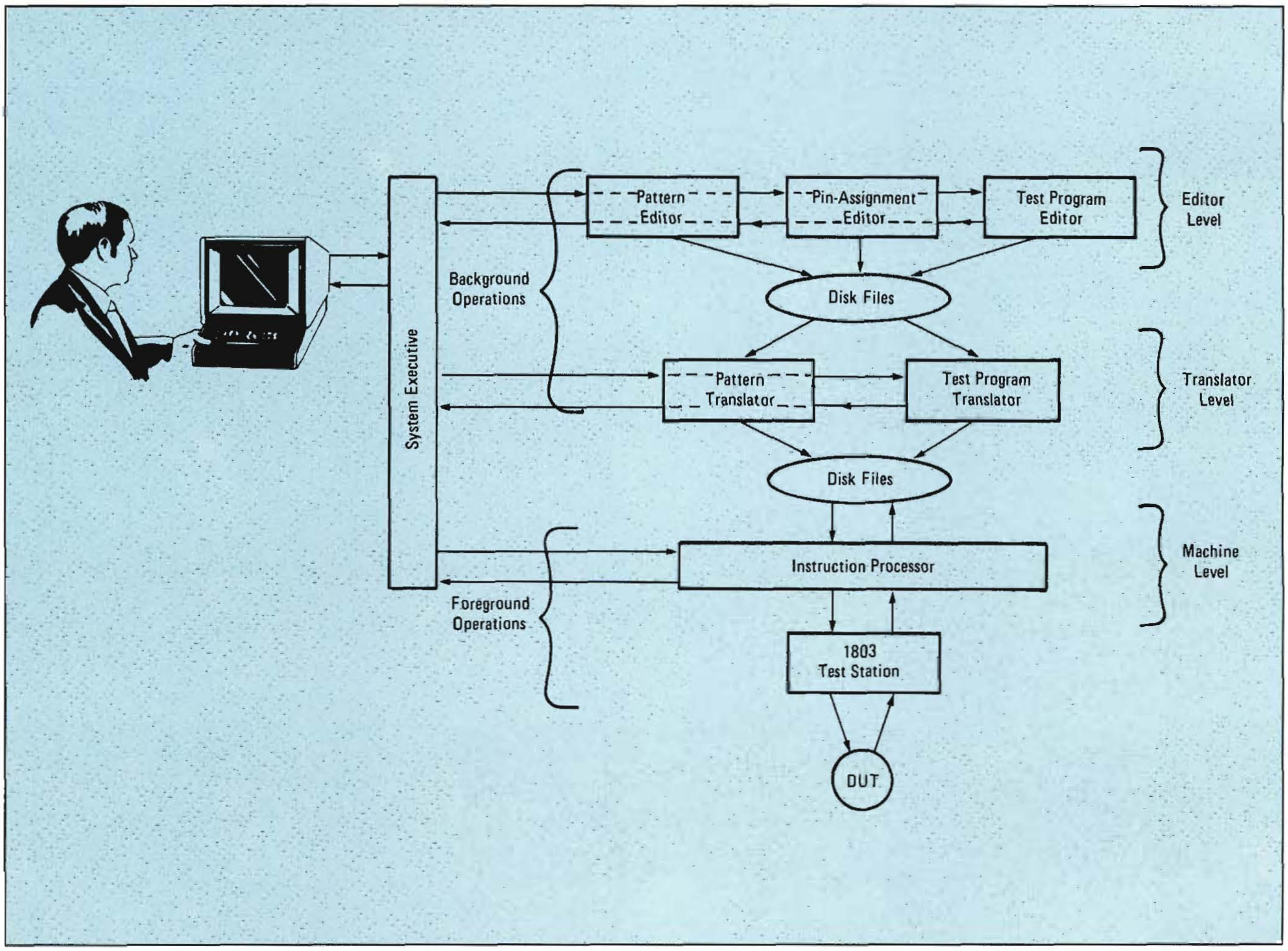
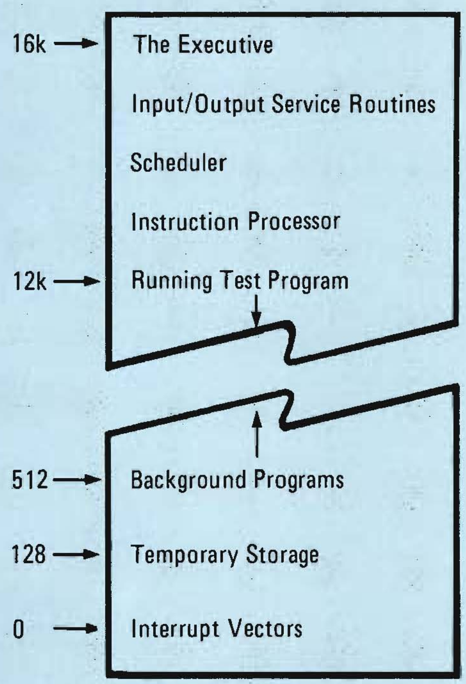


Fig. 2. *Organization of the Software Operating System for the S-3260 System.*

By this time you may be concerned about getting it all together: editors, translators, background, foreground, and who knows what else? Fortunately, there's help built into the Software Operating System. This comes from the Executive. The Executive is a disk operating system which does file handling, program loading, background scheduling, and accepts data logging directives at test-program run time (see special description on Core Memory Utilization and Fig. 3).

CORE MEMORY UTILIZATION



Although the user does not need to be concerned about core-memory utilization when operating this system, an understanding of how the software operating system and the core memory inter-relate is helpful in understanding the overall system.

Fig. 3 is a graphic representation of how the 16K (16,000) words of core memory are used in running a program. The top 4000 words of memory between memory location 16K and 12K are occupied by the Executive, input/output service routines, the scheduler, and the instruction processor, in that order. The running test program is loaded downward from the instruction processor.

From the bottom of core, the first 128 words are occupied by interrupt vectors. The temporary storage occupies the area between the 128th and 512th words. Background programs are loaded upwards from the 512th word. The point at which the downward loaded test program meets the upward loaded background programs is controlled by the scheduler and the loader.

Fig. 3. *Graphic representation of core memory utilization by the computer.*

The Editors

The Editors consist of three separate editors to aid in test program preparation.

Test Program Editor. The Test Program Editor aids in the preparation of the test statements. This editor is line number oriented. To enter a statement, type a line number and the test command. For example:

```
 99.00 WHEN  ERROR     110
100.00 MOVE  REGISTER  (1,16) TO SECTOR
       ON    PINLIST
```

Additional statements can be added between two sequential statements as follows:

```
 99.00 WHEN  ERROR     110
100.00 MOVE  REGISTER  (1,16) TO SECTOR
       ON    PINLIST
 99.01 LOOP  100    IND=1,60
 99.02 HIDRIVE=5.0 V-50mV*IND ON DPINS
```

Statements 99.01 and 99.02 would appear in the program between 99.00 and 100.00. If the Editor was asked to list the program, it would appear in the correct line number sequence.

The Test Program Editor also allows statements to be erased either singly or in blocks, and replacement of individual lines by typing the original line number and the new command statement.

Certain programming errors are detected and may be corrected at the time the program is entered. Other program errors are not detected until the program is actually translated or run. An example of the latter would be a command to transfer program control to a non-existent line location in the test program. When this is encountered in translation, an error statement is printed along with the line number of the command statement where the error occurred. Then the programmer can enter the correct information from the terminal.

Another feature of the Test Program Editor is to list either the entire program or individual lines within the program. This allows the programmer to inspect or modify the program.

Pattern Editor. Patterns refer to the sequence of addresses and/or control data applied for functional testing of a device. A variety of patterns are in common usage, each one best suited to test particular types of devices.[1] The purpose of the Pattern Editor is to format the test pattern data into a two-dimensional matrix or table. A pattern-table row corresponds to data sent to the DUT; one row for each cycle of a clock sequence. A pattern-table column corresponds to the sequence of data at a particular pin of the DUT; one column for each active pin.

---

[1] For further information on patterns, refer to TEKTRONIX Automated Systems Application Note No. 2, "Test Patterns and Their Use In LSI Memory Diagnostics."

For simple devices, the test pattern can be developed manually. However, as the device becomes more complex, the difficulties in generation of the test pattern increase similarly. Through the use of the Pattern Editor and the interactive programming features of TEKTEST III, the Controller can be used to help develop the pattern according to a given algorithm or established logic sequence. If a pattern can be described by a closed algorithm, the test pattern can be generated under software control with the Algorithmic Program Generator.

Pin Assignment Editor. The pins of the device under test are referred to by a reference pin name and coordinated with an Input/Output Sector Card of the tester by program statements. The Pin Assignment Editor assists the programmer in preparing this list. Basic operation of this editor is similar to the Test Program Editor.

The Man/Machine Interface

The S-3260 System includes a Graphic Display Terminal both for input of programs or test data and for output of test results. The Executive portion of the software operating system serves as a coordinator between the input from the terminal and the rest of the system. Since the Executive is a disk-file based system, its operation is very fast. This speed becomes important in the interactive program preparation capability of the Software Operating System.

A major feature of interactive program preparation is on-line editing. Through the Executive, the operator communicates with the software system and receives quick feedback in the form of prompts and error messages. Several interactive loops are provided in the system for on-line editing (see Fig. 4). For example, assume that the programmer enters a program statement. If this statement contains certain errors, an error message is printed on the terminal (Loop 1) even before the programmer can move his fingers to type the next part of the program. This quick feedback allows the operator to make the correction immediately rather than repeating this same error throughout a program. As a result, considerable time is saved in test program preparation compared to off-line program preparation.

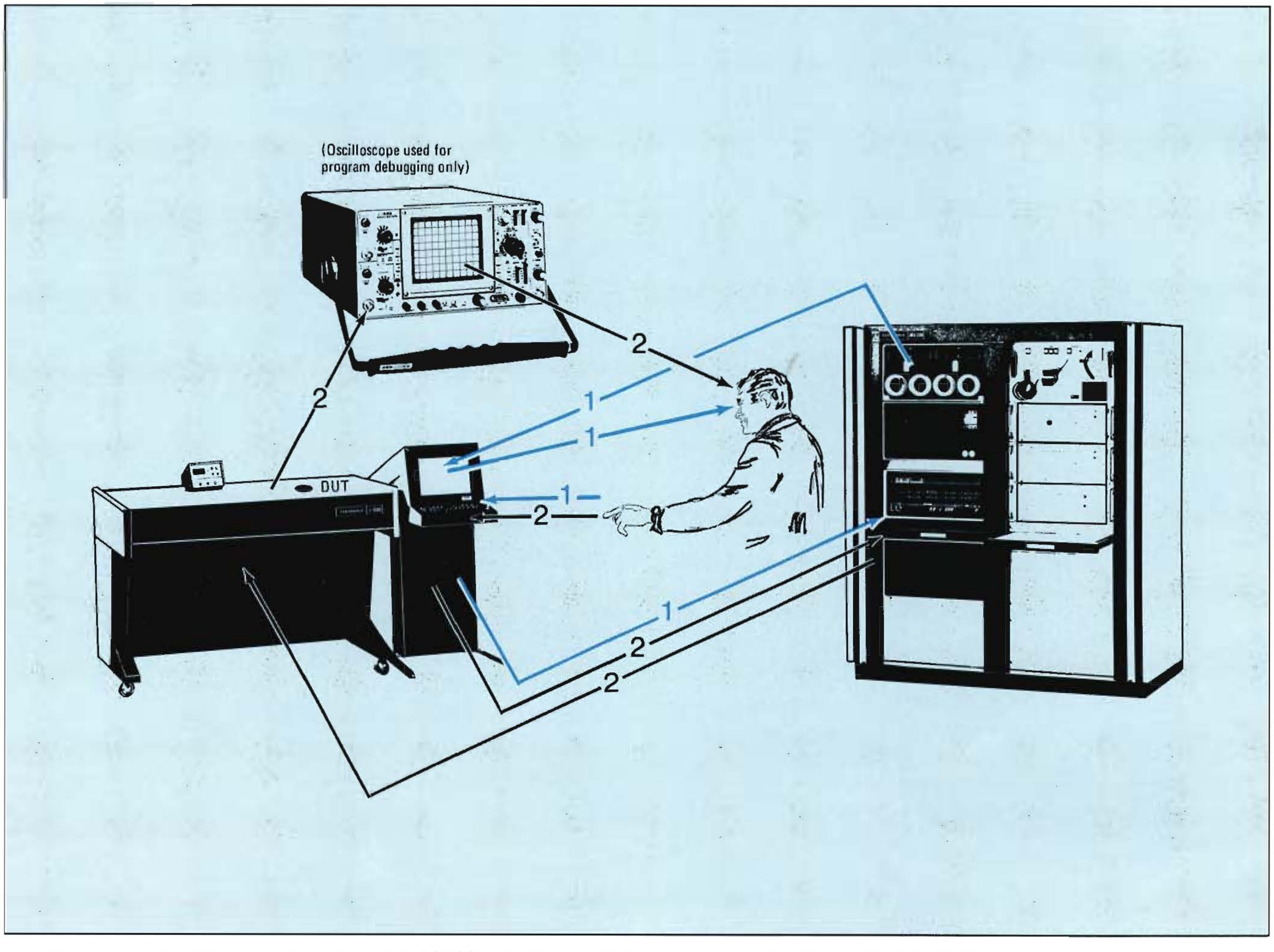


Fig. 4. The Man/Machine interface provided by the interactive program capabilities of TEKTEST III.

A second kind of interaction involves the operator more directly in test program debugging (Loop 2). As part of the system hardware, a buffer channel is provided so that any pin of the device under test (DUT) can be monitored with a test oscilloscope. A trigger output is also provided by the clock generator. This trigger can be programmed to allow examination of an individual data pattern within a functional sequence by the oscilloscope. In this way, the operator is actively involved in the process of program development and debugging.

Command Statements

Command statements consist of three elements; line no., command name, and command argument. A typical example is:

39.00	COMPARE	PINLST WITH TABL99
Line No.	*Command name*	*Command argument*

The line no. identifies the correct sequence of a command statement in the program.

The command name defines the type of operation to be performed.

The command argument can consist of symbols of up to six characters, constants, or arithmetic expressions. The type of command used determines the format of the command argument.

For other examples of typical command statements, see the discussion on the Test Program Editor.

Functional Testing

The concept of functional testing with an automated test system is similar to testing with discrete instrumentation (see Fig. 5). The functional test system consists of three parts: the generator or stimulus, the unit or device under test, and an observing or measuring instrument.

It should be noted that for functional testing with the S-3260 System, the device under test is measured each time the stimulus is changed. This form of testing is often called real-time testing or single-shot testing and should be distinguished from repetitive stimulation required by sampling oscilloscope based systems. Let's examine the three parts of the functional test system for the S-3260 as they relate to the software operating system.

Parameters of the Stimulus. The stimulus source must be characterized by the software in time and amplitude. When sequential or memory devices are tested, the time/amplitude must also be specified relative to a clock cycle. When the device under test contains memory, the input patterns must be applied in specific order to carry the device from one state to another. If memoryless, the input patterns can be applied in any order.

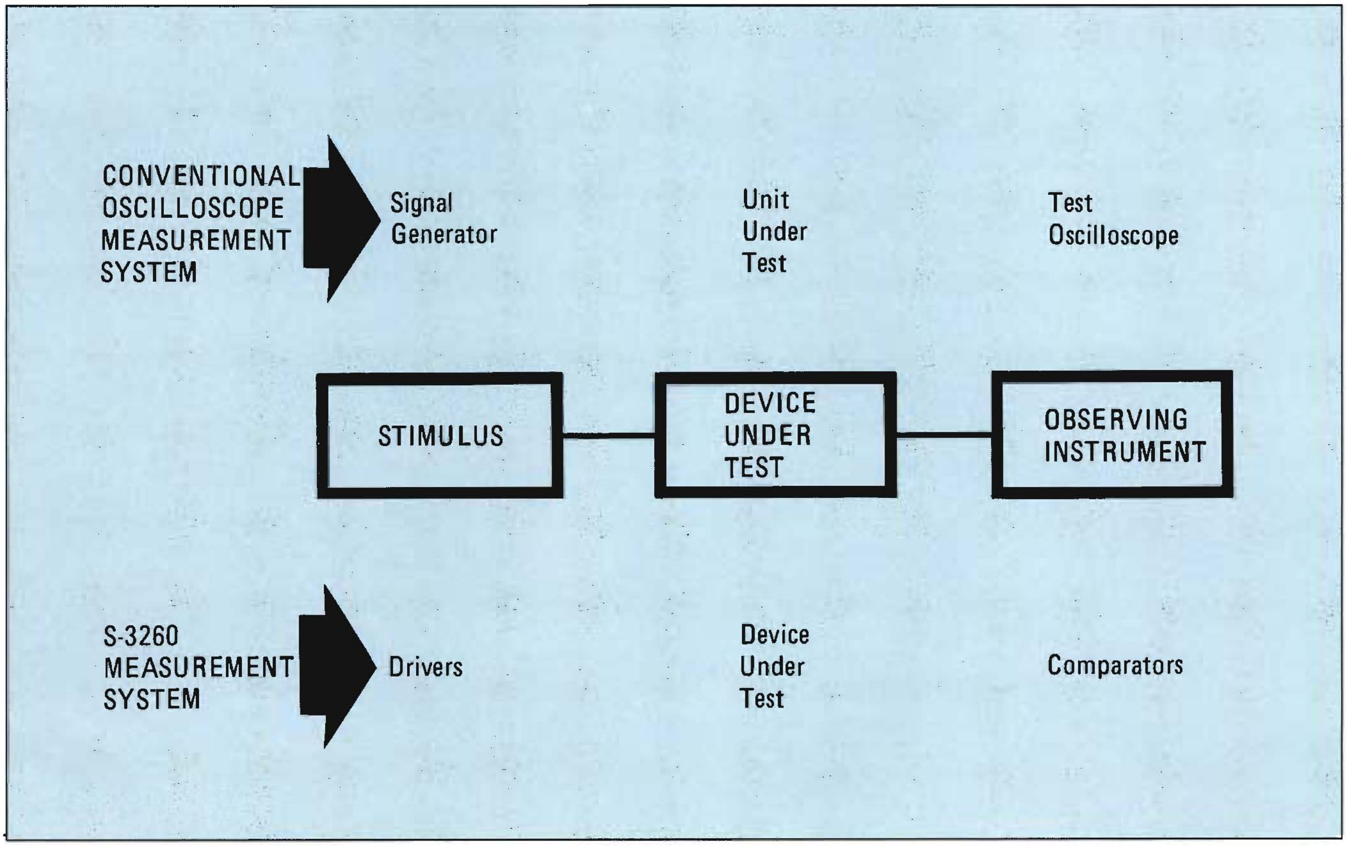


***Fig. 5.** Comparison between S-3260 functional testing system and a conventional oscilloscope measurement system.*

For logic devices the purpose of functional testing is to determine that all meaningful logic states can be reached according to the specified transition rules and that all meaningful inputs produce the desired results.

Environment of the Device Under Test. Interface to the device under test (DUT), can be conveniently broken down into two categories: input and output. The input functions can all be operated through the drivers located in the test station in close proximity to the DUT. This includes input data, address, control, and supply pins.

For functional tests, the output pins are connected to the comparators.

Nature of the Measurement Instrument. The measurement instruments for functional testing are comparators at each Sector Card which make a decision on the basis of expected data and time and amplitude references. The result of the functional test is a binary decision. This decision is communicated to the system Controller which determines the resultant action to be taken in the test program.

Parametric Testing

In parametric testing, current or voltage values or a time interval are measured. Current and voltage measurements can be made separately or while forcing, respectively, a voltage or a current.

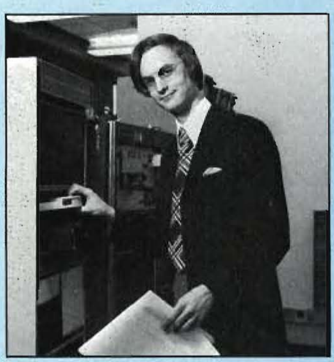
The program for a voltage measurement must specify two pins of the device under test, one of which may be ground. Current measurements must specify the pin of the DUT and the voltage supply between which the current is measured.

Time intervals are measured with the aid of the comparators. When the voltage at a designated start pin passes through a specified reference level, the time-interval measurement begins. It is stopped by a specified transition through a reference level at the stop comparator pin.

The result of a parametric measurement does not have a direct binary decision value. The result of the measurement is an analog quantity which must be compared against specified limits of the test program to diagnose the condition of the DUT. Measured values may be used as arguments in other commands, entered into arithmetic expressions, and be printed or logged as specified by the program.

SUMMARY

In this article, we have seen only a brief over-view of TEKTEST III—the Software Operating System for the TEKTRONIX S-3260 Automated Test System. The real power and flexibility of this new Software Operating System and automated test system cannot be presented within the context of these few pages.[2] What we have seen is that TEKTEST III is a new programming language, powerful enough to control the full range of hardware capability in the S-3260 System, yet easily understood by the systems engineer who may be relatively untrained in computer programming methods. As such, TEKTEST III can become a useful, flexible tool for your automated testing applications.



W. E. Kehret

OUR AUTHOR

Bill joined TEK in 1966 after receiving a B.A. in Physics from The College of Wooster. He has continued his education with graduate study in Electrical Engineering at Oregon State University and is currently participating in a Systems Science Ph. D. program at Portland State University. Prior to his present work in the Automated Systems Group, Bill worked as design engineer in the Sampling and Digital Instruments group and Advanced Product Development.

As leisure-time activities, Bill and his wife Bonnie enjoy sailing, skiing, and tennis.

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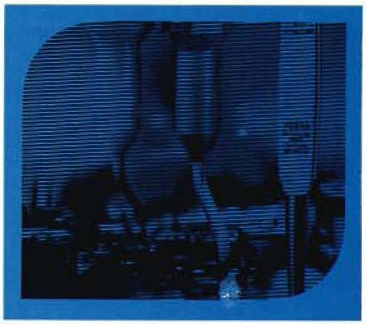
[2] For a complete discussion of TEKTEST III, request a copy of "S-3260 Automated Test System Control Through TEKTEST III Software" from Automated Systems, Tektronix, Inc., Beaverton, OR.

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). Part II dealt with making the differential measurement. The relative merits of the ADDED mode technique and the true differential amplifier were discussed. The use of the differential comparator and DC offset were also covered. In this final article of the series we will discuss the problem of overdriving the amplifier inputs and some seldom used techniques such as the "guarded" input.

PART III

INPUT LIMITATIONS AND GUARDED MEASUREMENTS

Maximum Common-Mode Voltage

The question often arises, "what is the maximum common-mode voltage that can be applied to a differential input?" There is no set answer to this question. This will vary from instrument to instrument. However, we can get a better understanding of this question if we understand the problems involved.

There are two major problems caused by large common-mode signals:

(1) The amplifier stages may be caused to operate in the nonlinear region resulting in degradation of CMR capability.

(2) Component failure may occur in the input circuitry.

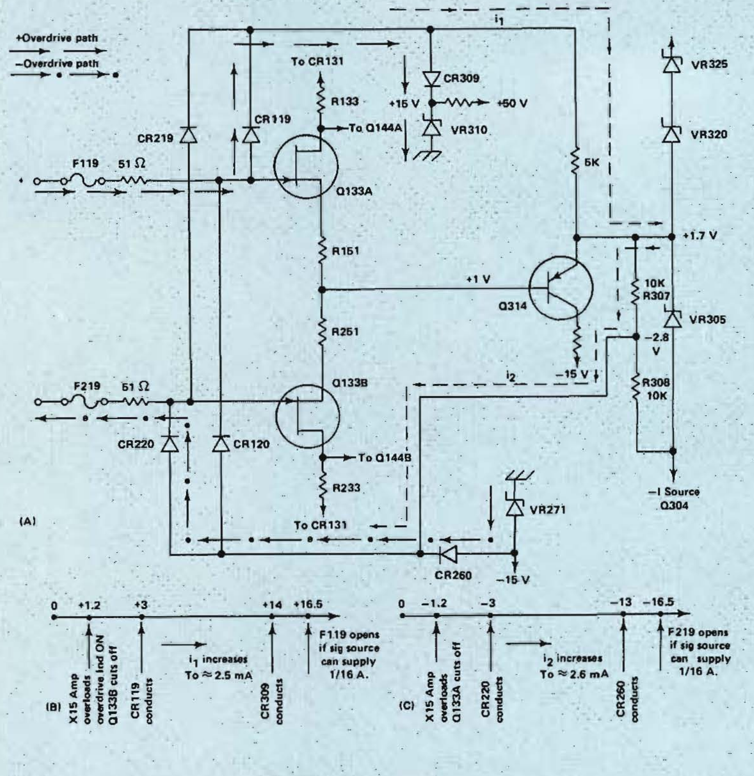
You will recall in Part I of this series there were two methods by which CMR was achieved in a differential amplifier—by the use of an active longtail, or by using a floating power supply for the input amplifier. The longtail method assumed that both the desired signal and the common-mode signal generated separate currents which were operating within the linear design limits of the active device. It stands to reason that large common-mode voltages will drive the input amplifiers into saturation invalidating the CMRR specifications. The same argument can be applied to amplifiers using the floating power supply technique. The mechanism is different but the results are the same.

Most differential comparators and amplifiers provide the operator with some indication of this condition with an overdrive lamp located on the front panel. The lamp indicates an overdrive condition from either signal and/or common-mode voltage.

Common-mode voltage normally takes two forms—a DC voltage common to both inputs, and an induced voltage, either through ground loops or EMI.

It is plain to see that this combination may damage input components, especially in those amplifiers such as the Type 7A22 that do not use attenuators in the most sensitive positions. With this fact in mind, the inputs are normally protected with the use of diode clamps and fuses (NOTE: resistor limiting is not used since component tolerance may upset symmetry). An example of this type of protection is shown in Fig. 1.

It is wise to check that the DC voltages at the point of measurement do not exceed those specified in the manual for common-mode signal conditions. If you must use probes, and invariably you will have to, use only the recommended probes for the instrument and make sure the probes are properly compensated.



There are two different kinds of overdrive associated with the Type 7A22, (a) single-ended overdrive, with one input grounded, and (b) common-mode overdrive, with approximately equal input voltages.

(a) Assume the —input grounded and a steadily increasing voltage on the +input. The chart in Fig. 1(B) indicates the sequence of events: F119 will open if the + signal source can supply 1/16 amp of current. If this much current is not present, the +input remains at +16.5 V, with the overdrive current flowing to ground as shown in Fig. 1(A).

Now assume the +input grounded and a steadily increasing —voltage on the —input. The sequence of events is shown in Fig. 1(C).

(b) For common-mode overdrives the clamping sequence is essentially similar, except the X15 amplifier does not overload, and the current i_2 does not flow until the input reaches approximately —13 V. The fuse opening current paths are shown in Fig. 1(A).

For differential overdrive the action is a combination of the + and — single-ended sequences, with the —input supplying i_2. (In effect the 5 kΩ resistor is connected across the inputs when the differential voltage reaches 3 V). The fuses will not open until one or both inputs reach +16.5 V or —16.5 V.

Fig. 1. (A) Simplified schematic showing input protection for the Type 7A22. (B) and (C) show sequence of events leading to excessive overdrive.

Input Impedance Limitations

In Part I of this series we dealt with the CMR problem where the two source impedances were different. The solution was to remove the 1 MΩ input resistors thereby creating a very high input impedance.

It becomes clear that the higher the input impedance, the better the apparent CMR will be, concluding that if

$$Z_{in(C\text{-}M)} = \frac{\Delta E_{in(C\text{-}M)}}{\Delta I_{in(C\text{-}M)}}$$

then if $\Delta I_{in(C\text{-}M)} \rightarrow 0$, $Z_{in(C\text{-}M)} \rightarrow \infty$.

Clearly if $Z_{in(C\text{-}M)} \rightarrow \infty$, no common mode signal can appear differentially due to an unbalanced source impedance. [Note that ΔI_{in} should be independent of temperature. Removing the 1 MΩ input resistors defines ΔI_{in} in terms of gate current (assuming FET input devices) which will vary with temperature, introducing an offset condition.]

Fig. 2 shows the problem as it exists. Here common-mode currents flow through R_1, Z_1 and R_2, Z_2 together with the desired signal. Imbalance in any of these components will lower the apparent CMR. There are several design techniques that help us approach the desired result of $Z_{in(C\text{-}M)} \rightarrow \infty$. We will examine three solutions: the floating amplifier, the guard, and a technique to increase the apparent input resistance.

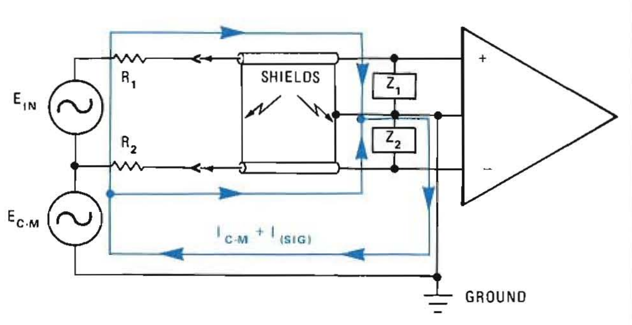


Fig. 2. Diagram showing the influence of the common-mode signal. R_1 and R_2 are the source impedance; Z_1, Z_2 the effective input impedances which include the input RC time constants plus cable and stray capacitances.

The first solution is to isolate the amplifier, thereby removing the common-mode path. This certainly meets our immediate goal (refer Fig. 3). Notice that both input terminals and the floating ground of the amplifier move together both in amplitude and phase with the common-mode signal. This meets our requirement that $\Delta I_{(C\text{-}M)} \rightarrow 0$ since no current will flow through an impedance if there is no potential difference across that impedance.

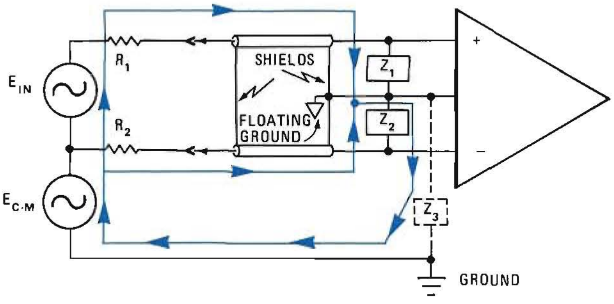


Fig. 3. Diagram depicting the floating amplifier technique. The amplifier effectively floats above ground. R_1, R_2, Z_1, Z_2 are the same components described in Fig. 2. Z_3 is the isolating impedance between the floating amplifier ground and the actual ground. Z_3 which is predominantly capacitive reactance in parallel with leakage reactances, is very large at low frequencies thus inhibiting $I_{C\cdot M}$.

This is an acceptable method of improving the apparent CMR and is widely used by instrument manufacturers. However, it is not the final answer since stray capacitance still can exist between the isolated amplifier and ground. This stray capacitance can be all but eliminated by placing an electrically isolated shield between the floating amplifier circuit and ground. This shield is referred to as the "guard shield." The guard shield is connected to a front panel terminal called the "guard terminal." The method of connection is important, refer to Fig. 4. If your instrument has a guard terminal provided, do not leave the terminal disconnected.

The second solution is the use of the "driven guard". The isolated amplifier method described above relied on the fact that the whole amplifier and its input circuit floated above ground. While this is satisfactory for many applications, in some cases, especially medical equipment, such a technique could be hazardous to the patient's health. Safety requires that the measuring instrument and its environment be referenced to ground.

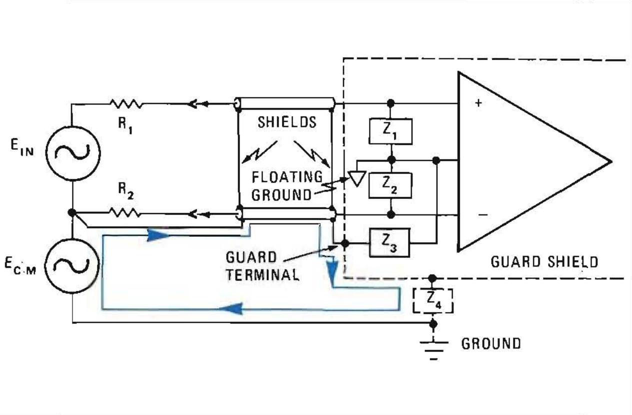


Fig. 4. Diagram showing guarded amplifier technique. Here, the floating amplifier shown in Fig. 3 is isolated by a shield, all but eliminating the impedance Z_3 described in Fig. 3. The net result is that $E_{C\cdot M}$ is confined to the path shown through Z_4, the effective impedance between the guard shield and ground. Z_3 is the effective impedance between the floating ground and the guard shield. Note the method of connection. The cable shield is connected to the guard terminal and the source as shown. The cable shields must be covered with an insulating material.

If the measuring instrument has a differential input, the "driven guard" is a possible solution to common-mode problems. An example of this technique is seen in the TEKTRONIX 410 Physiological monitor, refer Fig. 5. Here the common-mode signal appearing at the FET inputs is coupled through Q111 to the input cables shield. The net result is that both the input circuit and the shield move together in amplitude and phase with the common-mode signal. This meets our initial requirement that $\Delta I_{in(C\text{-}M)} \rightarrow 0$. Q111 acts to isolate the input amplifier from the shield. The emitter circuit of Q111 may be thought of as a guard terminal "driven" by Q111.

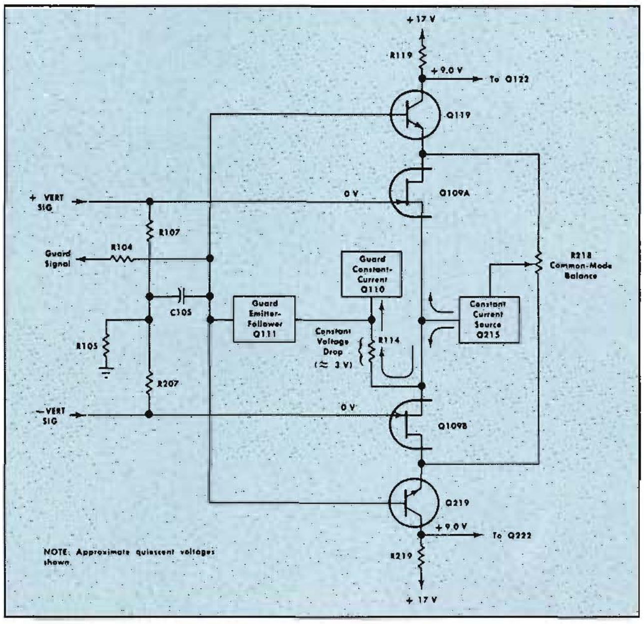
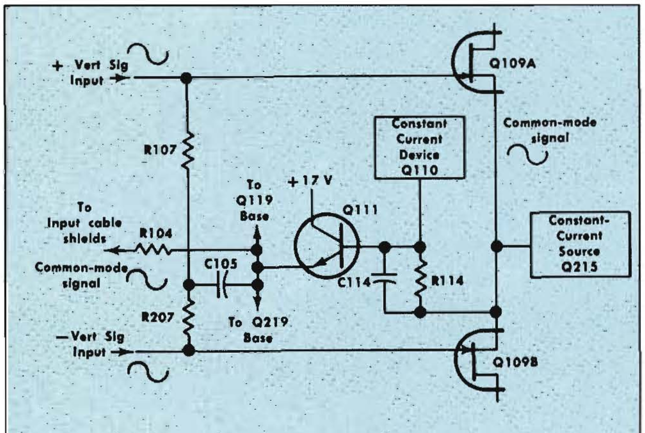


Fig. 5. Simplified diagram of the Vertical Amplifier input stage in the TEKTRONIX 410 Physiological Monitor.

The third solution is to increase the "apparent input resistance." Recall that one method to increase the input impedance is to remove the 1 MΩ input resistors as shown earlier. However this defines I_{in} in terms of the gate current which is temperature dependent. An alternative to this is shown in Fig. 6. Here the common-mode signal is returned to the "lower" end of the input resistors resulting in a theoretical increase in apparent input resistance of 2000 times.

Before leaving the subject of differential amplifiers there is one other technique for improving CMR that we should discuss.



Assume that 99.95% of a 60 Hz common-mode signal applied to the input FET gates is passed through the guard circuit to the R107-R207 juncture. Thus, a 1-volt common-mode signal applied to the inputs produces a 999.5 mV in-phase signal at R107-R207 juncture. With only a 0.5 mV change across R107 and R207 the effect is an apparent multiplication of R107 and R207 values, as shown by:

$$\text{(1)}\quad R_{in} = \frac{\Delta E_{in}}{\Delta I_{in}}, \text{ where } \Delta E_{in} = 1 \text{ Volt and}$$

$$\Delta I_{in} = \frac{E_{in} - E_{guard}}{R107},$$

$$= \frac{1 \text{ Volt} - 999.5 \text{ mV}}{R107},$$

$$= \frac{0.5 \text{ mV}}{R107}$$

$$\text{(2)}\quad R_{in} = \frac{1 \text{ Volt}}{\frac{0.5 \text{ mV}}{R107}}$$

$$\text{(3)}\quad = \frac{1 \text{ Volt} \times R107}{0.5 \times 10^{-3} \text{Volt}}$$

$$\text{(4)}\quad = R107 \times 2 \times 10^{3}$$

For example, applying a value of 10 MΩ to R107 and R207 results in an apparent input impedance of 20,000 MΩ for each side. The value realized in practice is substantially lower, because R107 and R207 are paralleled by many resistive and capacitive leakage paths which cannot be guarded.

Fig. 6. Calculating the apparent input impedance to common-mode signal.

High Frequency Common-Mode Rejection

We normally associate common-mode signals to the low frequencies such as 60 Hz ground loops. However, by definition common-mode signals can occur at any frequency. Common-mode often is seen in signal lines and systems as noise spike, clock pulse and the like. Suppression of these interfering signals often becomes a problem especially when interfacing subassemblies or racks of equipment.

A partial solution to this problem is found by using a balun (balanced transmission line to unbalanced transmission line device).

A balun can take the form of a bifilar wound transformer which can be made to have broadband characteristics. As a result of being bifilar wound, equal and opposite currents due to differential signals generate no net flux, hence encounter no inductance; these signals will pass through the device unattenuated. For common-mode currents the opposite is true, the device acts as an inductance inhibiting these currents. This type of balun often takes the form of a toroid core on which two or three bifilar wound turns are placed. These devices are frequently used in high-speed circuitry (see Fig. 7).

Summary

The differential amplifier can be used to solve many difficult measurement problems. Some are solved most easily using a differential comparator; others require full differential capability with DC offset. Whatever the measurement, satisfactory results depend on the user's knowledge of differential techniques and the limitations of his equipment.

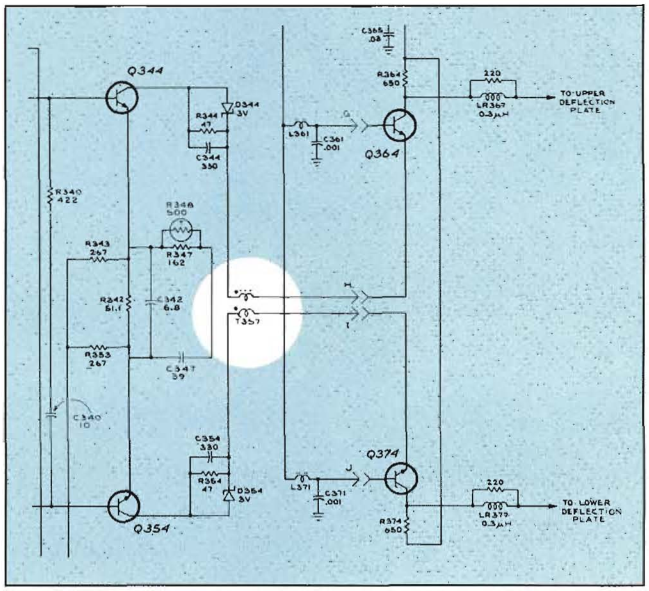


Fig. 7. Partial diagram of the TEKTRONIX 453 Vertical Output Amplifier showing use of a balun device to suppress H.F. interfering signals when coupling between subassemblies.

SERVICE SCOPE

REPAIRING OSCILLOSCOPE PROBES

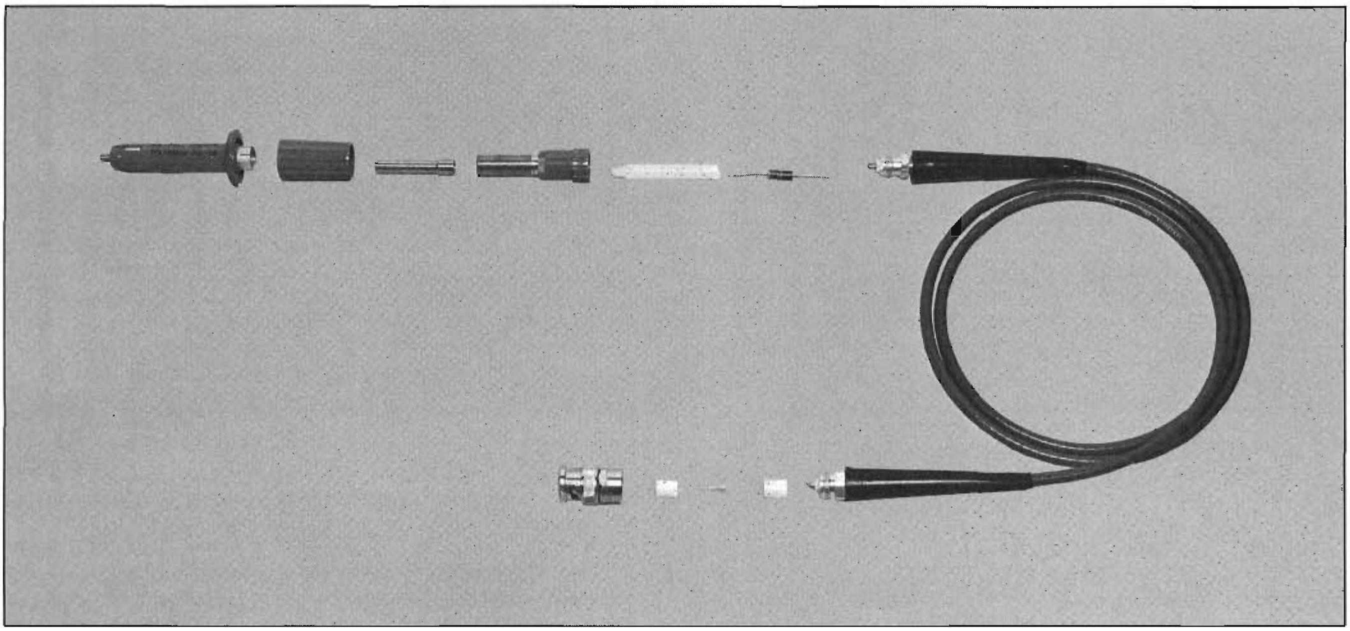


***Fig. 1.** The P6006 Probe disassembled to show the individual parts making up the probe.*

Are there any dusty twenty dollar bills hanging on your test lead rack or laying in the work bench drawer? There probably are but you don't recognize them since they're in the form of oscilloscope probes with open cables, broken probe tips, etc. With just a little time and a few parts you can put those dusty twenty dollar bills back to work for your company.

About this time someone says, "Oh yeah? I've tried repairing those probe cables and you can't solder to the center conductor. It's resistance wire and solder rolls off it like water off a duck's back". He's right, it does so let's try a different approach—let's replace the entire probe cable. TEKTRONIX supplies replacement cables complete with boots and bushings to connect to the probe body and the connector. And you don't have to solder to the resistance wire; a solderable lead or terminal is provided at both ends of the cable. You can usually replace the probe cable in just a few minutes. Sound interesting? Then let's take a more thorough look at probe repair.

There are basically three types of probes to consider: passive voltage attenuator probes, current probes and probes using active devices such as FET's. Passive attenuator probes are by far the most numerous and the easiest to repair so let's discuss these first.

Passive Attenuator Probes

Passive probes are usually designed to provide optimum performance when used with a particular instrument. This results in minor variations in the construction of the different probe types. For example, you've probably noticed the differences in the approach to low-frequency compensation. With some probes you loosen the locking sleeve and rotate the probe body. In others, it's a screwdriver adjustment in the compensating box. Some probes also contain high-frequency adjustments. These are calibrated at the factory for a specific oscilloscope input capacitance. While it's not necessary to check these adjustments as often as the low-frequency compensation, it would be well to check them after performing probe repairs.

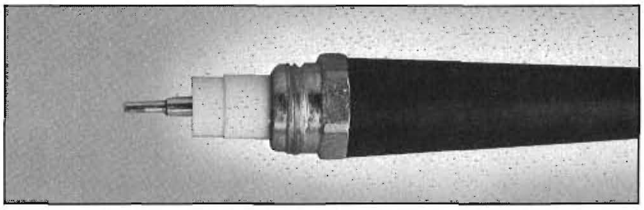


***Fig. 2.** The probe contact pin and insulating bushing on the BNC connector end of the probe cable. Some pins are crimped on, others are soldered.*

The passive probes are easy to disassemble for changing the probe cable. The instructions and exploded view of the probe in the manual are helpful in describing how the probe comes apart. You may have a little difficulty in removing the probe contact pin and insulator bushing from the BNC connector end of the probe cable, especially on some of the P6006's. The usual procedure in assembly is to solder a short piece (about 5/16") of #20 wire to the copper stud on the end of the probe cable. The insulating bushing is slipped in place over the wire, and the probe contact pin is then soldered to the wire extending from the bushing. On some probes the contact pin is crimped on rather than soldered. It is not feasible to salvage these. When you order the replacement probe cable it would be well to order some spare probe contact pins and insulating bushings.

The Needed Items

The first item you'll need for each type of probe to be repaired is a manual. This contains a complete breakdown of the probe assembly, part numbers, schematic, maintenance and calibration details and probe characteristics. Some parts are also made available as part of a subassembly as it is sometimes easier to replace the subassembly than the individual part. The manual usually lists the part number for the subassembly. If you don't have the necessary manuals, contact your nearest Tektronix Field Office.

The only special tools you will need in addition to those normally found on the workbench are a few thin open end wrenches. If not available locally, these can be manufactured by grinding down standard thickness wrenches. The manual will tell you the wrenches needed for the probe being repaired.

The test equipment needed to check high frequency compensation is dependent upon the bandwidth of the probe to be checked. If you don't have the equipment called for in the manual, contact your Field Engineer for alternatives.

CURRENT PROBES

There are three general types of current probes manufactured by TEKTRONIX: high-frequency current probes which use a current transformer permanently wired into the circuitry as a test point, clip-on AC current probes and clip-on DC current probes. We will concern ourself with only the latter two. Let's look first at AC current probes.

AC Current Probes

The two clip-on AC current probes which we will discuss are the P6021 and P6022. They are similar in construction but differ in bandwidth capability and physical size.

The most common problem encountered with these probes is dirt or some other foreign substance on the pole faces, causing poor low-frequency response or noise. The probe should be taken apart and cleaned if you have these symptoms.

The manual describes how to disassemble the probe. However, there are a few techniques which will simplify the task. The probes contain some small parts so it would be well to work with a clean cloth or piece of felt on the workbench to avoid losing parts. You will note that the thumb-controlled slider which opens and closes the transformer core, is spring loaded. As with most spring loaded devices you can experience some surprises when taking the probes apart unless you exercise care.

The first step is to remove the rubber boot at the end of the probe body. With the probe body held in the left hand, firmly grasp the boot with the thumb and forefinger of the right hand on the sides of the boot and working the boot from side to side slide it to the rear. It's a firm fit and will take a little effort.

Next, carefully lift the upper half of the probe body slightly at the rear and slide it off the front of the probe. Here's where the surprises come in. You will need to keep firm pressure down on the thumb cam of the slider or the slider spring will pop the slider out. This is especially true of the P6022. The next thing to watch for is the small metal ball setting in a detent on top of the slider. It's easy to lose this unless you're working over a surface where the ball won't roll. Remove the ball if it hasn't already fallen out.

You may have difficulty getting the top cover over the probe nose on the P6021. This is due to the insulating sleeve in the lower transformer core. Squeezing the top and bottom of the front portion of the top cover will help in removing the cover. Remember this also when you reassemble the probe.

To remove the slider it's best to turn the probe so that the slider portion is on the bottom. This prevents the components in the slider from falling out. With the P6022, you will probably want to remove the spring and spring retainer before turning the probe over to remove the slider.

It is a simple matter to remove the printed circuit board and current transformer in the P6021. After removing the two Phillips-head screws securing the plastic spring retainer, just pull up gently on the cable at the rear of the probe. Lift the circuit board, transformer, and cable straight up out of the probe body as a unit. A scribe can be used to work the header free at the front of the circuit board if necessary. When replacing the Phillips-head screws, tighten them so they are just snug; excessive torque will strip the plastic threads.

It's a little more of a chore to remove the board and transformer in the P6022. There are two points you will need to unsolder before lifting out the cable, board, and transformer as a unit. You should use a small iron to avoid applying excessive heat to the cable and printed circuit board.

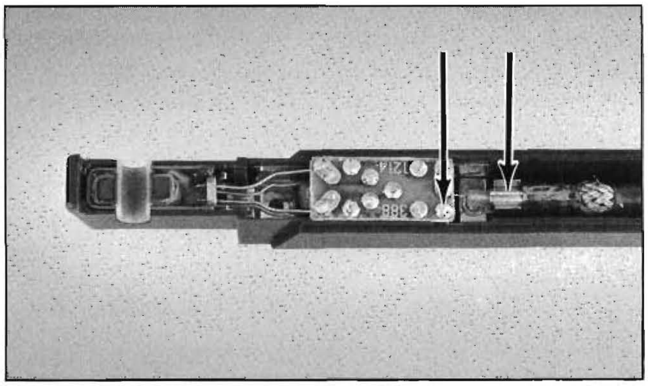


Fig. 3. *Arrows point to the two points to be unsoldered in the P6022 when removing the cable, circuit board and transformer.*

Cleaning The Transformer

The transformer pole faces and the surrounding mu-metal shield should be clean and free from scratches. There are a number of methods you can use to clean them. A soft bristle toothbrush with a rubber gum-massage tip works well. The rubber tip is used to clean the pole faces and the brush to remove the residue and dust. Another technique used to clean the pole face is to use a hard-surfaced piece of paper such as coated stock. Lay the paper on a flat surface and rub the pole piece back and forth in a polishing motion. Brush away any loose particles. Sometimes a bright spot of metal will adhere to the pole face. This can be removed by a sharp tool such as a scalpel or X-acto knife, being careful not to scratch or gouge the pole face. Once you have the surfaces clean, avoid touching them with the fingers.

Before reassembling the probe, place a minute amount of Lubriplate or similar lubricant to the contact area of the grounding tabs on the slider. This assures smooth operation and eliminates squeaking of the slider. If you have replaced any components, or the probe cable, the high-frequency response should be checked using the procedure in the manual. You will find the short-pulse technique described in the January, 1971 issue of TEKSCOPE helpful in adjusting the pulse response.

The DC Current Probe

Now let's take a look at the P6042 DC Current Probe. The construction of the DC current probe is similar to that of the AC probes with the exception of two small screws on the bottom of the probe body that must be removed to disassemble the probe. You should use care in removing the printed circuit board and transformer as the wires in the multi-conductor cable are small and easily broken.

The probe is permanently attached to a unit containing the power supply, amplifiers and degaussing circuitry. It also provides convenient storage for the probe. Since this unit houses all of the active devices except the Hall-effect device, it is the most likely place to suspect trouble if the probe malfunctions.

The Current Probe Amplifier

The amplifier consists of essentially two amplifiers—low frequency and high frequency. The output of the Hall device in the probe is fed into the low-frequency amplifier. The ouptut of this amplifier passes through the current transformer in the probe, which provides the high-frequency portion of the signal. The combined signals then pass through the high-frequency amplifier to the output connector.

The front panel DEGAUSS switch provides a convenient means of isolating the low-frequency and high-frequency amplifiers. Holding the DEGAUSS switch depressed, you can check the DC operation of the high-frequency amplifier by rotating the OUTPUT DC LEVEL knob and noting that you have control of the output DC level. The high-frequency operation can be checked by uncoupling the attenuator lead at J80 and feeding an external RF signal into J80. A cable with a female BNC on one end and a male Selectro Connector on the other is handy for this purpose (Tektronix Part No. 175-0419-00).

If the entire system is badly unbalanced DC-wise you may have a broken wire in the probe. Also check the probe wires where they terminate in the amplifier unit. Remember that the probe slider has to be completely closed to get a signal on-screen. If you find it necessary to pull the low-frequency amplifier stages Q44, Q45, or Q53, Q54 which are mounted in heat sinks, be sure and turn off the power first. They are easily damaged if removed with the power on.

The Degaussing Operation

It is necessary to degauss the probe frequently and it is important that the degaussing circuit work properly. The General Radio 50 Ω terminating loop called for in the list of calibration fixtures in the manual, provides a convenient means of feeding the degaussing signal into the test scope. Use a GR-to-BNC adapter to connect the current loop to the input of the scope; then clip the current probe around the loop and depress the DEGAUSS switch. (You will need to activate the interlock switch in the probe storage compartment.) You should see a damped sine-wave signal about 400 mV in amplitude and 200 ms in duration. In some units the amplitude is reduced to about 100 mV or less if the DEGAUSS switch is depressed slowly. This can be cured by adjusting the degaussing switch contact that is connected to the lead going to square pin H on the etched-circuit board.

To complete the discussion on the DC current probe we would like to note a change in the manual calibration procedure. Step 9 (e) under Adjust CURRENT/DIV BALANCE Range should be revised to read, "Adjust both R16 and R17 for a CURRENT/DIV BALANCE range of ±55 ma". Both R16 and R17 will be near mid-range when the adjustment is correct.

Repairing FET Probes

The new high-frequency FET probes available today pack outstanding performance in a very small space. Because of the sub-miniature parts and close physical tolerances needed to construct such a probe, extreme care is required during servicing. We recommend you return these probes to the factory for repair.

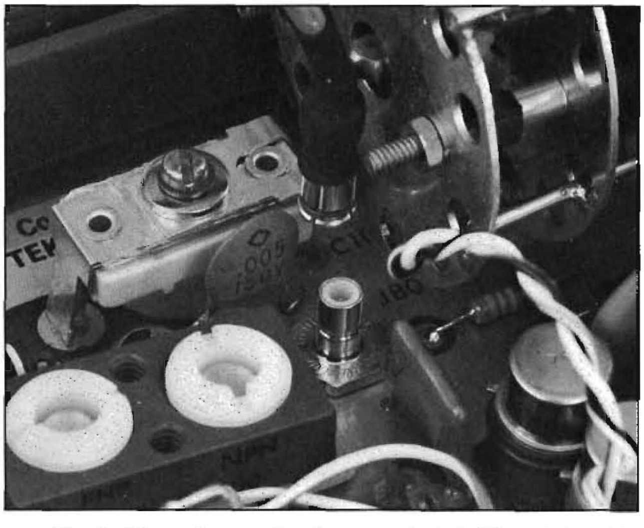


Fig. 4. Attenuator can be disconnected at J80 and signal inserted to check high-frequency amplifier of the P6042.

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Customer Information from Tektronix, Inc., P.O. Box 500, Beaverton, Oregon 97005

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R564B (5 ea.), 2A60 (10 ea); still in original container. Make offer. Smith Kline Instruments, Inc., Tony Escabar, 440 Page Mill Rd., P.O. Box 10577, Palo Alto, CA. 94306. (415) 321-9200.

535A/CA/L/Scope Cart. Walt Stansbury, Director Engineering, KOLR-TV, Springfield, MO. (417) 862-7474.

Telequipment TLD54. Lou Toth, GTE Information Systems, Boulder, CO. (303) 449-7800.

INSTRUMENTS FOR SALE

7704. Fred McNeil, XYTEX Corp., Boulder, CO. (303) 447-2531.

585 (3); 535; 82 (2); 86; MC; 53/54G; Telequipment D52 (3). Gene Lowrance, Zeta Research, Inc., 1043 Stuart St., Lafayette, CA. 94549. (415) 284-5200.

581A/82, $1050. W. Soffner, 3209 Valley View, W. Covina, CA. 91792. (213) 964-3709.

531A/CA/Scope Cart, pkg. price $650. St. Joseph Light & Power Co., 520 Francis, St. Joseph, MO. 64502.

564 Mod 115B; 3C66; 2A63. Sell or trade. Carl Hagerling, 2273 Grandview Ave., Apt. 3, Cleveland, OH. 44106. (216) 462-2947.

2A63, $175. (unused). Harry Mark, Dept. of Chemistry, Univ. of Cincinnati, Cincinnati, OH. 45221. (513) 475-3672.

517A. Make offer. Howard L. Foot, Univ. of Rochester, Physics Dept., Rochester, NY. (716) 275-4383.

555, 21A, & 22A. Don Branz, Warner Electric Brake & Clutch Co., 449 Gardner St., S. Beloit, IL. 61080. (815) 389-3771, Ext. 373.

575/cart, $650. Exc. cond. Bob Fredericks, P.O. Box 104, Essex Junction, VT. 05452. (802) 372-4417.

547/CA/W, $1100. P. Prossen, 5231 Loyola Ave., Westminister, CA. 92683. (714) 892-6049.

422, $900. Dennis Eveland, 27310 Seco Canyon Rd., Saugus, CA. 91350. (213) 469-1173 or (805) 259-2617.

575 Mod 122C w/all adapters. Exc. cond. AirComm Engineering, Inc., Griffin, GA. 30223. (404) 227-1442.

575, Exc. cond, Reas. David L. Bowler, Dept. of Engineering, Swarthmore College, Swarthmore, PA. 19081. (215) 544-7900.

524AD. Richard Olson, 323 East 33rd St., Erie, PA. 16504. (814) 866-1731.

TU-2, $30; 84, $50; D, $30; H, $50; L, $90. All in good cond. Don Necker, 4520 Graywood, Long Beach, CA. 90808. (213) 425-4259.

INSTRUMENTS FOR SALE

453, $1495. William Stevens, P.O. Box 218, Shelburne, VT. 05482. (802) 985-3341.

511AD, $150. Lesly W. Williams, 2866 N.W. 34th Tr., Ft. Lauderdale, FL. 33311. (305) 731-7013.

545A / 1A6 / CA / P6013 Probe / Camera / Scopecart, $1000. F. H. Bratton, P.O. Box 345, Marian, VA. 24354.

524AD/Scope cart/ (2) 10X probes, $375. R. J. Files, Diocesan TV Center, 1345 Admiral Lane, Uniondale, NY. 11553.

611. George Thielen, General Air Freight Corp., P.O. Box 66102, Chicago, IL. 60666. (312) 678-5000.

422s (20 ea). Dan Sullivan, Tally Corp., 8301 S. 180th St., Kent, WA. 98031. (206) 251-5584.

INSTRUMENTS WANTED

519 w/camera. George Busch, Univ. of Colorado, Chemistry Dept., Boulder CO. 80302. (303) 443-2211, Ext. 6292.

564B in good cond. Mr. Rea Gault, Detroit Testing Labs., 12800 Northend Ave., Detroit, MI. 48237. (313) 398-2100.

502A or 530/540 Series Oscilloscope. J. A. Sippel, Flow Technology, Inc., 401 S. Hayden Rd., Tempe, AZ. 85281.

200-2 Scope Carts (3). Will pay $65-80 ea depending on cond. Ronny Brown, (516) 293-4100.

Telequipment D67, D54, D66, or DM66 in good cond. R. W. Ames, 132 Evergreen, Tonawanda, NY. 14150.

Telequipment S54, D54, or D67. Lloyd Vincent, (800) 443-2701, Ext. 43.

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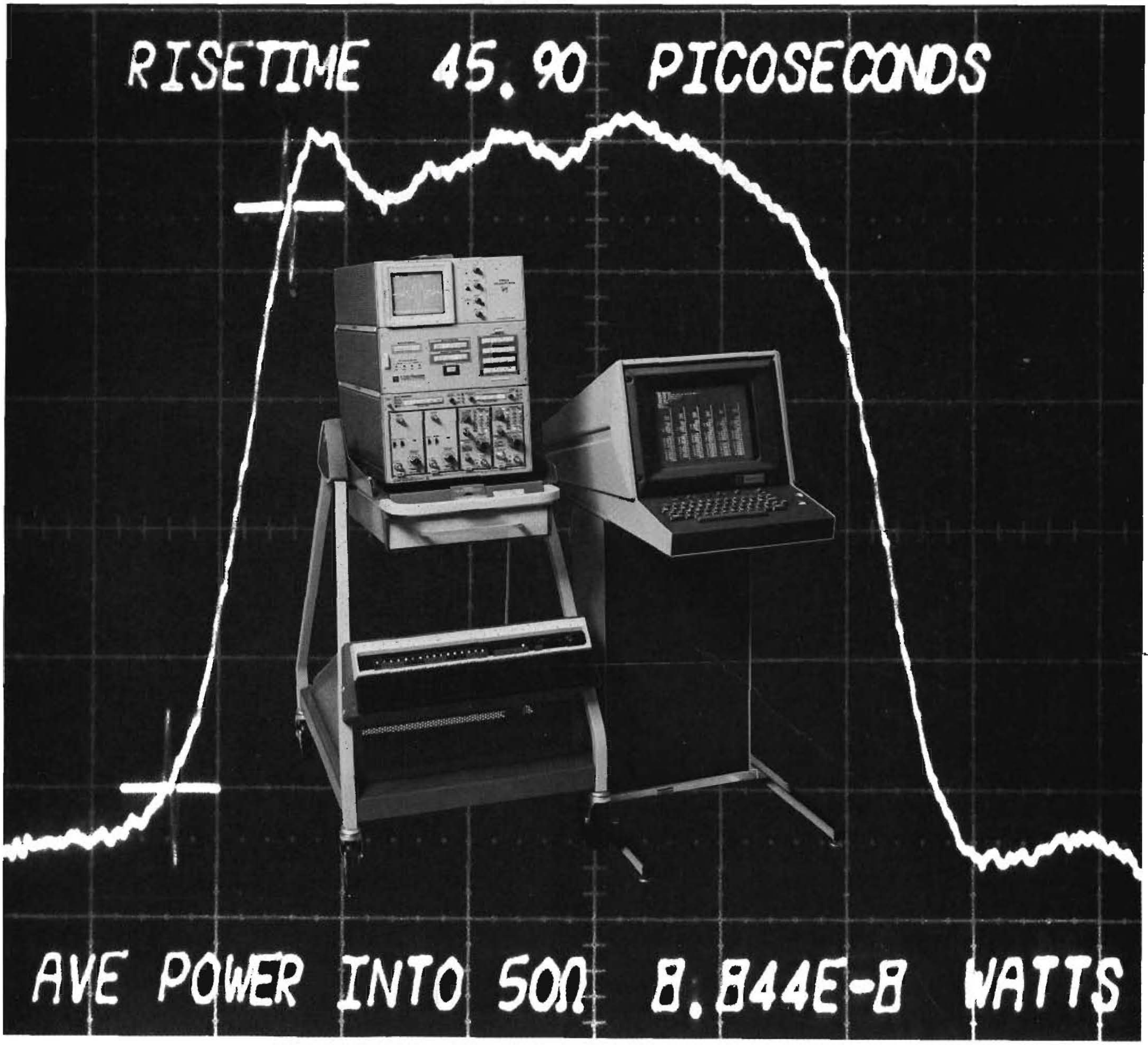
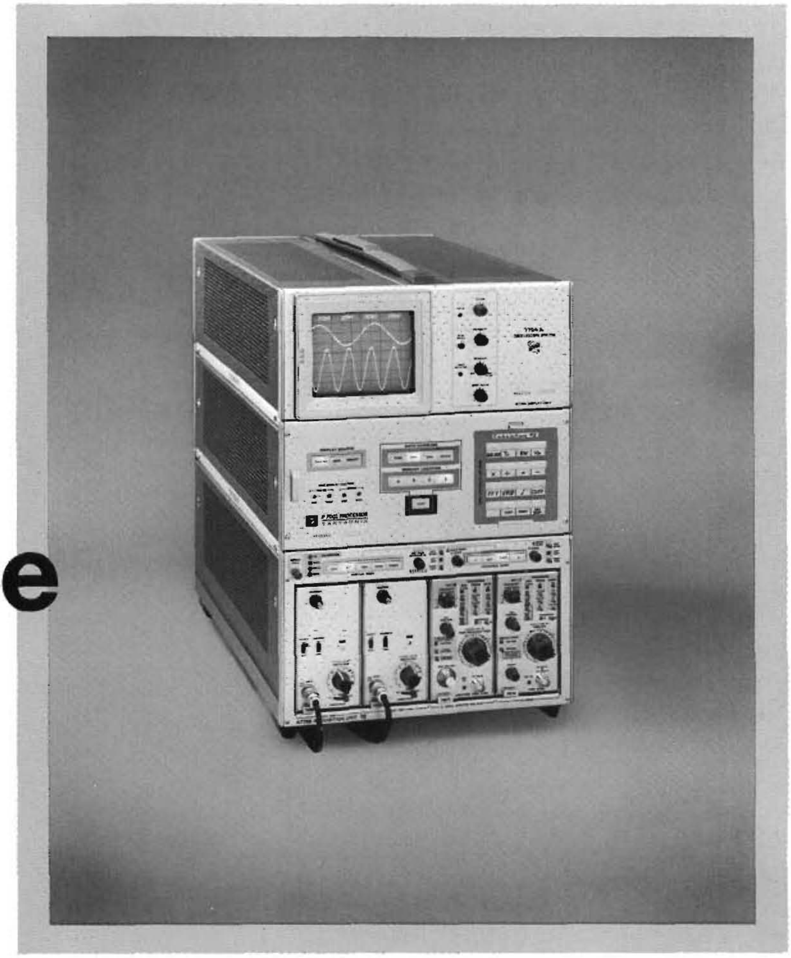
TEKSCOPE

MARCH/APRIL 1973



- THE OSCILLOSCOPE WITH COMPUTING POWER
- PORTABLE POWER
- PRESERVING SCOPE BANDWIDTH AND SENSITIVITY
- SERVICING THE 7T11 TRIGGER CIRCUIT

The Oscilloscope with Computing Power



by *Hiro Moriyasu*, *Luis Navarro*, *Jack Gilmore* and *Bruce Hamilton*

The miracles of electronics—from computers and moon walks, to color television and 6-minute baked potatoes—have one thing in common. They are possible because of the oscilloscope. This instrument, more than any other, has opened the door for scientific advancement. And now it seems destined to open that door still wider.

For the first time, the oscilloscope has acquired the calculating power of the computer. Not as an "add-on" capability but as an integral part of the measuring function.

The groundwork for this propitious marriage of the oscilloscope and the computer was laid over two years ago when design work started on the 7704A Oscilloscope. With over thirty plug-ins available for signal acquisition and display, the 7704A would be an ideal candidate for such a marriage. Accordingly, the 7704A was designed for modular construction. The top module, or display unit, contains the CRT, high voltage power supply and output amplifiers. The lower module, or acquisition unit, contains the CRT Readout circuitry, the low voltage power supplies, and houses the plug-in units.

Cover: *The measurements indicated by the CRT READOUT were made by computer. The signal was acquired and displayed by the new Tektronix Digital Processing Oscilloscope pictured in the center.*

Between these two units we have inserted a third module which we call the P7001 Processor. This unit digitizes the acquired signal and provides storage and interface to a powerful minicomputer.

These three modules—acquisition, processor and display, combine to form what we call the Digital Processing Oscilloscope; the most powerful general-purpose measuring tool available to scientists and engineers today.

Since the Processor is the key unit in the new Digital Processing Oscilloscope we will want to discuss it in detail. But before we do, let's consider some of the things this new tool can do.

- The full versatility of the 7704A as a conventional oscilloscope is retained and enhanced.
- Signal Averaging may be performed to extract signals from noise.
- Small aberrations caused by signal acquisition may be removed by the process of deconvolution using the Fast Fourier Transform algorithm in the Processor.
- Fast Fourier Transforms and Inverse Fast Fourier Transforms can be performed and the signals displayed simultaneously in *both* the time and frequency domains.
- A signal may be viewed after passing through an arbitrarily constructed digital filter that may not even be realizable in conventional circuitry.
- Processed waveforms may be operated upon, automatically scaled and assigned with nonelectrical units to present data in its most convenient form.
- Results of CAD (Computer Aided Design) analysis can be presented on-screen simultaneously with the actual waveforms produced by a real circuit, for a one-to-one comparison.

To get a clearer picture of what adding a computer to the oscilloscope can do for us let's take a closer look at one of these applications—that of performing signal averaging to extract signals from noise. Suppose the task is to measure the risetime of, and power contained in, the noisy signal pictured in Fig. 1. Using a conventional oscilloscope, it would be a difficult and time-consuming task with little confidence in the accuracy of the results. Now take a look at Fig. 2. This is the same signal as in Fig. 1 after being digitized by the Processor, routed to the computer for averaging of 1000 sweeps and then returned to the scope for display on the CRT. Note that the vertical deflection factor has been automatically scaled to fill the screen for optimum display resolution. Now, by pressing a single button on the P7001 Processor we can direct the computer to calculate the risetime and display it using the CRT READOUT. Markers are inserted on the waveform to indicate the 10 and 90% points selected by the program. Pressing another button directs the computer to calculate the average power the signal will deliver to a 50 Ω load. This is displayed at the bottom of the screen by CRT READOUT (Fig. 3). Both risetime and power are accurately measured in a matter of seconds. How long would it have taken you using conventional means?

Let's consider another example from the field of electronics. Suppose a circuit design engineer needs to determine the power generated within a transistor at each instant during some event. He can readily measure the collector current, I_C, and the collector-emitter voltage, V_{CE}. At any one instant the power is simply the product of these two variables; but if for his purposes the event consists of 500 instants—you see the problem. The arithmetic will take awhile. TEKTRONIX' new Digital Processing Oscilloscope will multiply these two waveforms and display the product, as another waveform, without delaying the engineer, (Fig. 4).

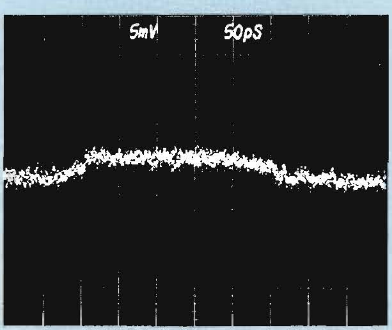


Fig. 1. *A noisy signal as acquired by the 7704A.*

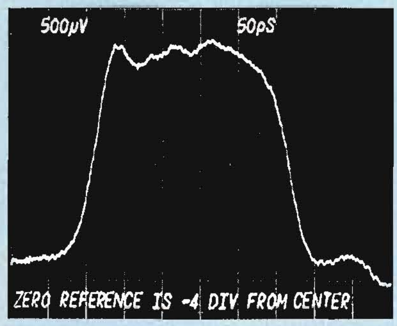


Fig. 2. *The same signal in Fig. 1 averaged 1000 times by the computer.*

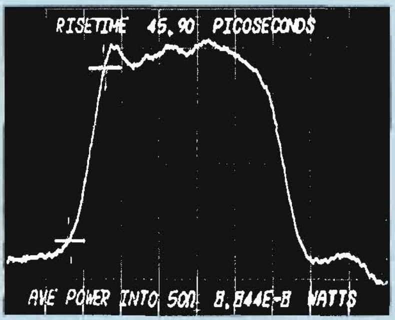


Fig. 3. *The computer calculates risetime and average power and displays it using CRT READOUT.*

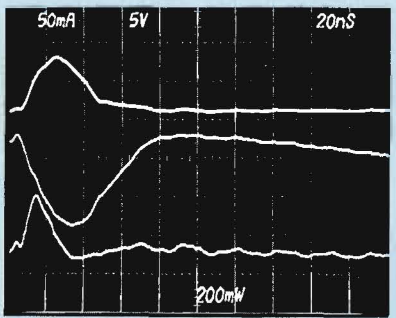


Fig. 4. *Voltage and current waveforms are multiplied by computer. Lower trace is resultant power waveform.*

Now let's take a look at the unit that makes these new measurements possible—the P7001 Processor.

Processor Architecture

The P7001 Processor is designed to provide maximum flexibility as a computer interface unit without degrading the performance of the basic 7704A Oscilloscope. The block diagram (Fig. 5) shows the architecture used to achieve this objective.

Basically, the Processor consists of two major parts: a Signal Interface and an Asynchronous Bus. The Signal Interface which controls the Display Unit receives its data from the Acquisition Unit and a variety of functional devices, 4½″ x 11″ EC Boards, which are plugged into the Asynchronous Bus.

The Asynchronous Bus allows the devices that are plugged into it to work independently from each other. Thus, the devices may be added or removed, as required, in order to achieve the configuration best suited to the problem at hand.

The configuration shown in Fig. 5 shows a typical mix of devices. The six devices shown use a total of eight of the eleven device positions available in the bus. Each device position consists of a single 72-pin edge connector which provides parallel access to power supplies, address, data and control lines.

A serially connected line, or daisy chain, in the bus establishes device priority. Connections are available at each device location for input and output of signals. Signals requiring wide bandwidth and/or low noise paths are routed directly from device to device via coaxial cables.

SAMPLE and HOLD and A/D CONVERTER

The heart of the Processor is a three-axis pseudo-random sampler and an A to D converter allowing simultaneous storage of up to four different waveforms, each in allocated and predesignated memory locations (A, B, C, D).

On an acquired signal the vertical axis is sampled every 6.5 microseconds and the two other major axes, horizontal and blanking, are sampled 95 nanoseconds later. This effectively displaces the vertical sample, in time, to the right of the original. A delay line in the display unit displaces the real time vertical by the same amount and thus coincidence of real time and stored signals is maintained when they are simultaneously displayed. Sampling clock noise (FM) is sufficient to eliminate nulls in the system response that would otherwise appear at harmonics of the Nyquist frequency.

The vertical sample of the acquired waveform is converted by a 10-bit successive approximation A to D converter to one of 1024 possible levels which correspond to ten CRT divisions, eight of which are displayed.

The A to D converter then converts the horizontal sample to one of 512 horizontal memory positions which correspond to the ten horizontal divisions on the CRT faceplate. However, if the blanking sample indicates that the CRT was blanked (retrace, channel switching, etc.) when the vertical or horizontal sample was taken, the converted data is discarded. Conversely, if the CRT was unblanked, a memory address is generated by adding the horizontal binary address to the location code (of A, B, C, or D) and the vertical binary word is stored at that address in the Processor memory.

The location code used to generate the memory address is derived from one of two sources, depending on whether or not multiple waveforms are being stored. If a single waveform is specified, a single memory location is used. If multiple waveforms are specified, the source codes are compared with the specified locations, and, if a match is found, the source codes are used as the location codes. If no match is found, the data is discarded. An additional data acquisition mode is available. The computer may, at any time, obtain directly from the A to D converter the value of the last vertical sample. This allows inputs of unchanging data in a single operation or construction of arrays consisting of more than 512 elements of slowly varying data.

PROCESSOR MEMORY

A 4K x 10 bit non-volatile core memory in the Processor serves to store data and act as a buffer for computer I/O. The memory stores acquired waveforms and scale factors for display and computer input, and stores computer

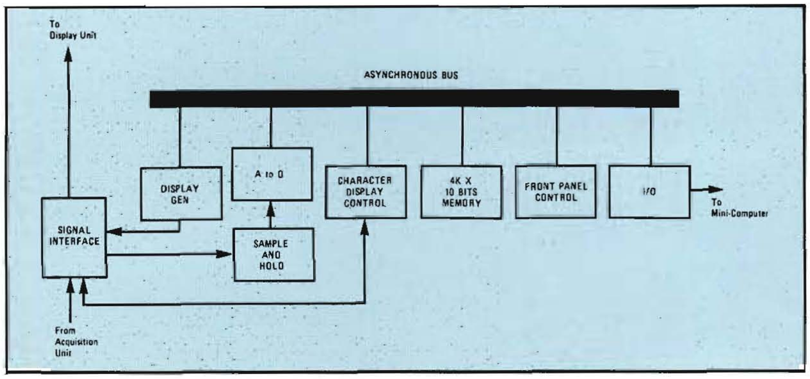


Fig. 5. Block diagram of the P7001 Processor.

output for display on the CRT. Data acquisition independent of I/O speed, and flicker-free displays are a result of this local memory.

I/O DEVICE

The I/O device provides a bilateral Processor-Computer link. The computer has full access to the Processor through the I/O device and the Processor, in turn, may interrupt the computer at any time.

DISPLAY GENERATOR

The Display Generator device is used to generate a CRT display of real-time computer output or data stored in the Processor memory. Any combination of four stored waveforms and four possible acquired waveforms may be displayed simultaneously. Also, since the display generator operates independent of other devices, changing data may be viewed during a store operation.

Two display modes are available: Y versus time (Y-T) and X versus Y (X-Y). In the (Y-T) mode, all specified memory locations (A,B,C,D) are examined sequentially by address (0-511) and all non-zero points in the array are plotted. In the (X-Y) mode, each point is plotted when directed by the computer, thus enabling the computer to generate a refreshed display of multi-valued functions (spirals, for instance).

Normally, a linear interpolation is made between the plotted coordinates, enhancing the intelligibility of rapidly varying plots or plots containing a few data points. If a point plot is desired, a strap option is easily installed on the display generator board at pins provided for this purpose.

When a STORE operation is initiated, all contents of the specified memory location (A,B,C, or D) are set to zero. Since the display generator will display only non-zero points, useful plots of single events may be generated even if the sweep speed is such that only a few points are acquired.

CHARACTER DISPLAY CONTROL

The character display control device allows use of the full character set of the 7704A for both computer input and display on the CRT. In the STORE mode, the Acquisition readout information is converted to ASCII and stored in the Processor memory, providing a permanent record of waveform scale factors. Thus, whenever a stored waveform is displayed, so are its scale factors.

Sixteen 80-character messages may be stored in the Processor memory locations. Four locations, A, B, C and D, are addressable from the front panel and normally contain only scale factors. The remaining twelve locations may contain messages from the computer to the operator and these messages, once stored, may be displayed with a single computer command.

FRONT PANEL CONTROL

Now let's take a look at the controls on the front panel of the Processor (Fig. 6). Pushbuttons on the front panel access logic circuits in the Processor, which in turn provide for simple control of the oscilloscope and its computer interface. Each time a new mode is selected such as STORE, START, etc., the Processor generates a computer interrupt which allows interaction between the operator-processor and the computer. The computer is in constant awareness of Processor status and, through the lighted pushbuttons, the operator is constantly informed. The pushbuttons are also controlled by the I/O to inform the operator of computer-initiated operations.

Ten of the twenty-eight front panel pushbuttons directly control the Processor. Two buttons set the status to STORE or HOLD, four buttons are used to designate the affected waveform memory location, A, B, C, or D, and three buttons set the CRT display source to PLUG-INS, BOTH, or MEMORY.

The START button is used to initiate any Processor or computer mode which will destroy previously stored waveform data in A, B, C or D and thereby reduces the possibility of inadvertent destruction of stored data.

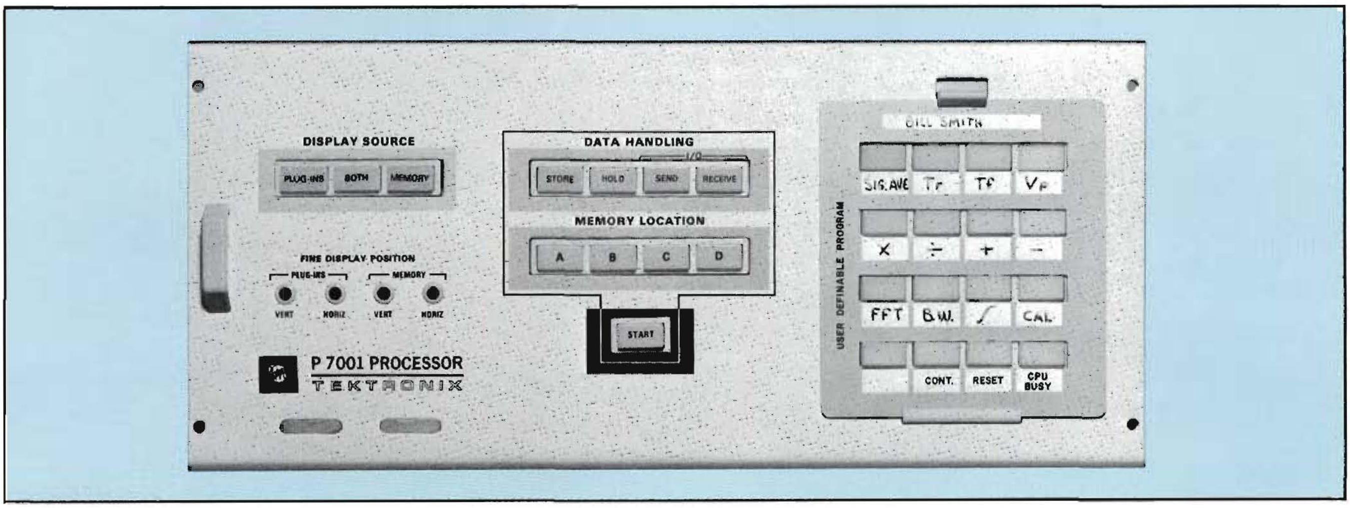


Fig. 6. Control panel of the P7001. A user-definable program overlay permits tailoring the program call buttons at right to your specific program.

The remaining eighteen pushbuttons are used to request computer action. The SEND and RECEIVE buttons direct the computer to input from the P7001 or output desired waveforms. Each time SEND or RECEIVE is used, the Processor is set into a HOLD mode, the acquired data is retained, and with a START command an interrupt is sent to the I/O unit. The 16 PROGRAM CALL buttons are used to direct the computer to execute user-definable programs and do not directly affect the Processor.

The computer, through I/O control, can access any individual device in the Processor and change any of its modes. This allows, under program control, operations such as simultaneous storage in, and display from, different memory locations. In addition, single sweep reset and end of sweep interrupt are available to the computer allowing further programming flexibility.

SOFTWARE

The software provided with the Digital Processing Oscilloscope plays an important role in the usability of the system. The language BASIC was chosen as a starting point for the software because it is a simple, interactive language that is easy to use. You can write a program, run it, modify the program, and run it again without reentering or recompiling the program. Some of the features of BASIC were expanded to adapt the language to the needs of the Digital Processing Oscilloscope. New statements were added to improve waveform processing, and special features were added to support the hardware. Wherever possible, the software was designed to minimize waveform storage requirements and speed up waveform processing. The software is called APD BASIC and is written for the Digital Equipment Corp. PDP-11 series minicomputers.

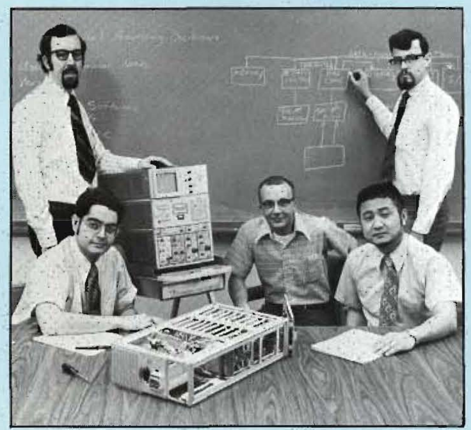
Summary

The Digital Processing Oscilloscope is a new concept in measurement capability. The calculating power of the modern computer is married to the waveform measuring power of the modern laboratory oscilloscope, creating a powerful new measuring tool. Signals that previously were difficult or impossible to measure are now displayed and measured with ease. Two or more signals can be combined to yield results that formerly required hours of computation. Signals displayed in the time domain can be quickly transformed to the frequency domain for further analysis. These, and many other measurement capabilities, are yours at the push of a button, with the new TEKTRONIX Digital Processing Oscilloscope.

ACKNOWLEDGEMENTS

As you might expect, many talented people were involved in the P7001 project. Inputs from Bill Walker, Wim Velsink, Bob LeBrun and others gave valuable direction in the planning stages. Early mechanical design was handled by Marlow Butler and Carl Dalby, with Colin Doward doing much of the later work under Bob Shand, Mechanical Project Leader. In the electronic portion, Jack Robinson and Bill Lucas designed the Sample and Hold circuitry; Jack Grimes, Dennis Keldsen and Mohamed Saba the A/D; Dick Beatty the Memory; Wayne Eshelman the Vector Generator; George Rhine the Interface I/O; and Bill Markwart the Readout Interface Circuitry. Gale Byers, with manufacturing responsibility for the P7001, gave valuable inputs on making the instrument buildable. Our thanks to others too numerous to mention, for their valuable contributions to the project.

Meet Our Authors



Bruce Hamilton—standing at left, was Software Project Leader. He obtained his BSEE from Oregon State Univ. in 1966 and his MSEE in '68 from Ohio State.

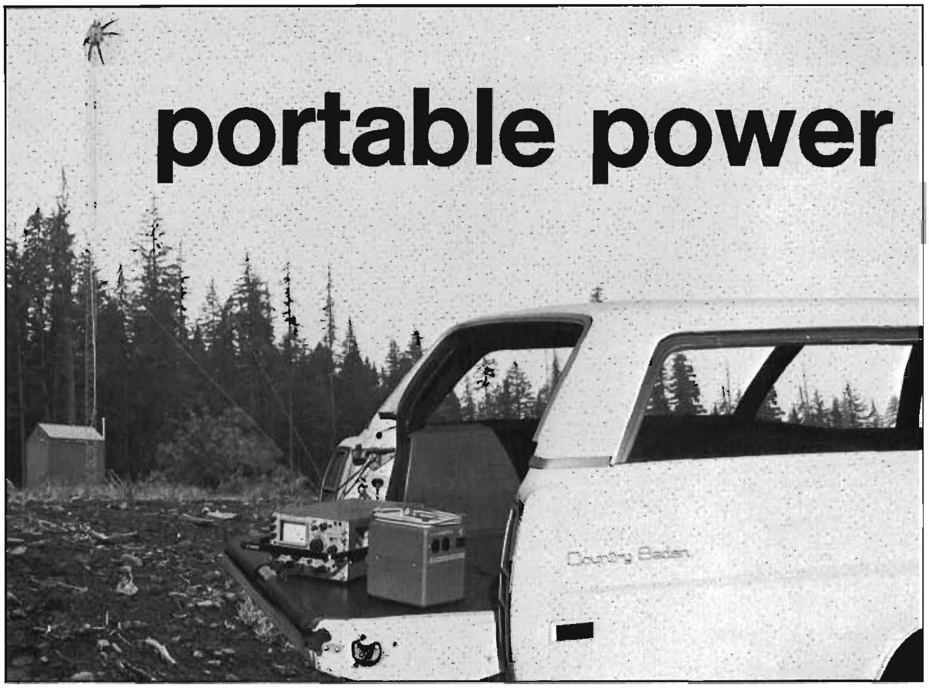
Luis Navarro—seated at left, was Hardware and Analog Circuits Project Leader. He obtained his BSEE in 1965 and MSEE in 1966 from the University of Nebraska.

Jack Gilmore—standing at right, was Logic Design Project Leader and also received his BSEE and MSEE from the University of Nebraska, though just a bit later in '66 and '68.

Hiro Moriyasu—seated at right, is Program Manager of the Computer Aided Measurements Group. He obtained his BSEE in 1959 and MSEE in 1969 from Oregon State University.

Bob Shand—the fellow seated in the middle, while not contributing words to this article did make a substantial contribution to the project as Mechanical Project Leader.

portable power



by

R. Michael Johnson,

Randy Eichman,

and

Al Schamel

How many times have you wanted to make a measurement and found no AC power available? Have noise transients on the AC line ever made your critical measurements practically useless? If you've had these or other problems with power sources, there are two new instruments from Tektronix, Inc. that will be of interest to you. First, there's the new TEKTRONIX 1105, a self-contained power source for operating your oscilloscope or other instrumentation away from the AC power line. The second unit is the 1106 which attaches to a 465 Option 7 or 475 Option 7 to make it a completely self-contained oscilloscope system.

Battery Power—Its Many Uses

Let's consider some of the applications for battery operation. The major reason for a battery-operated supply is instrument operation remote from any AC power source. However, there are many uses for battery operation when AC power is readily available. The battery-operated supply can serve as an extra wall socket when all of the AC sockets are in use. When used on a SCOPE-MOBILE® Cart or test cart, battery operation provides a completely mobile system with no power cords to get in the way.

Often the power line is carrying noise transients that might affect a critical measurement; the battery-operated supply disconnects the measuring instrument from the influence of this noise. Some measurements require a floating ground system. Battery operation allows this to be easily accomplished, but it must be kept in mind that the chassis and cabinet of instruments which are isolated from ground may become elevated to dangerous potentials.

The battery-operated supply can be used as a power converter since the battery supplies can usually be charged over a wider range of line voltages than many instruments will operate on. In this application, you can charge the batteries at the higher- or lower-than normal voltage, and later operate the instrument from the batteries. This can also be used to solve the problem of low-line voltage during hours of peak-power demand or fluctuations in the line voltage caused by heavy industrial equipment operating in the vicinity of your measurement.

Why A Separate Power Unit?

Now that we've seen some of the uses for battery-operated instruments you may be thinking that the answer is to design all instruments with battery operation built in. This would be ideal. However, even with the best circuit designs, compromises must be made to build in battery operation. Many of these compromises result in lesser performance for the battery-powered instruments, particularly at the upper limits of performance such as at maximum bandwidth, visual writing rate, etc. The concept of a separate power unit such as the 1105, or a separable battery unit such as the 1106, allows the basic instrument to be designed for best overall performance and minimal cost. If battery operation is needed at a later date, you can choose the battery-operated supply best-suited for the application.

There are other advantages to each of the new battery-operated supplies from Tektronix. Let's look at these in more detail.

The 1105—A Portable Wall Socket

Think of the 1105 as a portable wall socket that allows you to carry power to your measurement location. Now, any oscilloscope that draws less than 120 watts can become a portable. This includes the TEKTRONIX 453A and 454A. But don't limit its use to powering oscilloscopes. It can be used to power any instrument or combination of instruments that draws less than 120 watts and will operate on 60-Hertz squarewave voltages. The major items that cannot be operated from the 1105 are induction motors such as electric drills, which induce distortions back into the output of the 1105 power unit. This prevents it from operating correctly, or in extreme cases, damages the 1105. There are also some electronic instruments which cannot operate correctly on the squarewave output of the 1105. Among these are instruments which need a very accurate line frequency or waveshape for correct operation.

The 1105 offers an economy in battery operation if you have a variety of instruments which only occasionally need to be operated from batteries. Many laboratory instruments never intended for use away from the AC power line become "portable" when used with the free-standing 1105.

Since the 1105 is intended for remote applications, it is built rugged to withstand the use and abuse associated with portability. It has two built-in power sockets to power any two instruments whose total power consumption does not exceed 120 watts. These sockets match the sockets commonly in use; N.E.C. (duplex) sockets for U.S. models and I.E.C. sockets for European models.

The 1106—Take It, Or Leave It

While the 1106 provides portable power in much the same way as the 1105, it is designed in quite a different configuration. This power system is made specifically for the TEKTRONIX 465 and 475 Oscilloscopes. The 465 or 475 must be equipped with Option 7, which adds a DC-to-AC inverter board inside the instrument. With this option installed, the 465 or 475 can operate from external DC sources (11.5 to 14 volts and 22 to 28 volts) as well as from the AC line.

With the addition of the 1106 battery supply, completely self-contained operation is achieved. The 1106 contains the rechargeable batteries and the battery charger circuit. It attaches to the bottom of the 465 or 475 cabinet and supplies power to the instrument through a plug-in power cord.

Designing the 1106 as a unit separate from the oscilloscope provides several advantages. Most important, you need to carry the battery pack only when AC power will not be available—it can be added or removed in a matter of seconds. This quick removal is also an advantage if you must carry the oscilloscope/battery pack system for any distance. The 1106 has its own handle so you can remove it and carry a unit in each hand for a well-balanced load (see Fig. 1).

Fig. 1. *The 1106 can be separated from the oscilloscope for an easy-to-carry load.*

For continuous operation from batteries, two 1106 battery units can be easily interchanged. Since the battery charger is contained in the 1106 itself, the batteries can be recharged in one unit while the instrument is operated from the second unit. Interchangeability also allows you to use one battery pack to operate any of several 465s or 475s, as long as each instrument has Option 7 installed.

Another advantage already discussed is that the original design of the 465 and 475 was not compromised to build in battery operation. As a result, these instruments offer the best of two worlds—maximum instrument performance at a low price and fully portable battery operation.

A Look Beneath The Surface

While the 1105 and 1106 have quite a different outward appearance, they share many common features inside the cabinets. Both are powered by 20 type "F" nickel-cadmium cells. The battery circuits include a calibrated meter which indicates the amount of charge left.

Another feature of both instruments is a deep-discharge protection circuit (Fig 2) which shuts off the instrument when the batteries drop to a level where damage could occur by further discharge. This circuit senses the input voltage (battery level) and if it falls below about 22 volts, Schmitt trigger Q1-Q2 changes state so that Q2 is conducting. This turns on Q3 to forward bias diodes D1 and D2, by-passing the primary winding of the feedback transformer. This prevents feedback to inverter transistors Q4-Q5, shutting them down. They remain off, producing no output drive for this supply until the input voltage level rises above the turn-off level (i.e., batteries recharged).

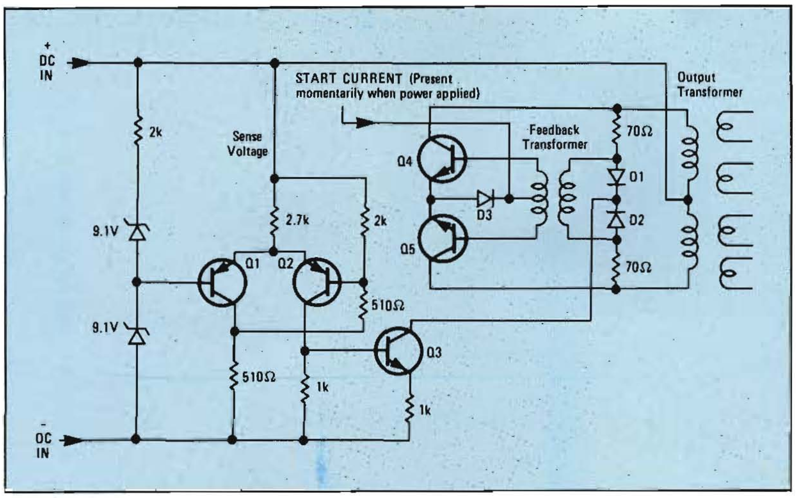


Fig. 2. *Simplified schematic of the deep-discharge protection circuit. Circuitry shown is part of Option 7 for the 465/475. The 1105 protection circuit is similar.*

The two instruments use different schemes for charging the batteries. The 1105 uses a single transformer which serves the dual-function of a step-down transformer when charging the batteries and a step-up transformer for power output. As a result, the batteries cannot be charged simultaneously with power output. The 1105 also incorporates a thermal-cutout charge rate selector. A characteristic of nickel-cadmium batteries is that they convert the charging current to heat as they reach full charge. The thermal-cutout charge selector senses the rapid increase in battery temperature as the batteries reach full charge and automatically switches the unit to trickle charge.

The batteries in the 1106 can be charged at the same time that the instrument is being operated from the AC line. Charge rate is determined by an external switch. Two rates are available—FULL, to charge the batteries, and TRICKLE, to maintain a full charge on the batteries once they've reached that level.

Summary

The 1105 and 1106 offer new freedom for your AC-powered instruments. No longer are your measurements limited by the length of the power cord. Instead, battery operation offers you portable power to make measurements at their source—anywhere.

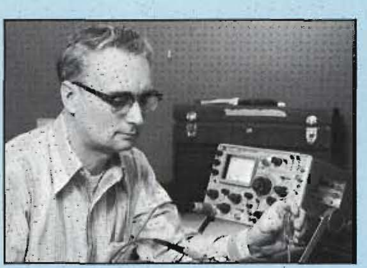
ACKNOWLEDGEMENTS

The design effort on the 1105/1106/Option 7 was coordinated by R. Michael Johnson. George Ermini provided evaluation support for these projects and the preliminary electrical design for the 1105. Randy Eichman completed the electrical design. Others involved in the 1105 were: Bill Cottingham, mechanical design and Sandra Lowe, prototype support. Electrical design of the 1106 and Option 7 for the 465/475 was by Al Schamel. Bob Twigg provided the mechanical design for the 1106 and Len McCracken filled a similar job for Option 7. Iona MacKay provided prototype support for the 1106 and Pat Simonson for Option 7.

ABOUT OUR AUTHORS

R. Michael Johnson

Bob joined TEK in 1960, shortly after earning his BSEE degree at Oregon State University. He received his MSEE in '68, also from O.S.U. Bob has been involved in the design of most of TEK's portables and also helped develop the TEKTRONIX 7000-Series instruments. His most recent involvement was as Project Leader on the new 465 which was presented in the September 1972 issue of TEKSCOPE. This project led to his present work on the 1105/1106/Option 7 units. Bob likes to relax while camping, fishing, or working with his coin collection.



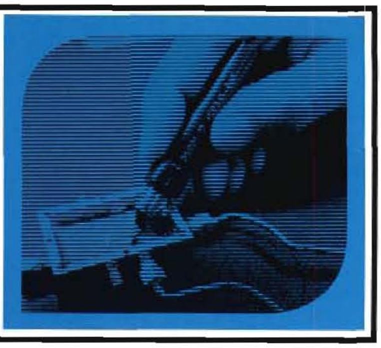
Randy Eichman

Randy is an old-timer at TEK, having started here in June of 1957. He received his early training in electronics while in the U.S. Army and has added to this by on-the-job training and specialized classes to keep abreast of recent advancements. Among the areas that Randy has worked in at TEK are the production test department, engineering evaluation, and custom product design. Randy enjoys ham radio and coin collecting in his spare time.

Al Schamel

Al attended Portland Community College to further the electronics training begun while in the U.S. Air Force. In 1965, he joined TEK in the production test department and now works as an Engineering Aide in the Portable Instrument Design group. In this position, he has assisted in the development of the 432, 434, and the 465 as well as the 1105/1106/Option 7. Leisure time pursuits for Al include working on his 1957 Thunderbird and growing roses.

TEKNIQUE



by Ron Peltola Accessories Design

Preserving Scope Bandwidth and Sensitivity

When is a 500-megahertz scope not a 500-megahertz scope? At first glance, this may seem like a facetious question, but the answer may come as somewhat of a shock. Anytime you connect a signal to the input of a high-frequency scope, you can lose a large percentage of the high-frequency information unless the signal source is carefully matched to the oscilloscope input. Since you probably bought your high-frequency scope because you need its extra display capabilities, you'll want to get all of the high-frequency performance designed into it. Here's some information to help in your high-frequency measurements.

Check the Specifications

The bandwidth and risetime of most oscilloscopes are given at a specific source impedance. Usually, this is stated similar to the following: ". . . driven from a 50-ohm terminated source" or, in other words, a 50-ohm source paralleled by a 50-ohm termination, which is equivalent to a 25-ohm source impedance. Bandwidth and risetime are seldom stated at some higher source impedance. As a result, you're left on your own to find out what the outcome might be.

Faced with this situation, you might speculate as to what source impedance will appreciably change the bandwidth of your measurement system. A one-kilohm source probably sounds high enough to affect the bandwidth, but 250 ohms doesn't sound very large, right? Well, let's take a look and see. Fig. 1 lists some of the high-frequency oscilloscope systems offered by Tektronix, Inc. and the approximate bandwidth when driven from both a 25-ohm and a 250-ohm source with various combinations of input connection methods. Particularly notice what happens when a X10 passive probe is used. In the worst case, bandwidth has degraded to about 20% of the original bandwidth.

What Causes This Loss?

This loss in bandwidth is caused by the interaction of the source resistance and the capacitance at the probe tip. Fig. 2 illustrates the equivalent circuit of the measuring system.

Is There A Solution?

There are several solutions to this measurement problem. One solution that may prove impractical in many cases is to only obtain the signal from a low-impedance source. There are two ways this can be done: obtain the signal from a 50-ohm source using a coax cable terminated in 50 ohms, or design probe jacks into the circuit at 25-ohm source impedance points. However, when troubleshooting in high-frequency systems, you often need to examine the signal at higher impedance points. A variety of passive probes are available which allow you to make these measurements with a minimum of capacitive loading. There are two problems with using passive probes: none of the passive probes can make high-frequency measurements over a wide range of input impedance, and all of the passive probes include signal attenuation. This prevents many of the critical measurements which must be made at maximum sensitivity.

An Active Solution

Active voltage probes use an active device such as a field-effect transistor (FET) to provide a high-input impedance. At the same time, the input circuitry of the probe can be designed to provide very low input capacitance. Most active probes include a wide-bandwidth amplifier to minimize probe attenuation. Fig. 3 lists the active probes presently available from Tektronix, Inc. along with their major characteristics.

SCOPE SYSTEM / PROBE	MAXIMUM SENSITIVITY	APPROX BANDWIDTH FROM 25-OHM SOURCE	APPROX BANDWIDTH FROM 250-OHM SOURCE
Type 475			
Without Probe	2 mV/DIV	≥200 MHz	. . . .
P6075A (X10)	20 mV/DIV	≥200 MHz	50 MHz
P6201 (X1)	2 mV/DIV	≥195 MHz	145 MHz
P6201 (X10)	20 mV/DIV	≥195 MHz	182 MHz
Type 485			
Without Probe	5 mV/DIV	350 MHz (50Ω input) 250 MHz (1MΩ input)	. . . .
P6053A (X10)	50 mV/DIV	250 MHz	50 MHz
P6201 (X1)	5 mV/DIV	325 MHz	185 MHz
P6201 (X10)	50 mV/DIV	325 MHz	273 MHz
7704A/7A18A (Opt 9)			
Without Probe	5 mV/DIV	170 MHz	. . . .
P6053A (X10)	50 mV/DIV	161 MHz	48.5 MHz
P6201 (X1)	5 mV/DIV	167 MHz	133 MHz
P6201 (X10)	50 mV/DIV	167 MHz	158 MHz
7904/7A16A			
Without Probe	5 mV/DIV	225 MHz	. . . .
P6053A (X10)	50 mV/DIV	200 MHz	49.5 MHz
P6201 (X1)	5 mV/DIV	218 MHz	155 MHz
P6201 (X10)	50 mV/DIV	218 MHz	200 MHz
7904/7A19			
Without Probe	10 mV/DIV	500 MHz (50 Ω input)	. . . .
P6201 (X1)	10 mV/DIV	430 MHz	195 MHz
P6201 (X10)	100 mV/DIV	430 MHz	324 MHz

Fig. 1. *Effect of source resistance and probe input impedance on scope system bandwidth.*

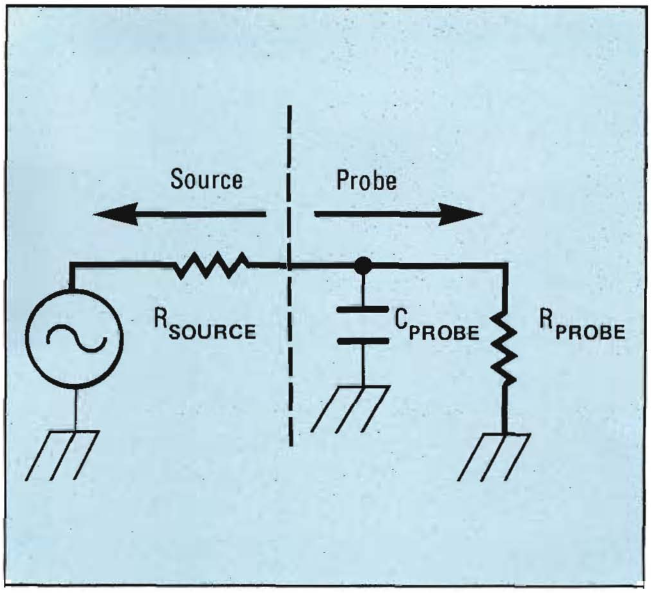


Fig. 2. *Equivalent circuit of probe and signal source.*

TYPE	ATTENUATION	LOADING		RISETIME IN ns
P6045 FET	1X	10 M	5.5 pF	1.5
	10X		2.5	
	100X		1.8	
P6046 DIFF/AMP	1X	1 M	10 pF	3.5
	10X	10 M	3	
P6051 FET	5X	1 M	2.8 pF	0.35
	20X		3.3	
	100X		2.0	
	200X		1.8	
P6201 FET	1X	100 K	3.0 pF	0.4
	10X	1 M	1.5	
	100X	1 M	1.5	

Fig. 3. *Active probes available from Tektronix, Inc.*

A Recent Addition.

The latest addition to the TEKTRONIX active probe family is the P6201 FET Probe. This probe features high input impedance at low capacitance, unity gain (i.e., 1X attenuation), and compatibility with either 50-ohm or one-megohm oscilloscope inputs. The probe is especially attractive for providing a high-impedance input for the 500-megahertz TEKTRONIX 7900/7A19 Oscilloscope or similar 50-ohm systems. When used with the 7900/7A19, the P6201 maintains sensitivity of 10 millivolts per centimeter at an overall bandwidth of at least 430 megahertz when driven from a 25-ohm source. Fig. 1 shows the resultant bandwidth when the P6201 is used with other high-frequency oscilloscope systems.

Many TEKTRONIX Oscilloscopes provide readout of the vertical deflection factor. Two methods are used to provide readout: either by lights located behind the skirt of the deflection factor knob, or with the exclusive CRT READOUT system which indicates the deflection factor on the CRT along with the waveform. The P6201 has resistively-coded attenuators which provide the correct readout of the deflection factor at the probe tip when used with these oscilloscopes. This greatly reduces the possibility of measurement errors caused by failing to take the probe attenuation into account.

Other Features of the P6201

A switch-selectable AC-DC coupling feature allows the DC component of a waveform to be removed without changing the probe's effective input capacitance. This is accomplished by use of a DC-reinsertion amplifier. The signal from the probe tip is connected to the oscilloscope through two parallel paths (see Fig. 4). The AC components of this signal are connected through the Probe Body AC Amplifier which has capacitive coupling at both the input and output. At the same time, the signal is direct coupled to the DC and LF Amplifier through the isolation resistor and the INPUT COUPLING switch. The isolation resistor allows AC coupling to be selected without affecting the input capacitance.

A broad-range DC-offset capability permits viewing of small signals riding on DC levels up to 200 volts (depending upon attenuator tip used) while maintaining DC coupled response. DC offset control is provided by the DC and LF Amplifier circuit. Fig. 5 shows the dynamic range and offset limitations of the P6201 and its attenuators. DC offset is most useful for observing low-frequency signals such as pulse trains, without the averaging or time-constant effects produced if AC coupling were used.

An internal 50-ohm termination can be selected when the P6201 is used on one-megohm vertical inputs.

Mechanical Considerations

Ever lose the use of a probe for days or even weeks because the nose pin on the probe tip broke? The probe body and each of the attenuators of the P6201 have screw-in nose pins for easy replacement of this vulnerable, but essential, part of the system.

The P6201 can be quickly attached to the vertical input connector. A special locking-type BNC connector allows quick connection. Power is supplied to the probe from probe power connectors on TEKTRONIX 7700 and 7900-Series mainframes, 475 and 485 Oscilloscopes, or by the 1101 Accessory Power Supply.

Summary

An essential part of high-frequency signal measurement is getting the signal to the input of the oscilloscope. When the source impedance is 50-ohms, most probes or cables provide satisfactory results. However, as the source impedance increases, the input characteristics of the probe determine the overall response of the measurement system. Passive probes can make some of the measurements at higher source impedances while active probes, with high input impedance and low capacitance, allow high-frequency measurements over a wide range of signal source impedances.

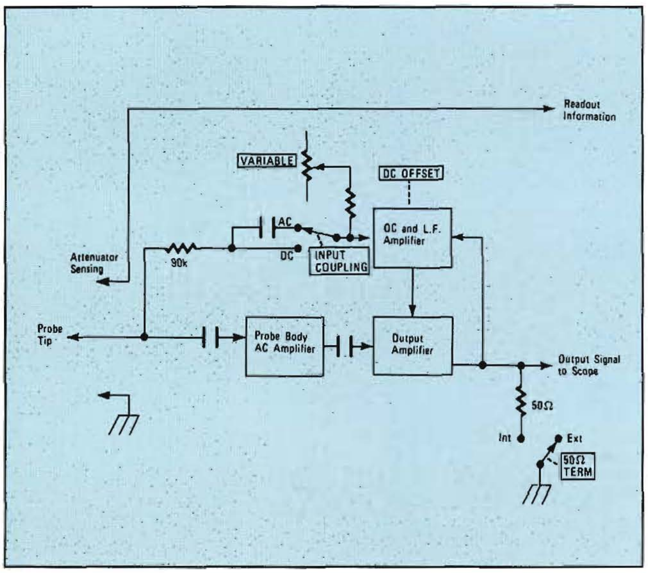


Fig. 4. *Block diagram of P6201.*

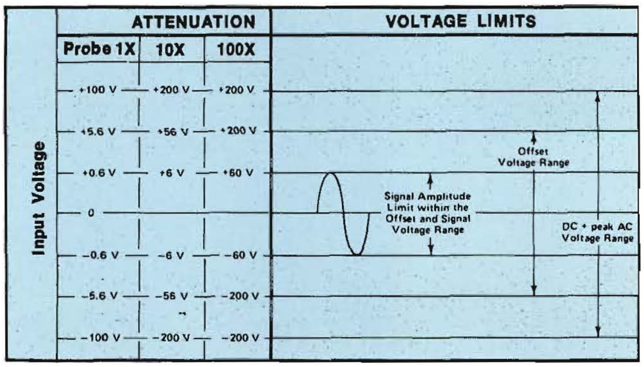


Fig. 5. *Dynamic and offset limitations of P6201 Probe and attenuators.*

References:

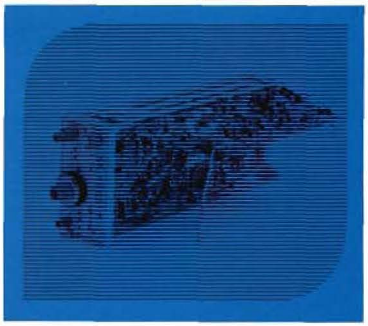
1. *"Probe Measurements", Tektronix Measurement Concepts Series, P/N 062-1120-00.*
2. *"Oscilloscope Probe Circuits", Tektronix Circuit Concepts Series, P/N 062-1146-00.*

MEET THE AUTHOR

Ron Peltola — Ron came to Tektronix in 1961 from Eugene Technical Vocational School in Eugene, Oregon. He has worked as an electronic technician in the Manufacturing Test Department and as an engineering assistant prior to his present job as a design engineer for the Accessories Design Group. Ron is coholder of Patent #3,710,270 with two other patents applied for. One of these is the Peltola coaxial connector described in the May 1972 issue of TEKSCOPE (see "The 7704A—Extended Performance Plus Modularity").

Ron is a native Oregonian. Besides family outings with his wife and three active boys, Ron enjoys metal and clay sculpture, chess, golf, and volleyball.

SERVICE SCOPE



by Ken Lindsay Sampling Staff Engineer

Servicing the Trigger Circuit in the 7T11 Sampling Sweep Unit

A finely-tuned racing car requires more frequent adjustment to keep it at its peak performance than the family car. Sampling instruments traditionally display a similar characteristic, and for much the same reason—they deal with high-speed phenomena. This article presents a simplified, yet complete, method for adjusting and troubleshooting the 7T11 Trigger Circuit.

It's frustrating to get three-fourths of the way through a calibration procedure and find a bad component that forces you to start all over again after replacement. To prevent this, it's a good idea to determine if any part of the circuit needs repair before starting to calibrate the unit. The following procedure will help you know how, and where, to look for trouble in the trigger circuit, as well as how to make the adjustments.

Initial Set-Up

1. Remove the side covers from the 7T11 and 7S11. Make sure the right side cover of the 7T11 is marked so it is not reinstalled on the 7S11. This cover should have "7T11" printed on it at the factory. Don't use any other in its place because part of the underside has a strip of insulating material applied to prevent accidental grounding of close components.
2. Since the 7T11 will be operated outside of the plug-in compartment, you will need to couple strobe pulses from the 7T11 to the 7S11. To do this, unplug the coaxial cable having a red tracer, visible through a slot in the top of the 7T11, from jack J344. Apply a piece of insulating tape to this connector to prevent it from accidentally short-circuiting anything inside the 7T11. Plug one end of the special coaxial cable (TEKTRONIX Part No. 012-0203-00) onto J344. Plug the other end of this cable into jack J430 near the rear of the left side of the 7S11 where a cable having a red tracer is normally installed. Route the cable through the 7S11 underneath the sampling head compartment. Tape the loose end of the connector that was unplugged from the 7S11.
3. If the 7T11 is calibrated in a 4-compartment 7000-Series mainframe, a separate test scope is not needed. Install a vertical plug-in such as the 7A13 or 7A12 in the left vertical compartment and a time-base plug-in such as a 7B70 in the right horizontal compartment. Then install the 7S11 containing an S-1 or S-2 Sampling Head into the right vertical compartment of the mainframe. In the adjacent horizontal compartment, install a rigid plug-in extender (067-0589-00) or flexible plug-in extender (067-0616-00). Install the 7T11 on the extender. (NOTE: The inside edge of the lower left hand plastic guide on the rigid extender may need to be beveled with a file or knife so the 7T11 fits easily and securely.) Turn on the scope power.
4. Select the RIGHT Vertical compartment and the "A" Horizontal compartment of the 7000-Series Oscilloscope for display. Set the 7S11 for 200 mV/DIV, the Dot Response pushbutton to NORMAL, and the DOT RESPONSE control with the white dot straight up. Set the 7T11 TIME POS RNG to 50 μs and TIME/DIV to 5 μs. Press the REP scan and SEQUENTIAL buttons.

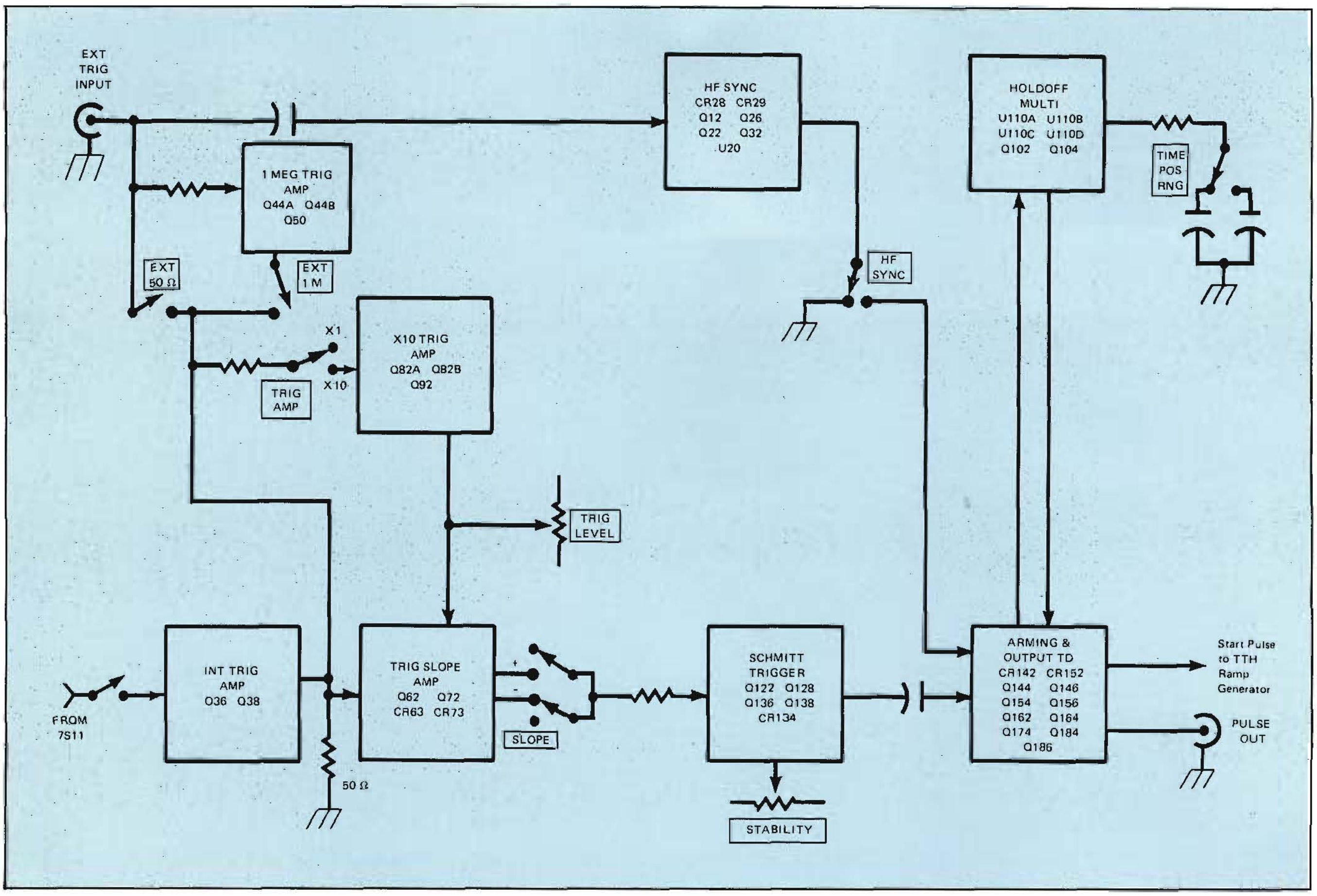


Fig. 1. *Block diagram of the 7T11 Trigger Circuit.*

The instruments are now set up to check the trigger circuits for proper operation. This setup also prepares the 7T11 for the adjustment procedure.

Trigger Checkout

In any mode of triggering except HF SYNC, it should be possible to control whether the sweep runs or not with the front panel STABILITY and TRIG LEVEL controls. In the HF SYNC mode, the sweep should run with any setting of these controls. Push the 50Ω EXT button and set the STABILITY fully clockwise. Set the TRIG LEVEL to approximately midrange and check for a free-running sweep. You should be able to start and stop the sweep by changing the setting of the TRIG LEVEL control. If a free-running sweep cannot be obtained, check for a pulse approximately 10 volts in amplitude at the 7T11 PULSE OUT jack using a test scope and 10X probe. If the pulse is present, it means that the triggers are functioning and there is a problem in some other section of the instrument. If no pulse is present, press the HF SYNC button and recheck the PULSE OUT. This bypasses much of the trigger input circuitry and Schmitt Trig Regenerator (see Fig. 1).

If a pulse is not present even with the HF SYNC button pressed, the trouble may be in the HF SYNC block, HOLD-OFF MULTI, or the output TD's. If there is a pulse present in the HF SYNC mode but not in EXT 50Ω mode, the Schmitt Trigger circuit is not functioning properly. Before troubleshooting the Schmitt, it's a good idea to push both + and – SLOPE buttons and X10 TRIG AMP button and recheck operation. A problem in either the Trig Slope Amp or X10 Trig Amp can hold the Schmitt in one state which will produce no output. Output from the Schmitt is dependent upon the switching action, not whether it's in its high or low state.

The Schmitt Trigger is a regenerative type of circuit. An output is delivered from the Schmitt when tunnel diode CR134 changes to its high-voltage state. The amount of current needed at the Schmitt input to cause CR134 to fire is determined by the front-panel STABILITY control and Stability Zero adjust R135. Input current is delivered to the emitter of Q122 from the Trig Slope Amp.

Trig Level Zero adjust R120 balances the Slope Amp so that the same current will be delivered when either

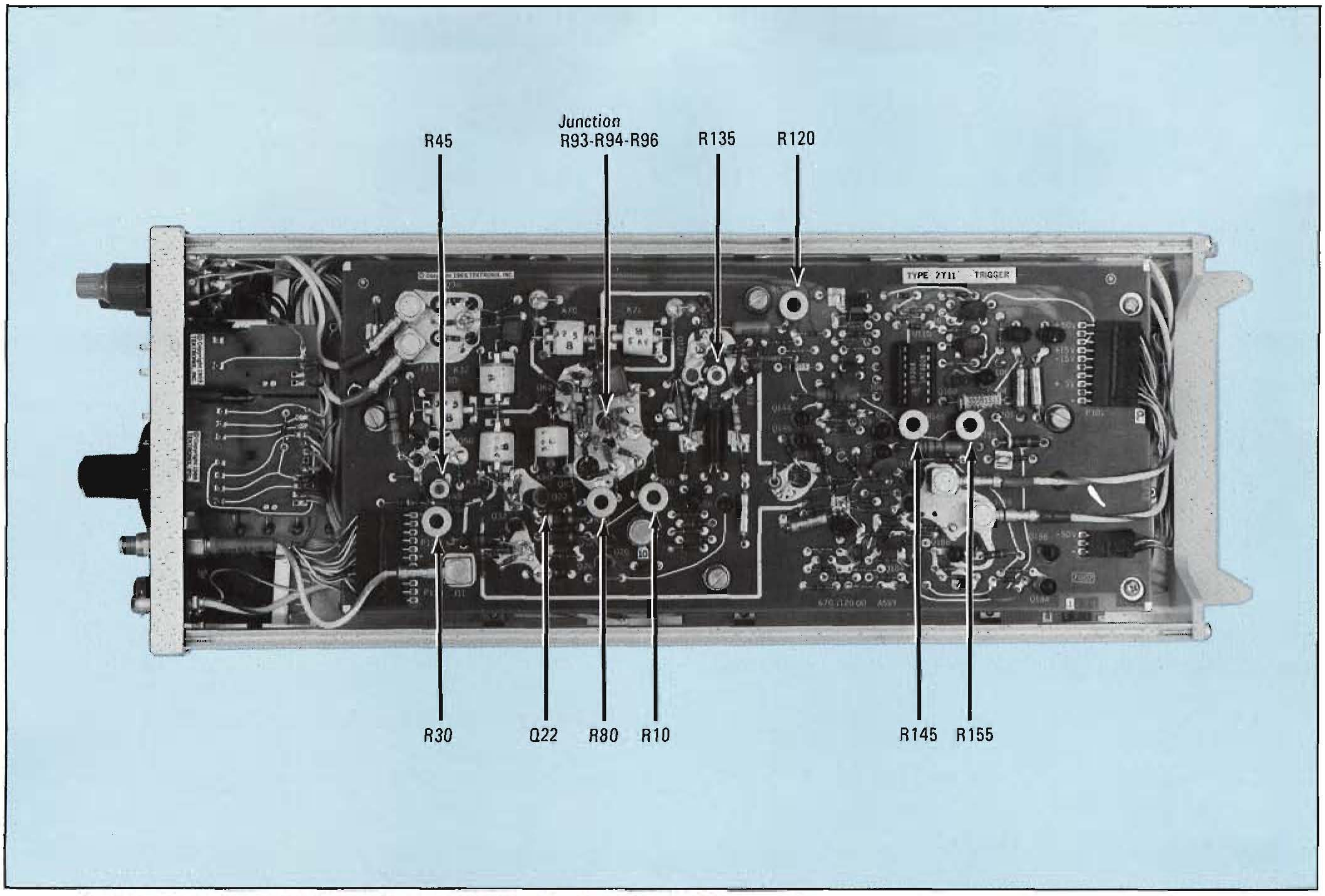


Fig. 2. *Location of Trigger test points and adjustments (right side of instrument).*

+ or − SLOPE is selected. The most common failure in the Schmitt circuit is tunnel diode CR134, or lamp DS136 in the optical isolator.

The output TD's, CR134 and CR152, can be checked with a DC-coupled test scope and 10X probe connected to the anode of each diode. Use an overall sensitivity of 5 volts/div since the 600 mV TD signal is riding on a −15 volt DC level. If a differential comparator plug-in is available, such as a 7A13 or W, use this at 200 mV/div (overall sensitivity) with −15 volts of offset voltage. This will make it easier to see when the TD switches.

Now, by adjusting R145 (for CR142 bias) and R155 (for CR152 Bias) throughout their entire range, you can see if the TD's turn off and on. If either of the TD's will not change state, it is either defective or there may be a problem in the Hold-Off Multi which is holding them in one state.

If trouble is encountered in the HF SYNC circuit and tunnel diode CR28 has to be changed, try to install the new one with a loop in the lead similar to the one being replaced. This loop is actually an inductor, and its distance from the board will effect the frequency of the sync oscillator. If trouble is encountered when adjusting R10 for the HF SYNC frequency range, moving the lead either closer to, or away from, the board may be all that is necessary.

The rest of the trigger circuitry, input, etc., can be checked quite easily by applying either an INT or EXT trigger signal and following it through the circuit with a test scope.

Trigger Adjustments

This procedure provides a quick method for the experienced technician to adjust the 7T11 Trigger Circuit. For a detailed calibration procedure including description of the equipment used and typical waveforms, refer to the 7T11 Instruction Manual.

Fig. 2 shows the location of the trigger adjustments and test points referred to in this procedure.

1. Push the REP button, SEQUENTIAL button, INT button, X1 TRIG AMP button, and the + SLOPE button. Set the TIME POS RNG to .5 μs and the TIME/DIV to 50 ns. Set the SCAN control to midrange and the STABILITY and TRIG LEVEL controls fully counterclockwise (ccw). Preset R155 and R145 fully clockwise (cw). There should be a free-running trace.

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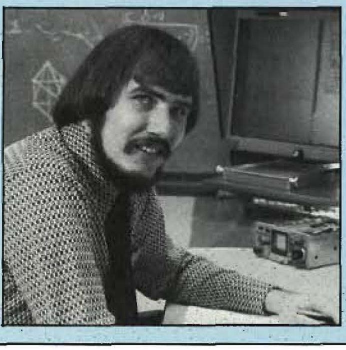
Editor: Gordon Allison, Ass't Editor: Dale Aufrecht, Graphic Designer: Tom Jones, Assistant: Diane Dillon.

2. Back off R155 (ccw) until the trace stops, then cw until sweep runs. Back off R145 (ccw) until sweep stops, then go about 10° more. If sweep will not stop, it may be necessary to back off R135 slightly. Set STABILITY cw and TRIG LEVEL for a free-running sweep.
3. Slowly turn the STABILITY ccw as far as possible while maintaining a free-running trace with the TRIG LEVEL. Note position of TRIG LEVEL. Press the −SLOPE button and adjust TRIG LEVEL for a free-running display. Note position of TRIG LEVEL. Center TRIG LEVEL between the two positions noted above and adjust R120 so sweep will free run while switching between + and − SLOPE buttons. (NOTE: It may be necessary to advance the STABILITY slightly while making this adjustment.)
4. Being careful not to move the setting of the STABILITY or TRIG LEVEL controls, press the 1 MΩ EXT trigger input button and adjust R45 for a free-running display.
5. Push the X10 TRIG AMP button and 50Ω EXT trigger input button. Monitor the DC voltage at the junction of R93, R94, and R96 (see Fig. 2) with a test scope and a 1X probe set at 50 mV/DIV. Adjust R80 for close to zero volts. Remove scope probe and press X1 TRIG AMP button.
6. Press the 7S11 NORMAL button and apply a 5 MHz to 50 MHz sinewave or squarewave to the S1 or S2 Sampling Head and the EXT TRIG INPUT connector with a "tee" connector. Trigger the display and adjust the signal source for 20 mV display amplitude. Set the STABILITY ccw and adjust R135 so that a stable, triggered display can be obtained with the TRIG LEVEL control while the STABILITY remains ccw. Remove the trigger signal and make sure the sweep will not free run at any setting of the TRIG LEVEL with the STABILITY ccw. If the sweep does free run, adjust R135 ccw slightly and recheck.
7. Connect the Pulse Output of the Type 284 Pulse Generator (or fast pulse from a similar generator such as the S-52) to the S1 or S2 Sampling Head and the Pre-Trig Out from the generator to the 7T11 EXT TRIG INPUT. Set the 7T11 TIME POS RNG to 50 ns and TIME/DIV to 1 ns. Set the Lead Time switch on the 284 to 75 ns or 150 ns. Set the 7T11 STABILITY control fully ccw and adjust the TRIG LEVEL for a stable display. Center the display with the TIME POSITION controls. Adjust R155 cw until the display jumps to the right approximately 3 ns, then ccw until it jumps back; then go ccw about 20° more. Next, adjust R145 cw until the display jumps a little to the right or breaks up; then adjust ccw for a stable display plus about 20° more rotation.
8. Disconnect all signals and set the STABILITY cw and TRIG LEVEL for a free-running display. Connect a coax cable between the EXT TRIG INPUT of the 7T11 and the vertical input to the 7S11; push the HF SYNC button. (NOTE: this will feed a synchronous trigger-kickout signal to the vertical.) Temporarily remove transistor Q22 (see Fig. 2) and set the TIME/DIV to 1 ns to display the kickout signal. Preset R30 about midrange and adjust R10 so the interval between waveforms may be varied between ≤3 ns and ≥4 ns using the front-panel STABILITY control.
9. Adjust R30 for the least display jitter as the STABILITY control is moved throughout its range. Reinstall Q22. Turn off the power and remove the 7T11 from the plug-in extender. Replace the original coax leads at J344 in the 7T11 and J430 in the 7S11. Replace the side panels.

This completes the trigger adjustments and triggering should now perform according to specifications. In a later Service Scope, we will look at troubleshooting and adjusting the timing section of the 7T11.



About Our Author

Ken Lindsay—In his four years at TEK, Ken has worked with sampling instruments in the Manufacturing Test Department, Factory Service Center, and now as a Marketing Staff Engineer. His present duties involve him in the introduction of new instruments as well as application and maintenance of older sampling instruments. Ken attended Idaho State University and Ricks College in his native state of Idaho before joining TEK.

For extra-curricular activities, Ken likes experimenting with electronics and has designed and built most of his own stereo system. He also enjoys working with sports cars and is the proud owner of a Triumph TR-6.

Ken and his wife Peggy are also enjoying getting settled in a new home they recently built.

TEKSCOPE

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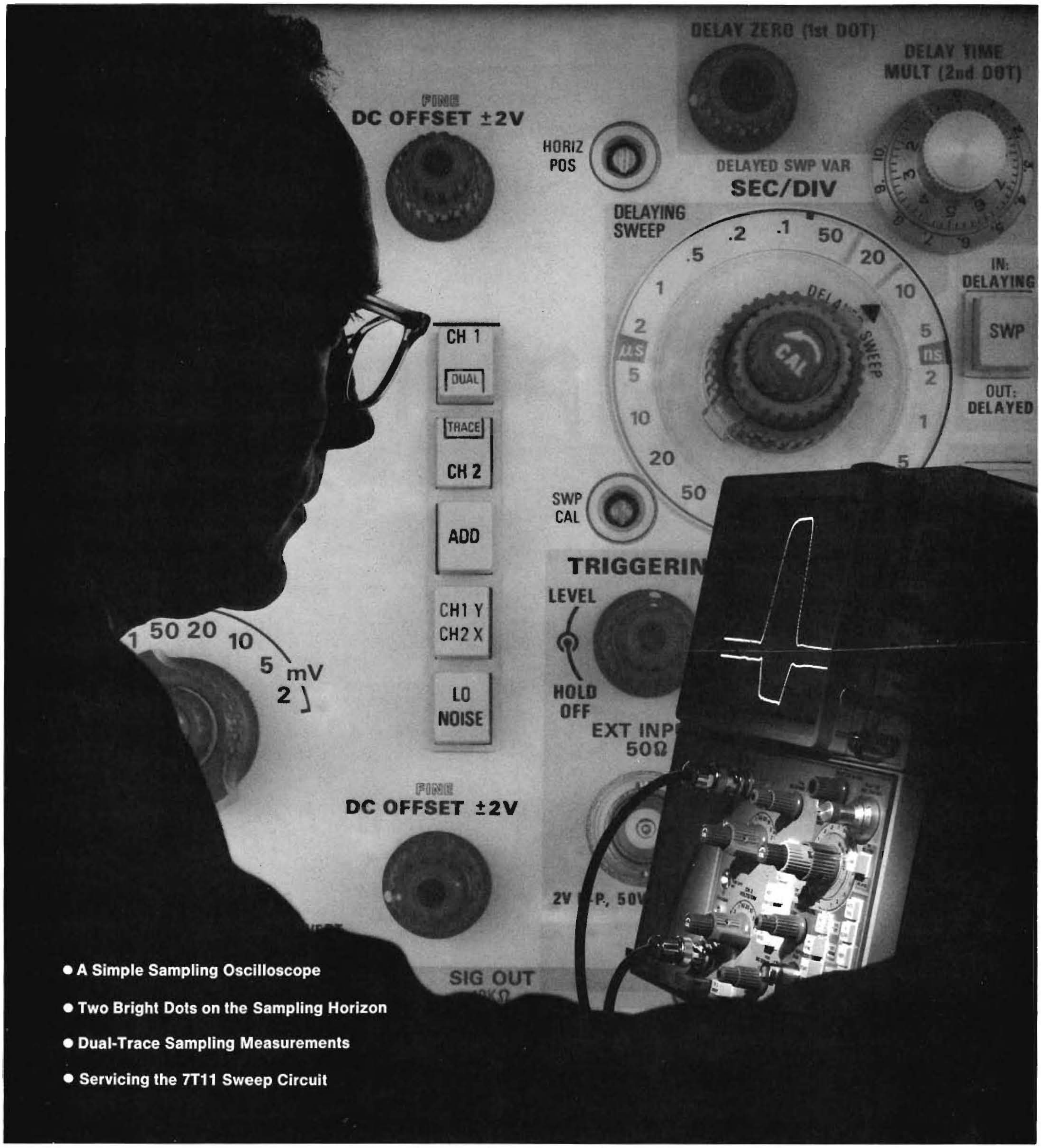
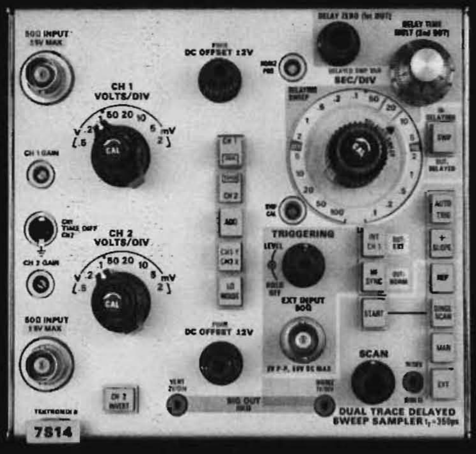


- A Simple Sampling Oscilloscope
- Two Bright Dots on the Sampling Horizon
- Dual-Trace Sampling Measurements
- Servicing the 7T11 Sweep Circuit



THE SIMPLE SAMPLING OSCILLOSCOPE

SAMPLING

by John A. Mulvey Sampling Staff Engineer

Most engineers who use sampling oscilloscopes prefer to use conventional scopes. We sell both kinds—should we care which kind people prefer? The answer is "yes," for reasons that may not be obvious.

Oscilloscope bandwidth technology changed in a dramatic way when sampling oscilloscopes were first introduced commercially fourteen years ago. The widest bandwidth available in a conventional oscilloscope at that time was about 100 MHz, while the bandwidth of the fastest sampling oscilloscope was 1 GHz—ten times greater. Sampling was sophisticated. It was a brand new art and the additional bandwidth cost quite a few additional dollars.

Since then the bandwidth of sophisticated sampling scopes has moved to the 12 to 18 GHz region, and they are still the most expensive scopes you can buy. But a dual-trace sampling scope of 1-GHz bandwidth is no longer what you would call sophisticated. What's new is that such an instrument can now be offered for less money than a dual-trace conventional scope of top bandwidth; and top bandwidth in conventional scopes is still only half way to 1 GHz. We should no longer regard all sampling oscilloscopes as high priced.

Cover: *The spotlight is turned on sampling in this issue. Two new sampling plug-ins bring unprecedented operating ease and measurement capability to users of sampling scopes.*

Persistent customer preference for conventional oscilloscopes is not based on price alone, however. Conventional scopes typically are easier to use and understand, and that seems to be of equal importance. Part of what makes an oscilloscope easy to use is having familiar responses. But many of the unfamiliar responses in sampling scopes don't have to be there. Some may be designed out, and that is better than trying to explain them away.

These two factors, high cost and unfamiliar responses, are two major reasons why engineers tend to avoid sampling scopes whenever possible. Knowing these factors is important to us because they tell us what improvements are needed to make sampling scopes more useful to you. We would like to tell you what we've done about both of these areas lately.

Meet the 5S14N and 7S14

Two new TEKTRONIX sampling plug-in units have been designed which embody such improvements. They are the 5S14N and the 7S14. Cost was held down to where the 5S14N, used in a 5103/D10 mainframe, represents the lowest priced 1-GHz, dual-trace, dual delay line sampling scope available. That, we think, is real progress—especially when you consider the inflation that has occurred since sampling scopes first came on the scene!

Electrically, the 5S14N and 7S14 are almost identical. The 5S14N operates in 5100-Series mainframes, the 7S14 in 7000-Series mainframes. The main difference between these units is that the 7S14 is equipped with coding circuitry to activate the CRT READOUT System in 7000-Series mainframes, whereas the 5S14N is not so equipped. The CRT READOUT System displays the selected VOLTS/DIV on the CRT along with the waveforms.

Packaging the same circuit design for use in both series of mainframes has several advantages. It gives you sampling at minimum cost whether you own a 5100-Series or 7000-Series scope. For those of you who prefer to buy a complete sampling scope and don't need the flexibility of plug-ins, it gives you a choice of sampling scopes. For example, here are some of the choices available to you:

- A sampler with conventional CRT.
- A sampler with conventional CRT and CRT READOUT.
- A sampler with bistable storage.
- A sampler with bistable storage and CRT READOUT.
- A sampler with variable-persistence storage and CRT READOUT.
- A sampler and a real-time oscilloscope in one package using a four-hole 7000-Series mainframe.

And there are other possible combinations.

Sampling and Storage Teamwork

One of the bothersome characteristics of sampling oscilloscopes shows up when you display short-duration pulses occurring at a low repetition rate. Sampling only one pulse at a time, it may take such a long time to produce each horizontal scan that you forget what the start of the trace looked like by the time you see the end! The use of a storage scope neatly solves this problem. Inexpensive bistable storage works fine and is available in either series of mainframes. Variable-persistence storage available in the 7000 Series offers an ideal display for low-repetition sampling since the persistence can be adjusted so the first trace just fades before the second trace is written.

No More Lost Beam with Auto Triggering

When operating any oscilloscope, the first job is to get a trace on-screen. If you have trouble doing this on a conventional scope, you usually press the BEAM FINDER button, note where the trace is located and then position it near center-screen. If everything is working normally, you're in business. It's not that easy with a sampler, however. Unless strobe pulses are being generated, the beam drifts off-screen vertically and nothing you can do will bring it back. If you're not aware of what's taking place you may assume the instrument needs repair.

The 5S14N and 7S14 overcome this problem with an automatic triggering mode. When you're in the AUTO mode, strobe pulses are generated at a low rate, even in the absence of trigger signals. This provides a slowly moving sweep allowing you to establish correct trace position. If you can't get a trace on-screen with the input signal disconnected, CRT intensity control centered, and the AUTO button pressed, you can be practically certain that you've got a problem for the repair lab—it's that foolproof.

If you're familiar with the peak-to-peak auto trigger mode available on many of the newer TEKTRONIX conventional oscilloscopes, you'll applaud the automatic trigger mode in the 5S14N and 7S14. It's very similar. When a trigger signal is applied in the AUTO mode, the circuit senses the positive and the negative peak levels of the signal and effectively applies these two levels across the front-panel LEVEL control. As a result, you can trigger at any point on the selected slope of the signal. The circuit is responsive to amplitude changes in the triggering signal, giving you nearly as much LEVEL control range on small signals as on large ones; and triggering is much easier on small signals than in the normal mode.

Traditionally, tunnel diodes have been used in sampling oscilloscope trigger circuits because they were the only components providing acceptably low trigger time-jitter.Tens-of-picoseconds of jitter is hardly discernable with the fastest sweeps in a conventional scope but becomes highly objectionable in a sampling scope. Using new high-speed emitter-coupled integrated circuits, low trigger-jitter is maintained in the 5S14N and 7S14 while providing the normal level-selection type of triggering found in conventional scopes.

Wide-range variable trigger holdoff is the most convenient way to trigger stably on a train of pulses having nearly equal amplitude but varying widths and spacing. Digital words are a common example. The 5S14N and 7S14 have a wide holdoff range that is effective for all time-per-division settings.

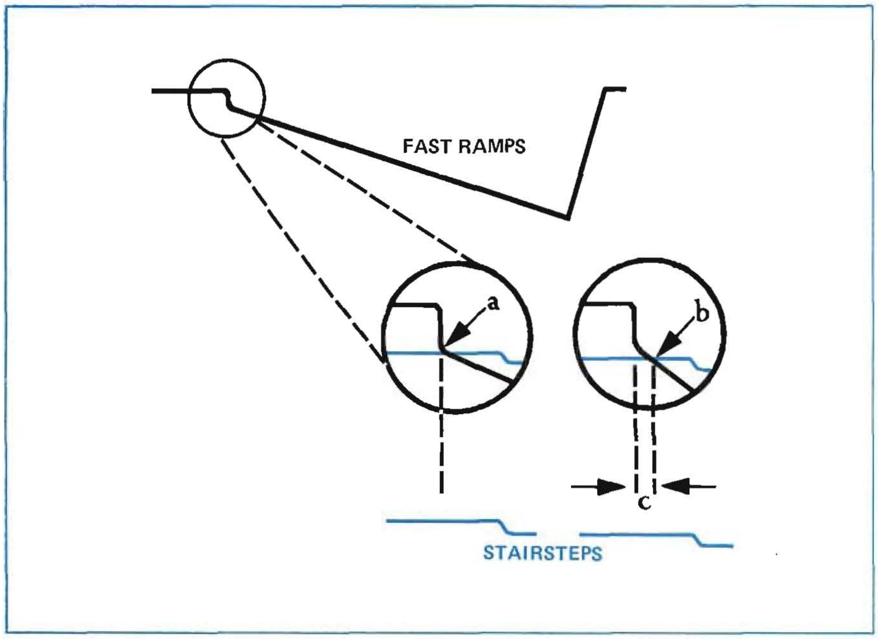


Fig. 1. *Timebase Non-linear Region*

A fast ramp is generated each time the triggering signal is recognized. A strobe pulse is generated each time a fast ramp crosses the existing level of a stairstep. Then the step generator advances one step and waits for the next fast ramp to cross the new level. Each fast ramp causes one sample to be taken of the vertical signal and causes the CRT beam to move horizontally one step.

If the top stairstep is set high enough to be above the linear region of the ramps (a) the time base will be non-linear. If the top level is set low enough to be in the linear region (b) leadtime will be lost. Lost leadtime (c) prevents leading edges of pulses from being displayed when time per CRT division is comparatively long.

Time base non-linearity may be confined to less than ½ of the first CRT division when sweep ***delay*** *instead of sweep* ***magnification*** *is provided. That permits leading edges to be displayed at practically any time per division.*

Ever Lose a Leading Edge?

The principal use for fast scopes is to look at fast signals, such as high-frequency sinewaves, very narrow pulses, or the risetime of very fast pulse edges. Scopes with built-in delay lines allow you to look at the leading edges of pulses when triggered on those edges. But when you decide to measure pulse width after measuring the risetime of a very fast pulse edge, you will have trouble with the average sampling scope if the pulses are microseconds wide and milliseconds apart. The same is not true of conventional scopes.

The trouble manifests itself in a very simple way. When you change the time per division enough to see the trailing edge of your pulse, the leading edge disappears! Often you can delay out and display the entire pulse following the one you are triggered on. But that involves a different set up and sometimes the period between successive pulses is not constant, causing excessive time-jitter in the display. At other times the sample rate may have to be reduced by a factor of 10 or more resulting in low sample-density and a flickering trace.

Why the Leading Edge Was Lost

The reason fast leading edges are not viewable on most sampling scopes when internally triggered and when the time scale is below about 50 or 100 ns/div, may be of interest. Most sampling scopes have only one fast-ramp generator circuit and the slope of this ramp is one thing that determines the time per division. In effect, any portion of the ramp may be magnified to reduce the time per division. The amount of magnification is another factor that determines the actual displayed time per division.

Because large amounts of magnification are invariably used to produce the shortest units of time per division, it is simple and convenient to let the fast ramp serve the additional function of producing time-base delay. For example, a ramp which is magnified 100 times can provide up to 100 screen-diameters of time delay.

Typically, an uncalibrated "time position" control on the front panel lets you select the amount of delay needed to position the signal of interest on-screen. When this time position control is set for minimum delay, the beginning of each scan corresponds to the beginning of the ramp. The first part of the ramp is always the most non-linear, and high amounts of magnification in this area may result in large timing errors over a large portion of the screen. There are two apparent solutions to this problem: (1) Adjust the circuits to skip the earliest part of the ramp; or (2) confine the non-linearity to a fraction of the first CRT division by not magnifying the ramp.

Sampling oscilloscopes have traditionally used the first alternative, skipping the earliest part of the ramp, and this is what causes fast leading edges to disappear at slower time per division settings. At the slower settings, fast leading edges are simply not sampled, therefore they can't be displayed.

Leading Edge Found

If you use only one fast ramp generator circuit and decide to confine the non-linear section to a fraction of the first division you lose delay capability for the slower ranges. However, by using two ramp generators, one mainly to delay the other, there is no penalty. With this arrangement you not only solve the problem but have a valuable conventional-scope feature—calibrated sweep delay. Borrowing familiar terminology we call one of the ramps the *delaying* sweep and the other the *delayed* sweep. The 5S14N and 7S14 bring calibrated delayed-sweep technology to the sampling world for the first time in an inexpensive sampling scope package.

Trailing Edge Tags Along Too

Using sweep delay instead of sweep magnification prevents another kind of problem—that of losing sight of a particular region of a waveform when merely trying to change the time per division. This happens if you inadvertently change the delay range when you mean only to change the time per division. This can easily happen when the delay-range switch and the time-per-division switch are operated by the same knob or are concentric interlocking knobs. In the 5S14N/7S14 two-ramp sweep delay system, the two knobs are not locked together. Therefore, the time delay doesn't change when you change the time-per-division knob.

Two Time Markers—A Happy Pair

In conventional delayed-sweep scopes the beginning of a bright segment of the trace identifies the end of the delay interval and the beginning of the delayed-sweep ramp. The sweep represented by the bright segment is displayed when the delaying sweep is selected as the CRT time base. When delayed sweeps are selected, the beginning of the trace corresponds to the beginning of the bright segment. This system works very well when identifying particular pulses in a pulse train, for example. But for delay measurements it leaves some doubt about where the delay interval commences.

What you would like to have is a bright spot in the trace, to show you where delay started. To produce such a bright spot at the fastest sweep rates of a conventional scope would require the generation of very narrow, high-amplitude pulses. But that tough requirement is not applicable to sampling scopes since the displayed equivalent-time sweeps are relatively slow. Accordingly, we've included just such a capability as a standard feature in the 5S14N/7S14.

With these plug-in units, two bright dots appear in the trace when the delaying sweep is selected. The first dot corresponds to time-zero and the second dot corresponds to the end of the delay interval—the point at which the delayed-sweep ramp starts. The position of the first dot is even controllable. With the DELAY ZERO control, it can be positioned anywhere over at least the first 9 divisions of the trace, allowing the user not only to know where delay starts but to choose where it starts. The second dot can be positioned anywhere on screen to the right of the first dot with the 10-turn precision DELAY TIME MULT dial. Each full turn of the dial

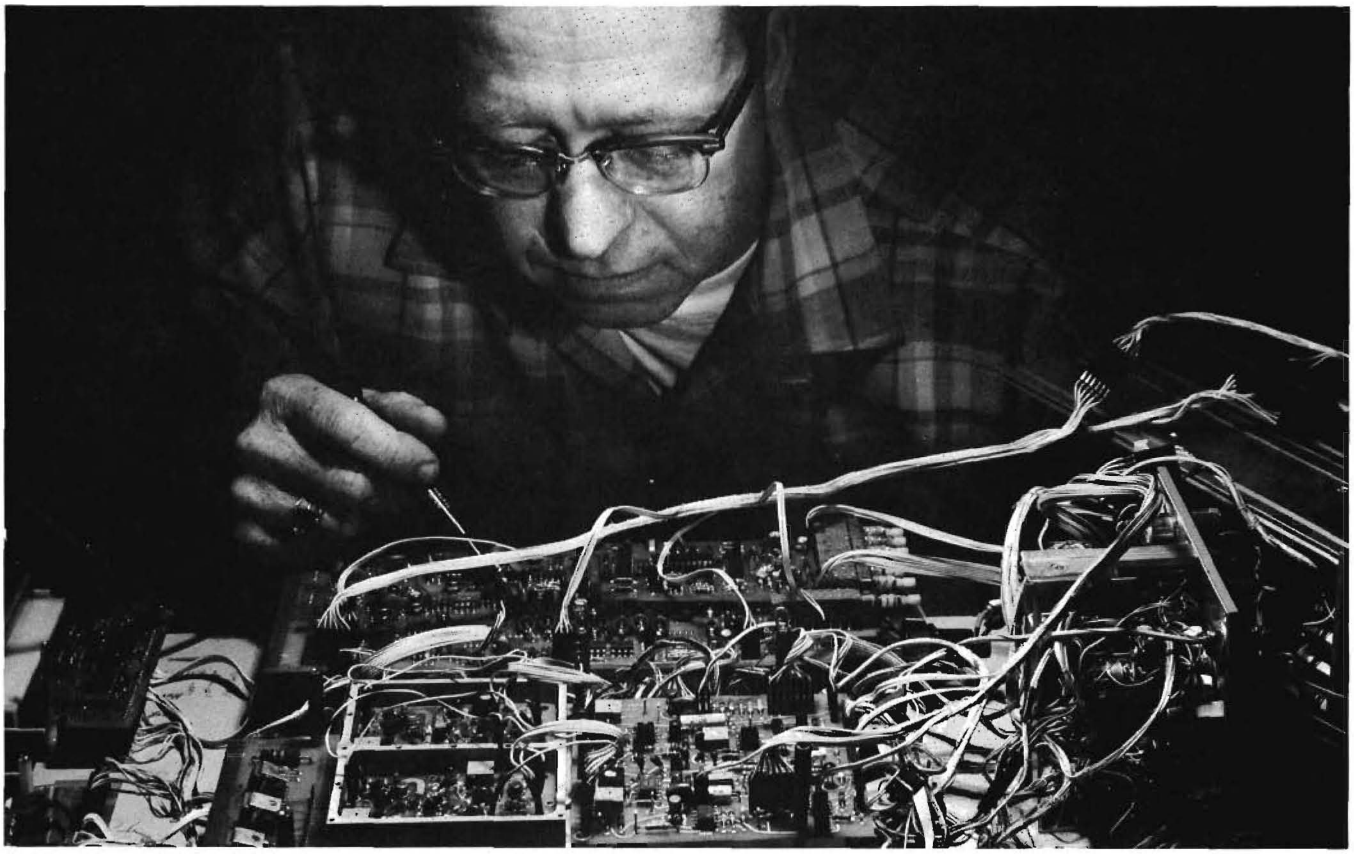


Fig. 2. Manufacturing economies are achieved by testing and calibrating circuit boards before installation in the plug-in

corresponds to the time of one division on the CRT. The position of the second dot can be made to coincide with the position of the first dot by setting the dial to 000, and if that position happens to be at the left edge of the screen it means the delayed sweep can be started with zero delay, or coincident with the delaying sweep.

To prevent the second dot from going off-screen when the DELAY TIME MULT dial setting is increased beyond that necessary to position the dot to the right end of the trace, the first dot is made to automatically back up. In other words, the 10-turn dial setting is always proportional to the separation between dots. The DELAY ZERO knob actually controls the position of both dots at the same time, maintaining a fixed separation between them until one of the dots reaches the end of the trace. At that point the knob may be turned further but without effect.

Two-Dot Time Measurements

The two dots identifying the beginning and end of the delay interval provide an accurate, unique and convenient way to make time measurements not even related to sweep delay. By positioning the two dots to the desired points on the waveform, the time between the points may be read from the 10-turn DELAY TIME MULT dial. This technique is particularly attractive for checking whether the time between the desired points is less than, or greater than, a predetermined amount selected by the dial. It is like being able to arbitrarily select the horizontal separation between any two vertical graticule lines to correspond to any specific time interval you may want to measure, e.g., 46.7 nanoseconds, and then being able to position the two lines any place across the screen.

Incidentally, you can even make corroborative checks on timing accuracy by seeing whether the number of CRT divisions between the dots equals the number of turns on the DELAY TIME MULT dial.

Two-Channel Delta Delay

One of the main reasons for having a dual-trace oscilloscope is to compare two signals. When the purpose of the comparison is to measure small time differences between the two signals, fast scopes are needed. Often the difference in signal delay through two similar cables is enough to impose a problem. For example, just a centimeter of difference in length between two identical cables can cause as much as 50-picoseconds difference in delay. When the cables are precisely the same length but have different propagation velocities there may be as much as 16 ps of difference in delay for each centimeter of length. A front-panel screw-driver control on the 5S14N and 7S14 lets you compensate for these differences (up to ± 1 ns) and, in effect, equalize the delay. You simply apply one signal to the inputs of both cables and minimize any difference in the display with the screwdriver control.

By pushing the CH2 INVERT button and the ADD button, the two sampled input signals should be equal and opposite in phase and amplitude, and nearly cancel each other to display a straight horizontal trace. With the CH2 INVERT pushbutton you can also make critical comparisons of two similar pulses that have opposite polarity.

Delta delay is also convenient when comparing the shapes of two similar signals that occur nanoseconds apart. You can superimpose them with the control after first selecting two input cables of unequal length to provide the right delay difference to bring the two signals into approximate coincidence.

Summary

The bandwidth of sampling oscilloscopes has increased by a greater factor than conventional scopes in the fourteen years since sampling scopes were introduced commercially, and the original gap in bandwidth has not yet been closed. Sampling scopes of 1-GHz bandwidth are no longer sophisticated or high priced. Some sell for less than conventional scopes that have half that bandwidth.

But sampling oscilloscopes have not been quite as easy to use or understand so they have not been readily accepted. A surprising number of response differences between sampling scopes and conventional scopes are not basic and may be eliminated by suitable design. The 5S14N and 7S14 are two new TEKTRONIX sampling plug-in units designed with these factors in mind. Some valuable new features not found in conventional scopes, or other sampling scopes, have been added.

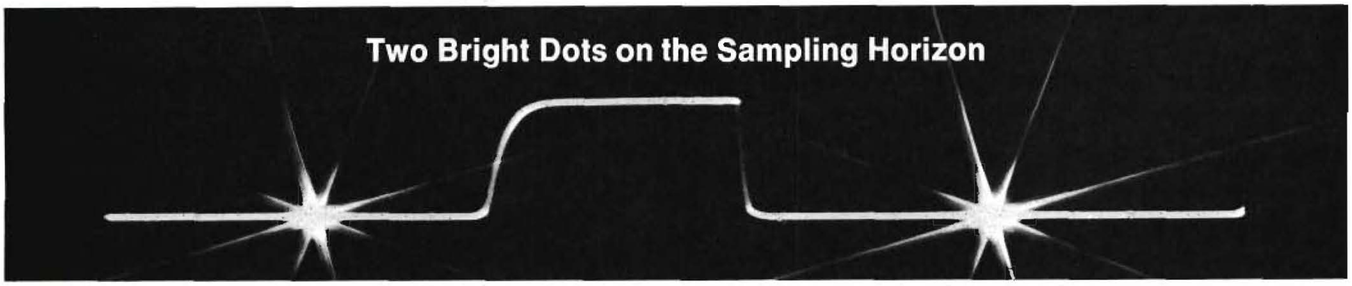
John A. Mulvey

John celebrated his 20th year with Tektronix last November. Most of this time, except for six years as a Field Engineer in the late 50's, he has been providing training and technical support to Field Engineers.

John is author of two Tektronix Concepts books—one on Semiconductor Device Measurements and one on Sampling Oscilloscope Circuits.

He enjoys golfing, fishing and philosophizing. Recently, with one of his three children, he has become a hot-air balloon enthusiast. His wife, Anne, will become a registered nurse this month fulfilling a lifelong ambition.

Two Bright Dots on the Sampling Horizon



Two bright new dots appear on the sampling horizon with the introduction of two new sampling plug-ins by Tektronix, Inc.—the 5S14N and 7S14. These two bright dots herald new measurement capability and operating ease for those of you making sampling measurements.

We might well name the dots "Alpha" and "Omega" since they mark the beginning and ending of a time window—a window that can be as short as 10 ns, as long as 1 ms, or any interval in between. You can set the window to an accuracy of 1% and position it anywhere on the sweep displayed on the CRT.

Actually, the two dots represent two points in time on the delaying sweep of the 5S14N/7S14. The position of the first dot is set by the front-panel DELAY ZERO control and the second dot is positioned by the DELAY TIME MULT dial. A broader discussion of the "why" and "how" of two-dot is presented in the article entitled "A Simple Sampling Oscilloscope."

Several applications for such a measurement capability come readily to mind; let's look at a few of the more useful ones.

Pulse Width Measurements

We often need to make pulse width measurements, and while they are not particularly difficult, they can be time consuming. Especially if the 50% points don't conveniently fall on the vertical graticule lines of the CRT. With these two dots it's relatively simple. The pulse to be measured is displayed using the Delaying Sweep. Sweep rate and vertical deflection factor are selected to present the entire pulse on-screen as you would for conventional pulse width measurements. The first dot is then set to the 50% point on the leading edge; the second dot to the 50% point on the trailing edge (see Fig. 1). The pulse width is then the product of the DELAY TIME MULT dial setting and the SEC/DIV setting.

If the rise and fall times are fast, you may notice that more than one sampling dot on the rise and fall are bright. This is because the bright dot occupies about one-tenth of a division on a horizontal trace. The beam is sometimes deflected vertically more rapidly than it is horizontally so the brightened portion appears longer vertically than horizontally. To avoid making an error in the time measurement, make sure you set the beginning of both the "start" and "stop" dots at the 50% points. Remember that the sweep is moving from left to right so the beginning of the bright dot is at the left.

A Variable Accurate Time Reference

In the opening remarks of this article we referred to the two-dot system as a time window that could be positioned anywhere on the trace. In production testing, this time window, or time reference, can be a real time saver. For example, suppose you need to check several devices for a pulse width of not more than 56.2 ns at the 50% points. The pulse is displayed on the Delaying Sweep with the SEC/DIV control set at 20 ns. Then the DELAY TIME MULT dial is set to 2.81 giving us a time interval of 56.2 ns. With the DELAY ZERO control the first dot is set to the 50% point on the leading edge of the pulse. Now note the position of the second dot. It should be at the 50% point on the trailing edge. If it is below the 50% point

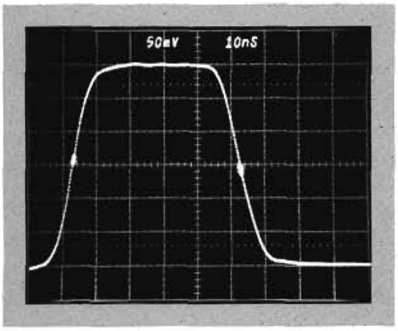


Fig. 1. Pulse width measurements with the two-dot system.

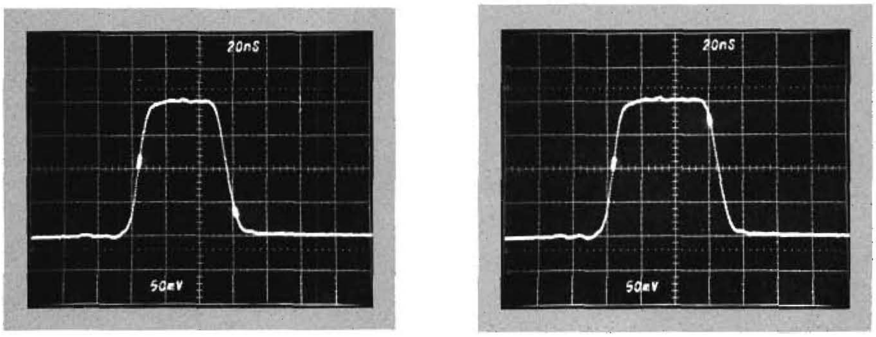


Fig. 2. Using two-dot to establish an accurate time reference on-screen.

A. Pulse width less than reference.

B. Pulse width greater than reference.

(see Fig. 2a), the pulse width is less than 56.2 ns; if above the 50% point (Fig. 2b), the pulse width is greater than 56.2 ns. Now you can rapidly test for proper pulse width on several devices without changing the setup. All you have to do is set the first dot to the 50% point on the leading edge and note the position of the second dot on the waveform.

Time Between Pulses Using Dual Trace

The two-dot system is also very useful for measuring the time between two independent pulses. The Teknique article in this issue discusses some of the precautions to be observed when making sampling dual-trace measurements. It would be well to review that article when setting up for this type of measurement.

Once you have the two pulses properly displayed on-screen, making the measurement is easy. Simply adjust the DELAY ZERO control to set the first dot to the 10% point on the rising edge of the first pulse. Then set the second dot to the 10% point of the rising edge of the second pulse, using the DELAY TIME MULT. (The 10% points are used to provide more accurate measurements between pulses with different risetimes.) The delay between the two pulses is now determined by multiplying the DELAY TIME MULT setting by the Delaying Sweep SEC/DIV setting.

You will notice there are now four dots on-screen (see Fig. 3). The first dot on each trace indicates the delay zero point, and the second dot the delay selected by the DELAY TIME MULT. You can ignore the two dots that are not indicating a measurement point.

Measuring Phase with Two-Dot

The two-dot system has several advantages when making phase measurements. Not only can they be made more quickly, but also more accurately since the time base accuracy doesn't have to be considered in the result. Fig. 4 shows the signals properly displayed for the measurement. Here again it would be well to refer to the Teknique article for setup procedures to minimize the possibility of error caused by differences in cable lengths, etc.

Once you have the signals displayed as in Fig. 4, the first dot is set to the point where the reference waveform first crosses the center. The DELAY TIME MULT is set to position the second dot to the point where the reference waveform crosses the center line one complete cycle later. Note the reading on the DELAY TIME MULT dial. The number of dial divisions corresponds to 360°, or one cycle. Now change the DELAY TIME MULT setting to move the second dot to where the second waveform crosses the center line the first time, and note the dial reading. The phase difference between the two signals is calculated using the simple formula:

$$\text{Phase Difference} = \frac{\text{Second DTM Reading}}{\text{First DTM Reading}} \times 360^\circ$$

Handy Reference Flags

Another convenient use of the two bright dots are as markers to flag points of interest on the display. For example, in the pulse train shown in Fig. 5, the marker is used to flag and identify the seventh pulse. To obtain this display, set up the system to show the complete pulse train. Turn the DELAY ZERO control fully counterclockwise to position the first dot to the left side of the graticule. Then, set the DELAY TIME MULT dial to 0 and slowly turn it clockwise to move the second dot across the screen. You can easily count the pulses as the bright dot moves across them until you are flagging the desired pulse. Note that the marker, or flag, is no longer on the correct pulse if the triggering or time-per-division is changed, or if the input signal changes.

Summary

This is but a brief overview of some of the measurement capabilities of the two-dot system, a standard feature of the new 5S14N/7S14 sampling plug-ins. Coupled with the operating ease of these new samplers, two-dot will help you get better answers, faster, in the arena of high-speed signals.

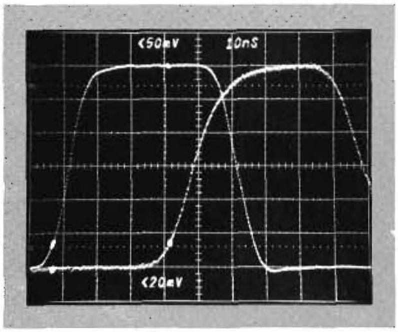


Fig. 3. Making time difference measurements between two pulses with two-dot.

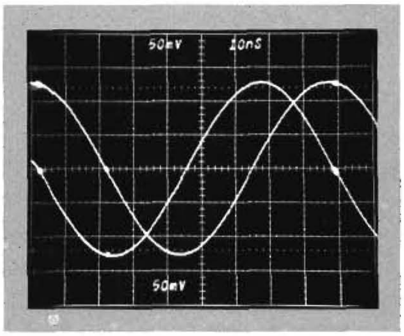


Fig. 4. Phase measurements are quickly and accurately made using two-dot.

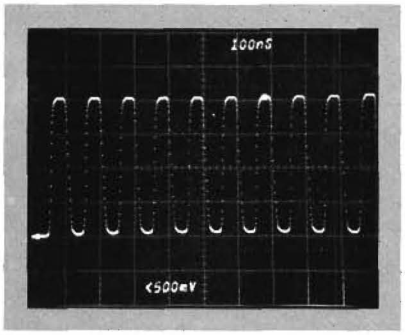
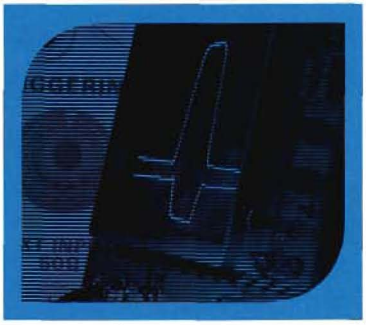


Fig. 5. Using two-dot as a flag on a complex waveform.

TEKNIQUE



Dual-Trace Time Difference Measurements with Sampling

Sampling techniques have been a vital part of electronic measurements for many years. However, both the complexity and high cost of sampling have limited its widespread application. With the introduction of the 5S14N/7S14 Dual-Trace Delayed Sweep Sampler (see feature article in this issue), sampling becomes easy to use and lower in cost than many conventional oscilloscopes. To aid the newcomer to sampling oscilloscopes as well as to refresh the techniques for the experienced sampling user, we present this review of some basic sampling measurements.

Dual-trace vertical systems, whether in sampling or conventional oscilloscopes, have greatly broadened the usefulness of the oscilloscope. Coupled with the unique features offered by sampling oscilloscopes, dual-trace operation makes possible some very useful and accurate measurements on the applied signals. In addition to being able to simultaneously view two signals and determine the time and amplitude relationship between them, dual-trace operation also allows interactive displays of the two signals; e.g., X-Y and added algebraically.

Accurate measurement of the time relationship between two independent signals is an important application of dual-trace oscilloscopes. Dual-trace sampling oscilloscopes provide new versatility for making these measurements. Many sampling oscilloscopes provide a delay-matching feature[1] which makes possible more precise time-difference measurements; these applications will describe the use of this feature in making accurate time measurements. While the same basic measurement techniques with which you may already be familiar can be used with sampling, some special precautions must be observed. Particular care should be taken in the areas of signal connections and cables; refer to the instruction manual accompanying your sampling system for further information.

Let's look at some of the basic techniques for measuring the time relationship between two signals with a dual-trace sampling system.

PHASE DIFFERENCE MEASUREMENT

Time difference between two sinewave signals of the same frequency may be measured using one of the signals as the reference and observing the phase difference between them. There are two convenient methods of measuring phase difference with a dual-trace sampling system. Both methods can measure signals up to the bandwidth limit of the vertical system. The main differences between these methods are in terms of accuracy and convenience.

Although these techniques can be applied to non-sinusoidal signals, we will only be looking at sinewave applications. With other than sinewave signals, the resultant display will depend on the waveshape of the applied signals. Also, the calculation methods given apply only to sinewave signals.

X-Y Phase Measurements

When displaying sinusoidal signals, the X-Y phase measurement method provides the familiar Lissajous display. This method can be used to measure the phase relationship of two identical frequencies, or to display the frequency relationship between two signals which

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[1] Standard feature on all current TEKTRONIX sampling oscilloscopes that can be used for dual-trace measurements.

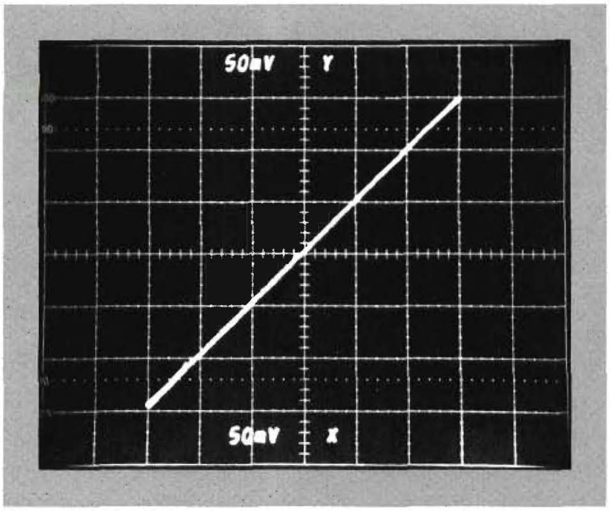


Fig. 1. An X-Y display of two sinewave signals in phase.

are harmonically related. Other uses for the Lissajous display are to check distortion of a signal or as a "null detector" for accurately matching phase. X-Y phase measurements with sampling can be made up to the bandwidth limit of the sampler. This is possible since sampling requires high-freqency circuitry only at the input to the system; low-frequency techniques are used through the amplifiers and to produce the display.

The prime prerequisite for the X-Y measurement is a dual-trace sampling system which has the X-Y display feature–some single-trace sampling vertical plug-in units can be installed in a horizontal compartment to provide the "X" portion of the display. To set up the units for correct display, set the vertical mode switch to X-Y and the time-base triggering controls to free run so it produces strobe pulses. Then, connect one of the signals to both inputs through a power divider and identical cables (the same cables which will be used for the measurement). Here's where the delay-matching adjustment comes in handy! Adjust this delay control for a straight-line display, slanted from the upper right-hand corner of the CRT to the lower left-hand corner. Now carefully adjust the deflection factors of both channels, using the variable controls as necessary, to obtain a display that is exactly six divisions both vertically and horizontally. Then, if necessary, readjust the delay for as straight a line as possible (if the sinewave has any distortion, it will be impossible to get a straight line). The display should appear similar to Fig. 1, indicating that the cables and two channels have been matched for minimum difference. If you're using a sampler that doesn't have the delay-matching feature, use the X-Y phase measurement method shown in Fig. 2 to determine how much phase shift is involved in the display. This inherent phase shift must be included in the final calculation of phase.

The smoothing controls on either channel should not be used unless the display requires it. If noise is excessive, on the display, adjust the smoothing controls of both channels the same amount (time-base triggering must be adjusted so the strobe pulses are triggered on one of the signals when using smoothing). Then, check that the display still indicates correct delay matching between channels. If necessary, repeat the delay-matching procedure.

Disconnect the power divider and connect the signals to be measured to the two inputs using the same cables as before. Check that the display is still six divisions both vertically and horizontally; adjust the deflection factor as necessary for the correct display. A difference in phase between the two signals is shown by the amount of opening in the loop. A circle display shows 90° phase difference and a straight line from upper left to lower right shows 180° phase shift. The phase difference between two signals can be measured accurately by using the method shown in Fig. 2 to calculate the sine of the phase angle between the two signals. The angle can then be obtained from a trigonometric table.

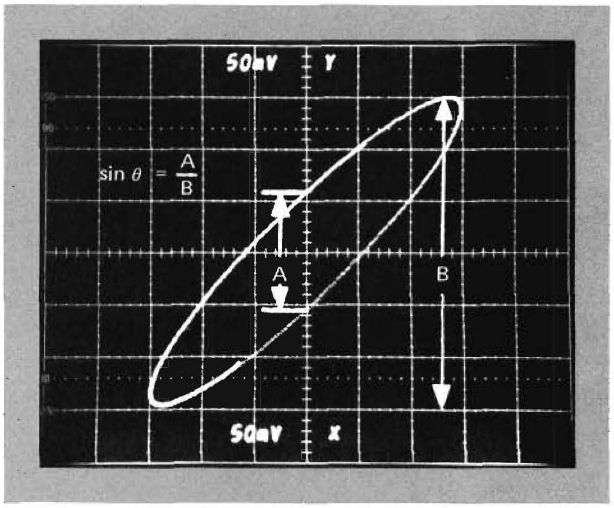


Fig. 2. Phase shift is easily calculated from this X-Y display.

If the instrument you are using cannot be adjusted to offset the inherent phase shift between the two channels and the cables, take this into account in the final calculation. It's often difficult to determine if this inherent phase shift should be added to, or subtracted from, the final result. To resolve this, use the method given under Dual-Trace Phase Measurements to determine if the inherent phase shift is leading (greater than 0°) or lagging (less than 0°). Maintaining one signal as a reference, repeat this check after measuring the phase on the Lissajous display to determine if the signal being measured is leading or lagging the reference. Now, algebraically add the inherent phase shift of the system and the measured phase shift between the signals to determine the overall phase shift.

The Lissajous figure can be used as a "null indicator" to adjust the phase shift through a device, or between devices. First, obtain an X-Y display as described previously. For best results, the sampler should have a front-panel delay control as units without this feature do not lend themselves well to this application. After the delay compensation has been correctly adjusted, apply the signals to the inputs through the cables used for setup. Then, calibrate the unit under test for a "null" indication, or zero delay, as shown by a straight line display from upper right to lower left. Other reference points can be chosen such as a full circle to indicate 90° delay, straight line from upper left to lower right for 180° delay, or any other display which indicates the desired amount of delay.

The "null" display can also be used for accurate frequency adjustment. After setting up the system with the reference signal, connect the signal to be adjusted to the other input. As the frequency of this signal is adjusted, a stable Lissajous display will be obtained only when the frequencies of the two signals are matched. At other frequencies, the display will appear to rotate on screen.

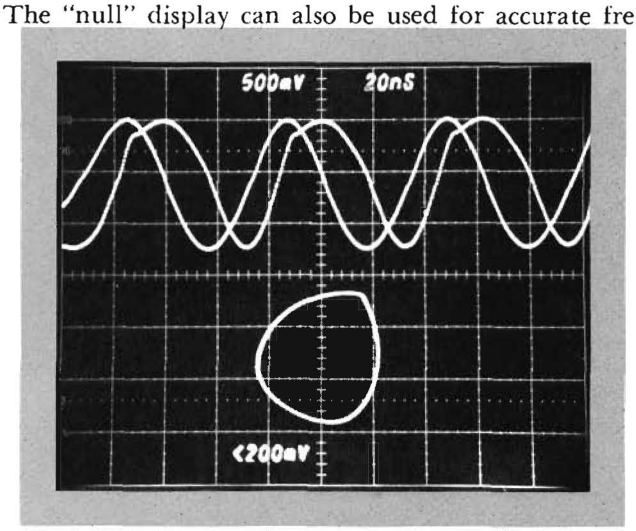


Fig. 3. Distortions in a sinewave signal are readily detected using an X-Y display.

Distortion of similar sinewaves is shown by irregularities in the proper shape of the Lissajous figure. After connecting the two signals to the inputs, adjust the front-panel delay control for a circular display; if this control does not have enough range to obtain a circular display, add delay in one channel with an additional length of cable. The distortion will appear as an anomaly in the display (see Fig. 3).

Dual-Trace Phase Measurements

This phase measurement method provides a very accurate means of determining phase, particularly where very small differences exist between the two signals. For this measurement, the signals must be the same frequency.

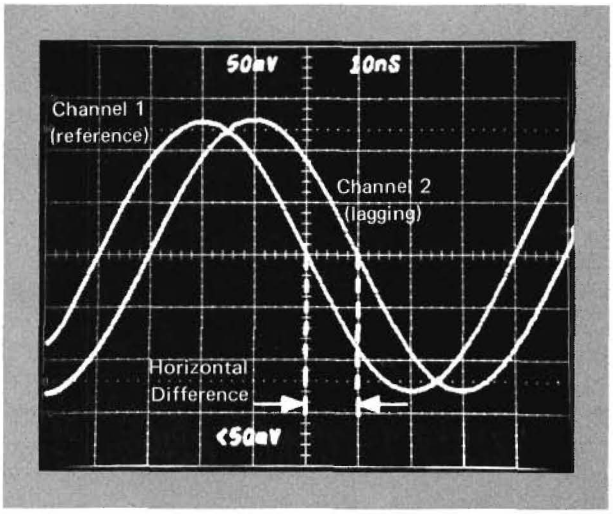


Fig. 4. Phase measurements are conveniently made using the time base and dual-trace display.

To set up the units for correct display, connect the primary or reference signal to both inputs through a power divider and identical cables (the same cables which will be used for the measurement). While displaying only one channel, adjust the time per division and the variable control so one complete cycle of the signal spans exactly eight horizontal divisions. This calibrates the system in terms of degrees/division which can now be expressed as 45°/division (i.e., 360° in the complete waveform, divided by 8 divisions of display equals 45°/division).

Now, set the sampler for dual-trace operation, triggered internally from the reference signal on one of the channels (if the sampler does not have the capability to internally trigger from only one channel, externally trigger the unit from the reference signal). With the same vertical deflection on both channels, adjust the front-panel delay control so the two traces coincide exactly. If your sampler does not have this feature, measure the horizontal difference between the two traces at corresponding points; then note the amount and direction of inherent delay (i.e., leading or lagging the reference) for use in the final calculation.

Disconnect the power divider and reconnect the reference signal to the channel which is providing the trigger. Connect the other signal to the remaining channel; adjust the vertical deflection factors if necessary, so the waveforms are the same height vertically. Now, measure the distance between corresponding points on the waveforms and multiply by 45°/division to determine the exact phase difference (see Fig. 4). If the inherent delay in the system could not be compensated, multiply this measured difference by 45°/division. Observation of the present display should indicate whether to add or subtract this inherent delay for the correct final result. For small phase differences, a more precise measurement can be made by increasing the time per division with the sweep magnifier or by using the delayed sweep for magnification (do not change variable control setting). The magnified horizontal rate can be determined by dividing the previous rate (45°/division) by the amount of magnification. Fig. 5 shows a typical magnified display.

This display can also be used as a "null indicator" similar to the X-Y method. First compensate for the inherent delay and connect the two input signals as described. Now, the delay of the unit under test can be adjusted for zero delay or phase shift. It can also be used to adjust the frequency of the unit under test. Since the display is triggered from the reference signal, the signal at the output of the unit under test will appear to "float" across the screen unless the two frequencies are closely matched.

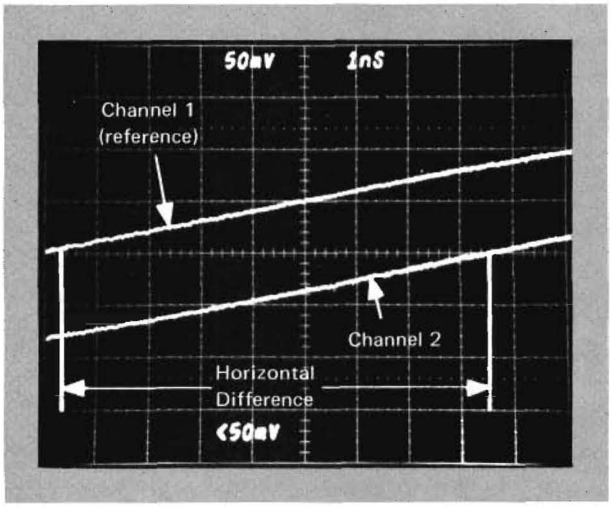


***Fig. 5.** High resolution multi-trace phase measurement with sweep rate increased 10 times.*

TIME DIFFERENCE MEASUREMENTS

The basic techniques of time-difference measurements are the same as for phase measurements. This measurement method is normally used when looking at pulses or two signals that are not time related.

In setting up the instrument for accurate measurement, connect the primary or reference signal to both inputs with a power divider and identical cables. Set the sampler for dual-trace operation, triggered internally from the signal on only one channel (if the sampler does not have internal triggering from only one channel, externally trigger the unit from the reference signal). Adjust the front-panel delay control so the two traces coincide exactly (this is easiest if the vertical deflection from both channels is the same). If your sampler does not have the delay compensation feature, note the amount and direction of horizontal difference (i.e., leading or lagging the reference) and take it into account in the final calculation.

Disconnect the power divider and reconnect the reference signal to the channel which is providing the trigger. Connect the other signal to the remaining channel. Adjust the vertical deflection factors, if necessary, so the waveforms are the same height vertically. Adjust the time per division so the points on the two waveforms between which the time-difference measurement is to be made are displayed within the graticule area (see Fig. 6). Now, measure the distance between the desired points on the two waveforms and multiply it by the time per division (take into account any inherent delay). This will provide accurate time difference if the horizontal variable control is in the calibrated position.

This display can also be used as a "null indicator". First compensate for the inherent delay and connect the two input signals as described. Then adjust the delay through the unit under test so the desired points on the reference trace and the output of the unit under test coincide. Of course, this setup can also be used to adjust the unit under test for a calibrated amount of delay using the graticule as a time reference to determine the correct amount of delay.

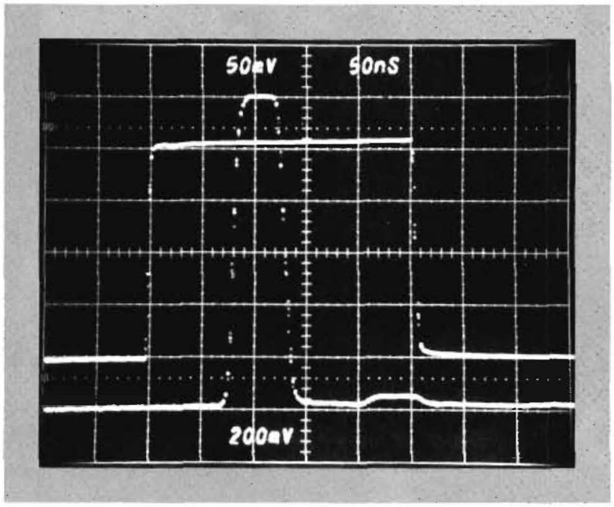
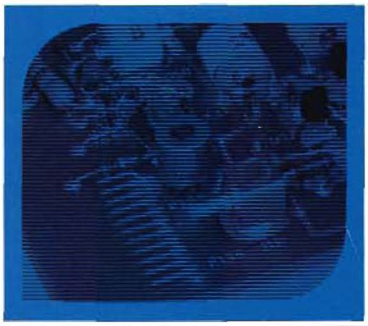


***Fig. 6.** Measuring time difference between two pulses.*

SUMMARY

Although the basic applications for sampling and conventional oscilloscopes are very similar, it's often easy to overlook some of the simple uses for sampling. Recent advancements in sampling instruments have made them easier to use and make many of these measurements easier and more accurate than with conventional oscilloscopes. We've only looked at some of the basic techniques for making accurate time measurements with a dual-trace sampling system. As you apply these basic techniques in your sampling measurements, you'll discover many new and useful applications for your sampling oscilloscope.



by Ken Lindsay Sampling Staff Engineer

Servicing the Sweep Circuit in the 7T11 Sampling Sweep Unit

In the March/April issue of TEKSCOPE, we looked at servicing the Trigger Circuit of the 7T11. This article provides a simplified method for adjusting and trouble-shooting the 7T11 Sweep Circuits.

Before beginning calibration or troubleshooting of the instrument, it's a good idea to review the basic theory of operation as given in the 7T11 Instruction Manual. This will help to identify the inter-relation of the stages within the Sweep Circuit so you can more easily locate problems or check the interaction of adjustments. A simplified block diagram of the 7T11, which identifies the active components associated with each block, is included in this article. The checkout procedure also includes information on instrument operation as it relates to the checks and adjustments to be made.

Initial Set-Up

1-4. Follow Steps 1 through 4 under initial Set-Up given in the previous article. Then, add the following steps:

5. Using a 5/16″ open-end wrench, remove the nut holding the 7T11 EXT TRIG INPUT jack to the front panel. Remove the jack from the front panel but leave the other end connected to the 7T11 Trigger circuit board.

6. Loosen the four locking screws that hold the Trigger circuit board in place; carefully lift the board loose. This board should always be handled with the utmost care so as not to break any of the delicate components or bend any of the closely spaced leads. Lift the whole circuit board up enough to slide the entire top edge of the board into the slot in the 7T11 upper chassis rail. This will support the trigger circuit board giving access to the adjustments and test points on the Timing circuit board.

Sweep Checkout

In the SEQUENTIAL equivalent time sampling mode, the 7T11 employs three separate ramp generators; a slow ramp generator and two fast ramp generators (refer to the simplified block diagram, Fig. 1). The Slow Ramp Generator produces a positive-going ramp from zero to about +10 volts with its slope controlled by the front-panel SCAN control. The main function of this ramp is to set a changing reference voltage for the Slewing Comparator and to indirectly produce horizontal deflection voltage to drive the mainframe amplifier. The output of the Slow Ramp Generator is applied to an inverting amplifier with a selectable gain from X.5 to X.001 determined by the front panel TIME/DIV switch. To check the operation of the Slow Ramp Generator, use a 10X probe and scope with an overall sensitivity of 2 volts/div. Check for a +10-volt ramp at TP636 on the Analog Logic circuit board with the slope adjustable with the SCAN control. In order to get a waveform at TP636, the TIME POS RNG must be set to 50 μs or faster and the trigger circuit should be free-running (push H-F SYNC button in).

One of the fast ramp generators is called a TTH (Time-To-Height) generator and is used to determine the basic timing of the 7T11. The slope of the TTH ramp output sets the basic timing and is controlled by the front-panel TIME POS RNG control. The stopped voltage level of the ramp, in conjunction with the Horizontal Amplifier, directly determines the horizontal drive voltage to the mainframe amplifier. The TTH

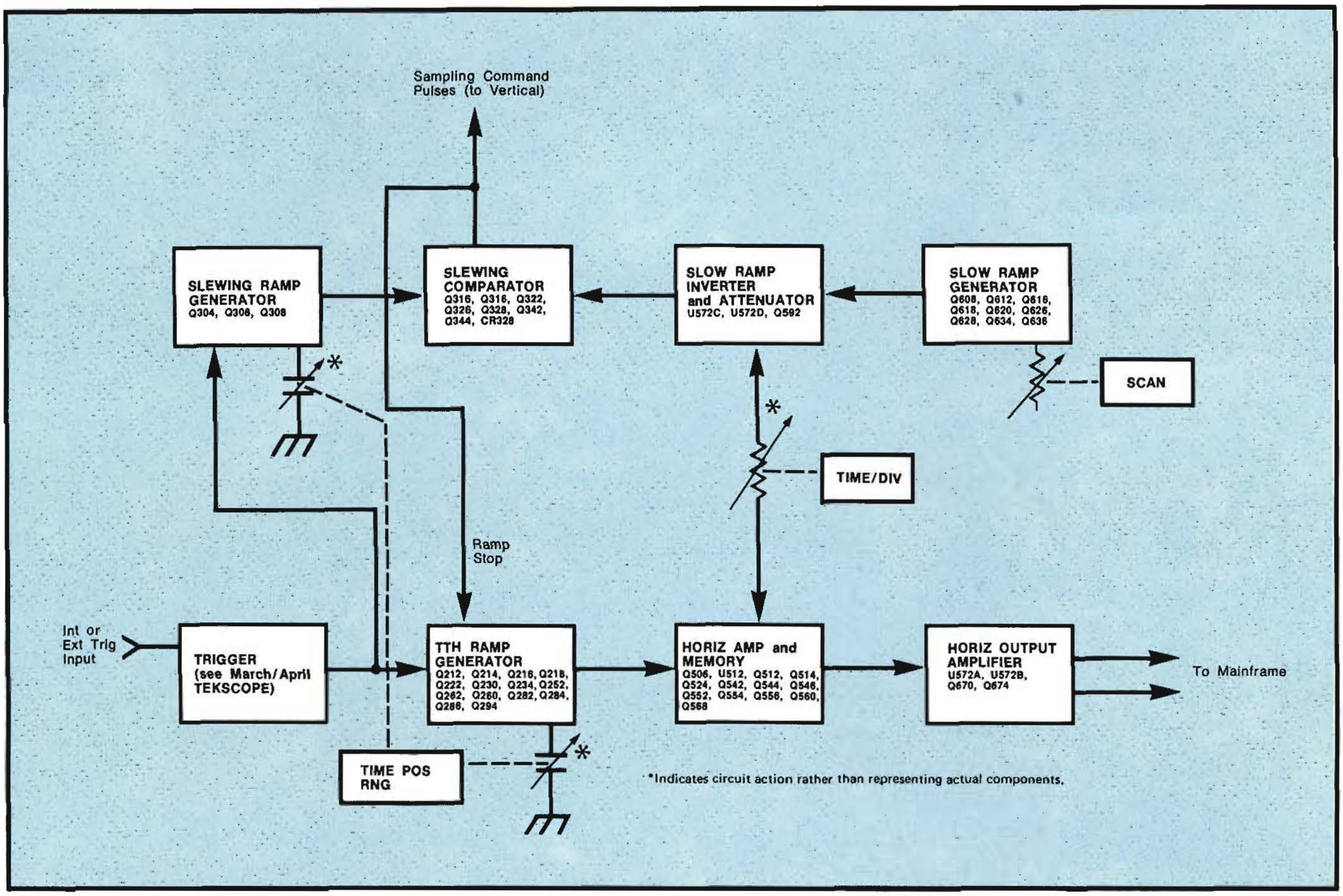


Fig. 1. 7T11 Sequential Mode block diagram (Components not shown are not active in this mode).

ramp output is always negative going in the SEQUENTIAL mode of operation, but may be positive, or produce no output at all in the RANDOM mode. The TTH ramp is initiated by an output from the Trigger circuit in the SEQUENTIAL sampling mode. To check the output of the TTH ramp generator use a 10X probe and scope with the overall sensitivity set at 1 volt/div. Connect the probe to TP286 on the Timing board and set the 7T11 controls as follows:

TIME POS RNG	50 μs
TIME/DIV	5 μs
TIME POSITION & FINE	Fully CW
SCAN	12 o'clock
REP	Pushed in
SEQUENTIAL	Pushed in
HF SYNC	Pushed in

The waveform at TP286 should be a succession of negative-going ramps starting at approximately zero volts and successively going to approximately −5 volts. If a component needs to be replaced in the TTH circuit, care should be exercised to match the lead length and component proximity of the part removed.

The other fast ramp generator, called the Slewing Ramp Generator, drives the other side of the Slewing Comparator. The slewing ramp runs at the same rate and slope as the TTH ramp and always runs negative. As with the TTH ramp, the slewing ramp is started by an output from the Trigger circuit. When the slewing ramp runs negative and reaches the level of the inverted slow ramp, an output is produced by the Slewing Comparator to two circuits. First, to the Vertical Sampling Unit to drive the Strobe Pulse Generator and cause a sample to be taken. The second is to the TTH Ramp Generator, stopping the run-down of the TTH ramp. This stopped level is then applied to the Horizontal Amplifier and Memory.

The Horizontal Amplifier is composed mainly of U512A, U512B, and U512D. U512A has a gain of X1, X2.5, or X5. Both U512B and U512D have a gain of X10. By changing the front-panel TIME/DIV switch, the overall gain can be changed between X1 and X500 in a 1, 2.5, and 5 sequence. As the gain of the Horizontal Amplifier is increased, the attenuation in the Slow Ramp Inverter is increased by the same amount. As a result, the Horizontal Amplifier amplifies a proportionately smaller section of the TTH ramp even though the gain is now greater. This provides a means of changing the TIME/DIV without altering the slope of the TTH ramp. The output of the Horizontal Amplifier is then

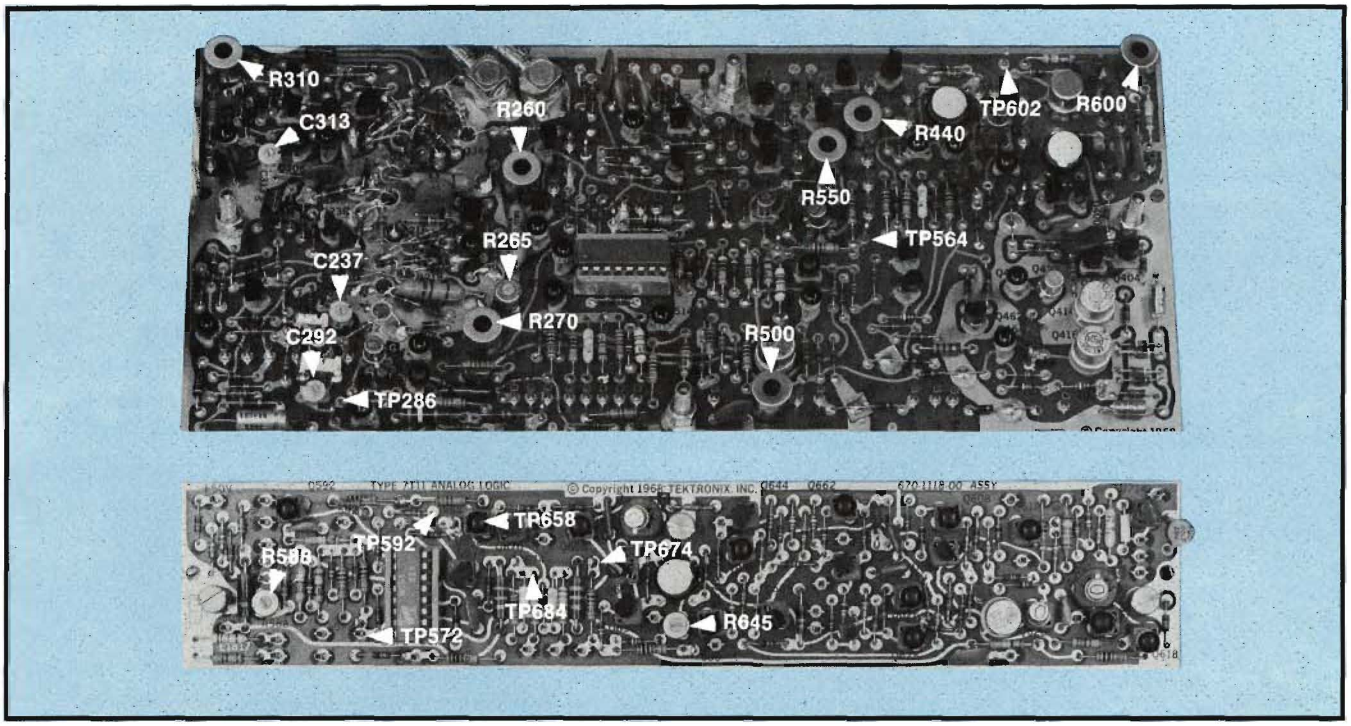


Fig. 2. Location of Sweep test points and adjustments.

gated through Q556 to the Horizontal Memory. The output of the Horizontal Memory may be checked at either the front-panel SWEEP OUT jack or TP564 on the Timing circuit board. Using a 10X probe and scope with the overall sensitivity set to 5 volts/div, check for a staircase output going from +5 to −5 volts with the rate controlled by the SCAN control (50 μs or faster range).

The output from the Horizontal Memory is applied to the Horizontal Output Amplifier. The Horizontal Output Amplifier, comprised of U572A and U572B, converts the staircase waveform input into the proper polarity waveforms to drive the 7000-Series mainframe. The output of U572A (at TP674) goes from −5 volts to +5 volts and the output of U572B (at TP684) goes from +5 volts to −5 volts.

Sweep Adjustments

This procedure provides a quick method for the experienced technician to adjust the 7T11 Sweep Circuit. For a detailed calibration procedure including description of the equipment used and typical waveforms, refer to the 7T11 Instruction Manual.

Refer to Fig. 2 for the location of adjustments and test points in this procedure.

1. Measure the voltage at test point TP602 on the Timing board using a precision DC voltmeter or differential comparator plug-in unit such as the 7A13. The voltage should be within about 1% of +10 volts. If not adjust R600 so it is.
2. Preset the 7T11 front-panel SWEEP CAL fully counterclockwise (ccw) and the 7T11 front-panel POSITION fully clockwise (cw). Set both front-panel TIME POSITION controls fully cw. Preset the Memory Gate Bal pot (R550) fully ccw.
3. Connect a 5X, 50 ohm BNC attenuator to the marker output of a time mark generator such as the TEKTRONIX 2901. To that, attach a BNC Tee and to the tee connect two 50 ohm cables (42 inch). To the far end of one cable attach a BNC-to-3mm adapter and to the other cable, attach a BNC-to-GR adapter. Set the 7S11 for 200 mV/DIV, the Dot Response pushbutton to NORMAL, and the DOT RESPONSE control with the white dot straight up. Set the 7T11 SWEEP RANGE switch fully clockwise for a 50 ms TIME POS RNG and set the TIME/DIV control for 5 ms. Press the HF SYNC pushbutton and a trace should appear. Position the trace with the 7S11 DC OFFSET control to center screen. Connect one of the two cables attached to the time mark generator to the Sampling Head in the 7S11 and the other to the EXT TRIG connector on the 7T11.
4. On the 7T11, push the 50Ω (EXT) button, the X1 TRIG AMP button, and the + SLOPE button. Push the 5 ms button on the Time Mark Generator and trigger on these pulses using the 7T11 TRIGGER LEVEL and STABILITY controls.
5. Note the position of the first marker and adjust the Real Time Zero pot (R500) so that the marker doesn't move to the left and moves no more than

about two divisions to the right while magnifying with the TIME/DIV control for any time per division from 5 ms through 50 μs. Be sure both TIME POSITION controls are fully cw while making this adjustment. Restore the TIME/DIV to 5 ms.

6. Adjust the Memory Gate Bal pot (R550) cw until the first pulse just barely starts to disappear.
7. Disconnect the markers from both the 7S11 and the 7T11 and free-run the trace using the STABILITY and TRIGGER LEVEL controls. The trace should free-run if the STABILITY control is fully cw and the TRIGGER LEVEL is set with the white dot approximately straight up.
8. Set the SCAN control fully cw. Push the REP and SEQUENTIAL buttons and change the SWEEP RANGE to the 50 μs TIME POS RNG. The time per division should now be 5 μs and there should be a free-running trace with about 5 to 10 dots per division. Push the MAN button. The SCAN should be able to move the beam left and right across most of the screen.
9. Connect a test scope to TP568 on the 7T11 Analog Logic board with a 1X probe. Set the vertical sensitivity to 50 mV/DIV and Input Coupling to DC. Free run the test scope time base at 50 μs/DIV.
10. Preadjust R588 for zero volts at test point TP658. Then, while rotating the SCAN control back and forth through about 180 degrees, preadjust R310 to minimize any shift in the DC level of the test-scope display.
11. Set the SCAN control fully ccw and adjust R645 so that the spot just becomes fully unblanked. Now set the SCAN fully cw and check that the spot does not blank. If it does, adjust R645 slightly ccw until it unblanks. Recheck that the spot does not blank with the SCAN control fully ccw.
12. Push the REP button and set the SCAN control to about 9 o'clock. Readjust R588, if necessary, for zero volts on the test-scope display. Fine adjust R310 to minimize any trace shift or bounce on the test-scope display.
13. Push the MAN button and set the front-panel SWEEP CAL and POSITION so the beam moves precisely 10 divisions between the left and right hand edges of the graticule while rotating the SCAN control throughout its range. It is normal for these pots to interact.
14. Reapply 5 ms time markers from the time mark generator to both the vertical and trigger inputs as before. Change the TIME POS RNG to 50 ms and the time per division to 5 ms and trigger on the markers. Adjust R265 for precisely one marker per division. The TIME POSITION controls may be used to line up the markers.
15. Change the TIME POS RNG to .5 ms. The time per division should now be 50 μs. Select 50 μs markers on the 2901 and trigger on them. Adjust R260 for precisely one marker per division.
16. Push the REP button and change the TIME POS RNG to 50 ns. Select 5 ns (sinewave) markers and trigger on them. Adjust C292 for precisely one marker per division.
17. Push the MAN button and set the TIME POSITION control cw. Using the test scope as before, adjust C313 for a minimum shift in DC level at test point TP658 as the SCAN control is rotated back and forth.
18. Push the REP button and set the SCAN control cw. Set both TIME POSITION controls fully cw and adjust C237 while observing how the beginning position of the trace moves. Adjust C237 to display as many of the early cycles of the sinewaves as possible without leaving a gap between the left edge of the graticule and the first dots in the trace while the time per division is changed from 5 ns to 100 ps.
19. Change the time markers to 50 ns, set the TIME POS RNG to .5 μs and the TIME/DIV to 50 ns, and trigger on the sinewaves. Switch to the MAN mode and position the beam precisely to center screen with the SCAN control. Push the RANDOM button and adjust R440 so there is no horizontal movement of the beam when switching back and forth between RANDOM and SEQUENTIAL. Push the REP button.
20. Disconnect the cables and the 5X attenuator from the time mark generator and place the 5X attenuator at the input to the sampling head. Connect a BSM-to-BNC adapter to the 7T11 PULSE OUT connector and connect a 50-ohm cable between the PULSE OUT and 5X attenuator on the sampling head input.
21. Free-run the sweep at 5 ns/DIV (50 ns TIME POS RNG). Push the RANDOM button and display the PULSE OUT. Use the TIME POSITION controls to place the step-signal near the left edge of the screen. Set the 7T11 to 1 ns/DIV and center the step signal. Set the 7S11 to 20 mV/DIV and center the signal with the 7S11 controls. Adjust the 7S11 DOT RESPONSE controls for the cleanest trace. Adjust R270 through its range while keeping the step on screen and set for the cleanest rise on the step signal.

This completes the timing adjustments on the 7T11. Replace the coax leads at J344 in the 7T11 and J430 in the 7S11. Fasten the 7T11 Trigger board in place and reinstall the TRIG IN jack in the front panel.

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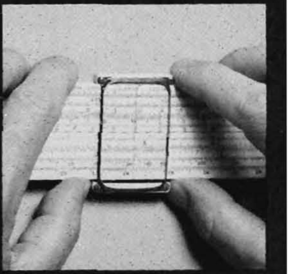

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Tektronix calculators are put through the same rigorous environmental testing as our oscilloscopes.

Cover: Man, from earliest times has used his fingers for counting. He's still using them today. Only now they count vast numbers simply by pressing the keys of a scientific programmable calculator such as the TEKTRONIX 31.

The Tektronix Calculator —It All Adds Up

With this issue of TekScope, Tektronix announces its new calculator line, featuring the TEKTRONIX 21 and 31 programmable calculators.

We're going to the great length of a TekScope issue to introduce these calculators, because many people, seeing their low prices, might assume them to possess far less capability than they actually have. And, to make descriptive problems worse, it's the kind of sophisticated capability that a specifications brochure can only begin to impart (although an excellent brochure *is* available on the 21 and 31).

So, in addition to designing, manufacturing and servicing the calculators, we have accepted the added task of helping new users, and potential users, discover their great usefulness, through various means.

Catch phrases like "natural math format" and "keyed-in programming" help spread the word that these calculators *are* a time-saving pleasure to use.

But there's another story. For, beyond doing the most commonly useful tasks uncommonly well, the Tektronix calculators will also do a wide range of tasks commonly thought of as impossible for machines in their price range.

With the components and accessories of the Tektronix calculator line, users can custom-fit their price/performance requirements, up to a very powerful level of sophistication. Options in memory capacity and silent printers can easily add up to the flexibility and power of a minicomputer, and yet sit compactly at deskside, to do as much as the user's ingenuity can demand.

Tektronix is committed to helping users tax their calculators to the utmost. Our specially inducted, experienced calculator sales people have gained an expertise *cum laude* in calculator capability. New and potential users will be encouraged to lean on them.

Additionally, a user's newsletter, called ArithmaTEK, will provide valuable access to the latest applications and ideas from the field.

As you read the following articles, we think you'll find that the contributions to this endeavor from all the Tektronix areas of expertise, add up to a calculator line worth looking into—even a whole issue's worth.

Larry Mayhew, Vice President
Information Display Division

The Calculator and You

Long before we trotted off to our first day at school we were being taught the rudiments of mathematics. Ask a little fella how old he is and he'll usually respond by proudly holding up two fingers. If perchance he is three, there may be a moment's hesitation while he decides which three fingers to unfold.

It didn't take long for the problems we encountered to outstrip our ability to count and display them using our fingers; even with the capacity added by removing our shoes and socks. And so we turned to machines. The abacus, perhaps the oldest known model, was invented in pre-Christian times and is still in use in many countries. Much more recently, in the last century, Charles Babbage built the first true forerunner of today's computer, a mechanical "analytical engine." Today, through the miracle of solid-state technology, we have fantastic calculating ability right at our fingertips. These new machines are called scientific programmable calculators—programmable meaning the calculator can remember and execute operations or keystrokes previously entered, and scientific referring to the mathematical capability of the machine.

There is just one problem—you can't walk up to one of these machines and solve even a basic equation without some special training. The first scientific calculators were developed by men who had previously built computers. Their approach produced a kind of "minicomputer" rather than a mathematical machine, and required special techniques for entering equations.

Now, two new calculators from Tektronix, the TEKTRONIX 21 and 31, offer a fresh approach to solving your problems. These machines have an easy to use language that follows the same rules of algebra that you learned in high school. Equations are entered into the calculators just as you would write them on the blackboard. Let's look at a few examples:

Here is how you write the mathematical expression on paper—	Here is how you write the mathematical expression on the Tektronix keyboard (after pressing $\boxed{\text{CLEAR}}$).
EXAMPLE: $4-3\times2=-2$	$\boxed{4}\boxed{-}\boxed{3}\boxed{\times}\boxed{2}\boxed{=}$ $-2.$
EXAMPLE: $\frac{(2+3)\times5}{(4+6)}=2.5$	$\boxed{(}\boxed{2}\boxed{+}\boxed{3}\boxed{)}\boxed{\times}\boxed{5}\boxed{\div}\boxed{(}\boxed{4}\boxed{+}\boxed{6}\boxed{)}\boxed{=}$ 2.5
EXAMPLE: $5\times4^{(.25+5/4)}=40.$	$\boxed{5}\boxed{\times}\boxed{4}\boxed{\times^{a}}\boxed{(}\boxed{.}\boxed{2}\boxed{5}\boxed{+}\boxed{5}\boxed{\div}\boxed{4}\boxed{)}\boxed{=}$ $40.$

You will note that the calculator observes mathematical heirarchy in solving each equation.

Coupled with the ease of problem entry is unequalled ease in programmability. This means your problem solving capability is not limited to those programs supplied by the calculator manufacturer. It's easy to write your own programs and enter them into the machine. In fact, with the "user definable" capability, discussed later, you can modify your calculator at will to communicate in terms unique to any discipline—be it mathematics, statistics, engineering, banking, physics or whatever.

Now let's take a closer look at these new calculators.

Data Entry

The data entry portion of the keyboard looks similar to that on any other scientific calculator. But there the similarity ends. With the TEK 21/31 keyboard you have perfect freedom to enter numbers using scientific notation, floating point, or you can mix them. The machine will accept and display them in whichever format you choose.

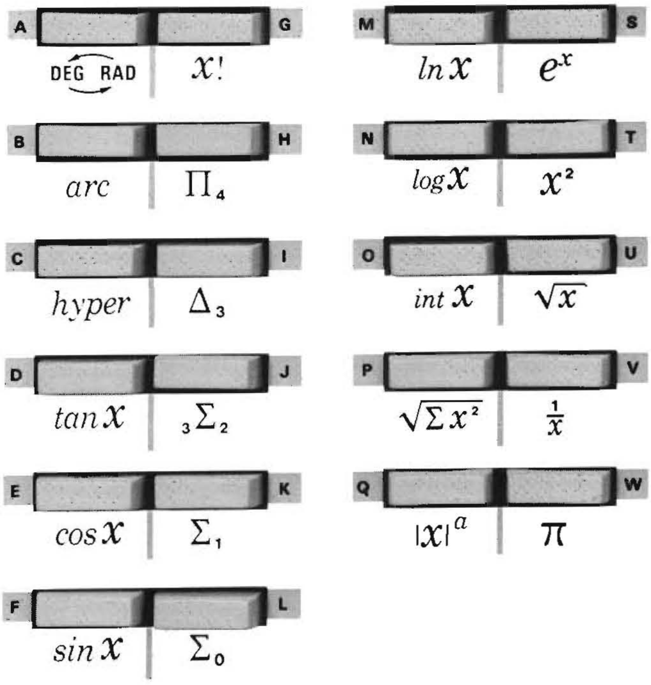
Data entry is limited to a ten-digit mantissa. However, the calculator performs all mathematical calculations with a twelve-digit mantissa in order to maintain accuracy and reduce round-off errors. The twelve-digit mantissa is maintained in the working registers of the calculator and rounded to ten digits for display. The two extra mantissa digits are known as "guard digits."

The Display and You

You can enter up to twelve digits in the display; ten digits in the mantissa and a two-digit exponent. And the display warns when you're in trouble—it will flash if you exceed the range of the calculator, if you ask it to perform an undefined math operation, or if a power failure occurs. The status lamps are another vital part of the display. They tell you if the calculator is working in degrees or radians, is in the learn mode, busy, stopped waiting for data, or if an address is incomplete.

The Math Keys—and More

The math keys, ordinarily used in performing math operations or in evaluating mathematical expressions within the capability of the calculator, are pictured at right.



The math keys are the same on the TEKTRONIX 21 and 31. However, on the 31 you'll find them doing double, or even triple, duty. By using a keyboard overlay, these twenty-four keys become user-definable. This means you can label your own subroutines in terminology familiar to you and execute them simply by pressing their respective keys. And you don't lose the math functions covered up by the overlay. They're instantly available by lifting off the overlay.

Alpha, too

The math keys, and all other programmable keys on the TEKTRONIX 31, have another function. In conjunction with the optional thermal printer, they provide alpha capability including a full set of punctuation, plus other symbols. They're available just by depressing the $\boxed{\text{ALPHA}}$ key. And the alpha keys can be used to label subroutines, too.

The TEKTRONIX 21 Memories

The TEKTRONIX 21 data registers and program memory are separate entities. The data portion consists of the ten "K" registers, each capable of storing any number within the range of the calculator. By double use of the K key (K_{K_0}), the registers can be addressed indirectly permitting, for example, simplified loading routines.

The basic program memory can handle 128 program steps or key strokes. You can expand to 256 or 512 steps with available options. The memory is continuous but may be addressed at eight equally spaced points using the f_0 through f_7 keys.

For permanent program storage the TEKTRONIX 21 comes standard with a Mag-Card reader. Each card can store 256 program steps. You can transfer programs from the card into the calculator, and vice versa, in an easy, straightforward manner.

The TEKTRONIX 31 Memories

The TEKTRONIX 31 offers considerably greater memory capacity. Here, again, the data registers and program memory are separated.

In addition to the ten "K" registers, the basic TEKTRONIX 31 has 64 data registers called "R" registers. Options are available to expand to 1000 "R" registers.

The basic program memory consists of 512 program steps, and you have a variety of options to choose from providing up to 8,192 steps.

Program control in the 31 differs from the 21 in that the f-key feature is replaced by a single program memory with subroutine capability.

MEMORY OPTIONS FOR THE TEKTRONIX 31

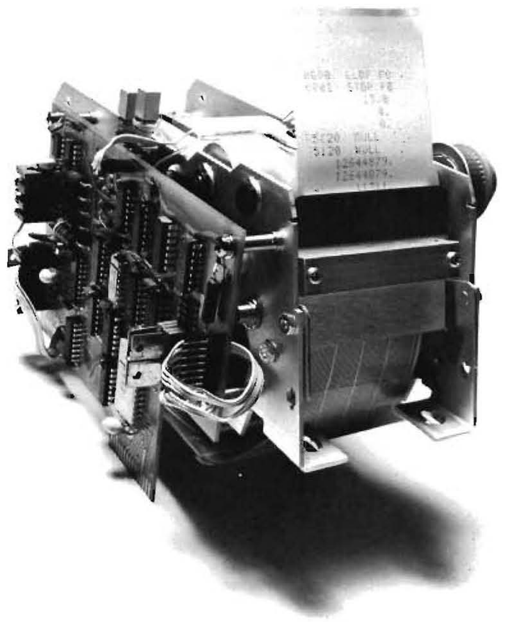
STEPS	REGISTERS					
	128	192	256	448	640	1000
1024	Option 2					
1536		Option 3				
2048			Option 4		Option 5	Option 8
3584				Option 6		
5120			Option 7		Option 9	
8192			Option 10			

Permanent storage capability for the 31 comes in two forms. An endless-loop tape cartridge storing up to 6000 program steps provides easy transfer of programs to or from the calculator.

This is augmented by PROM's (Programmable Read Only Memories). PROM's give you the capability to define your calculator the way you want it, instead of the way someone else thinks you want it. For example, by sending Tektronix the programs (in any form: cards, listings, etc.) you want incorporated in a PROM, you can define up to twenty-four keys as your own special set of keys. And with the User Definable Overlay you can label these keys with any nomenclature you choose. The PROM's and overlay sets can be exchanged in a matter of seconds to completely redefine your calculator.

The Printer is Optional

A compact thermal printer is available as an integral part of either the TEKTRONIX 21 or 31. The one for the 31 is a bit smarter—it gives you full alphanumerics plus a complete set of punctuation marks. The 21 is numeric only. Executing a program on the 31 is a breeze when you have the alphanumeric printer option. The calculator can tell you what to enter and how, or label the results in terminology you understand.



Summing It Up

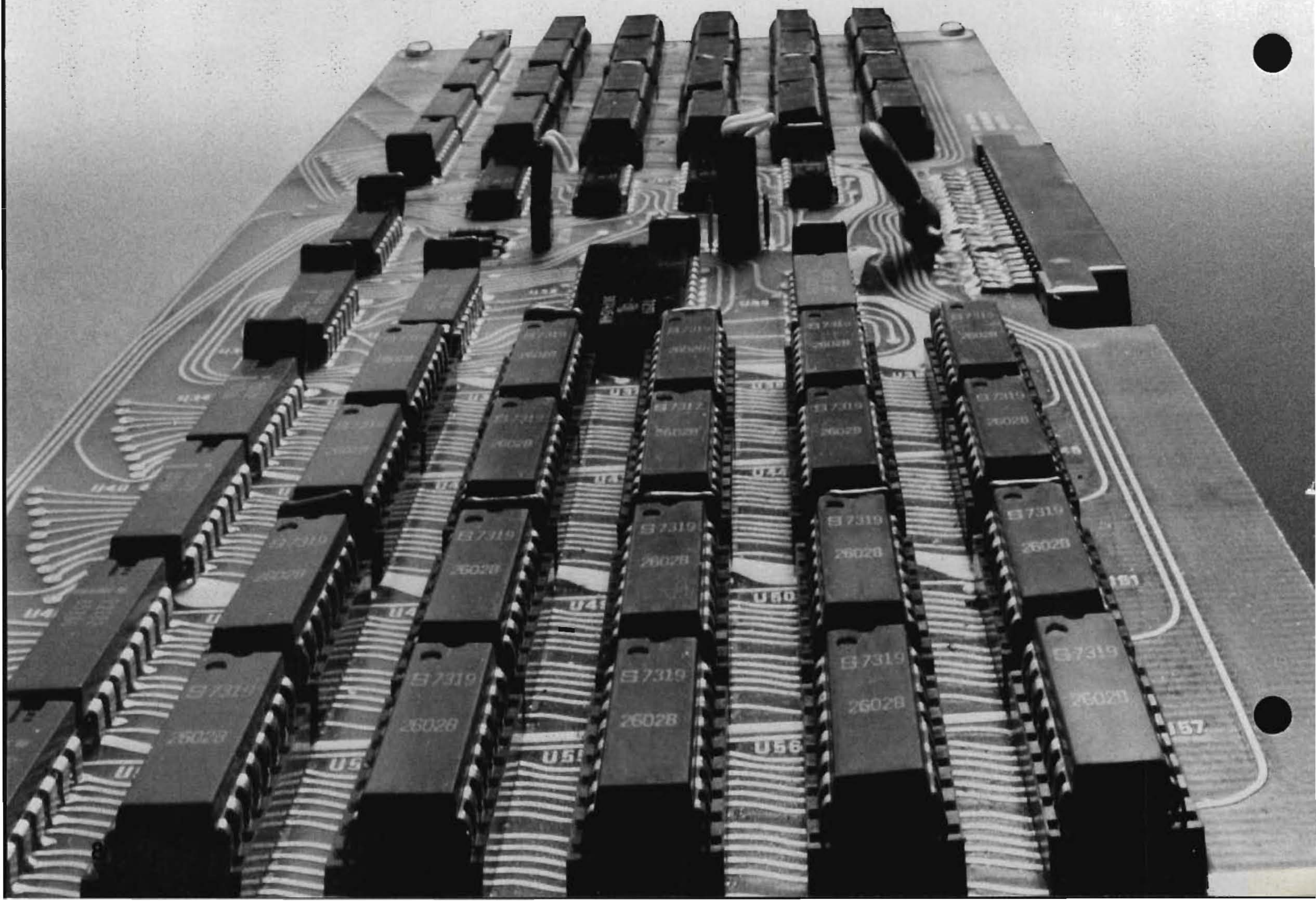
The TEKTRONIX 21 and 31 Calculators are designed to communicate in a language we all know—mathematics. You can walk up to them and start a "conversation" without need for an "interpreter." Whether your level of mathematics is elementary or sophisticated, you'll find them able to understand your problems, and come up with the right answer—every time.

A Close-up Look

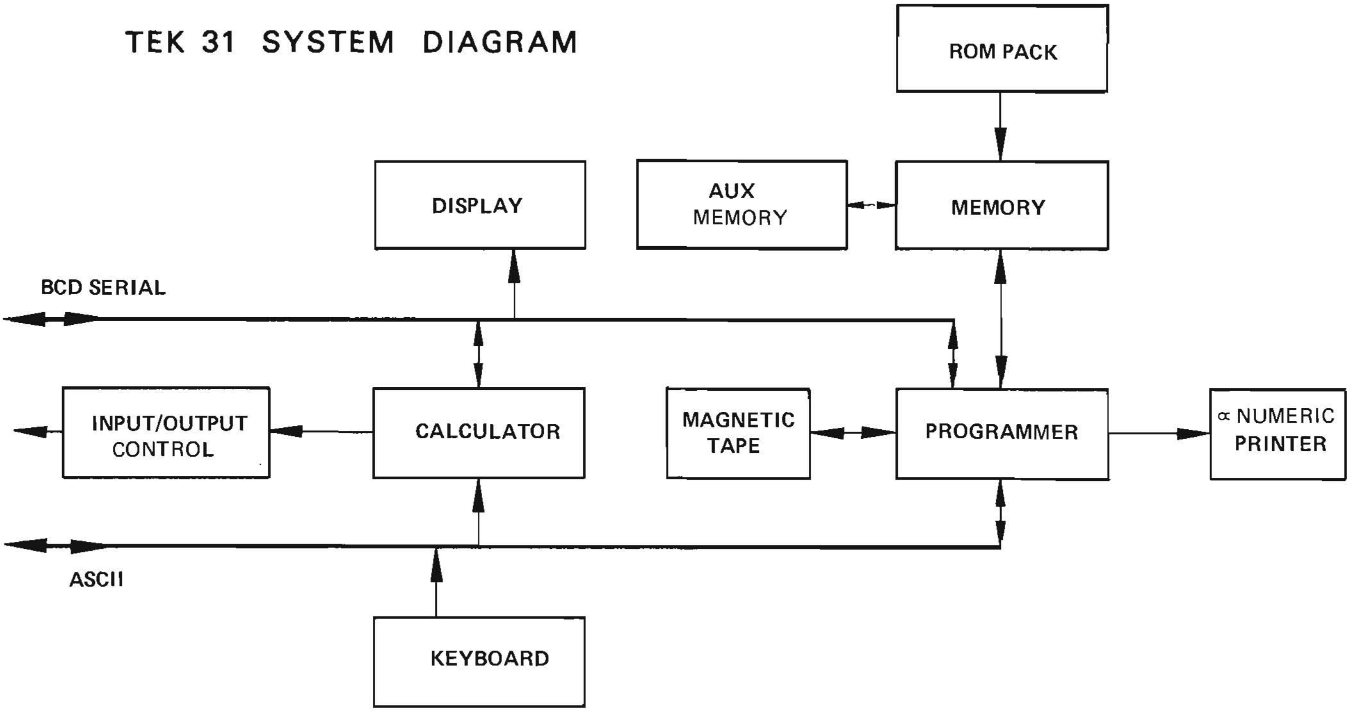
What's one of the first things you do when you're looking over a new car? Trip the latch and see how much power they've crammed under the hood. Let's "lift the hood" on the TEKTRONIX 21 and 31 Calculators and see how they stack up.

MOS LSI

You'll find the latest in MOS LSI design used in the calculator portion of the machine. Fifteen new MOS chips developed by Tektronix include a BCD arithmetic and logic unit, working registers, K storage and microprogram control ROM's.



TEK 31 SYSTEM DIAGRAM



Modular Construction

Another feature, apparent at first glance, is the limited number of printed circuit boards in the calculator; ten to be exact. This means fewer board interconnects for improved reliability. And service time is reduced by simplifying board replacement. Because calculators are less expensive to build using the large board concept you receive a double benefit—lower acquisition cost and lower maintenance cost.

Magnetic Storage

Standard equipment on the TEKTRONIX 21 and 31 includes a magnetic storage transport mechanism. The 21 uses a magnetic card while the 31 uses a continuous-loop tape with the added capacity it affords.

Options—More Than Frills

You can add horsepower as well as operating convenience to your calculator with the variety of options available for the TEKTRONIX 21 and 31. Among the most useful are the quiet thermal printers. The mechanism is the same in both machines with added electronics in the 31 providing alpha as well as numerics. Printing is accomplished by applying power to a row of 80 hybrid resistors deposited on the edge of a ceramic substrate. The resistors are arranged in 16 groups of 5 dots each. Seven cycles of applying power and advancing the stepping motor drive to the paper results in sixteen 5 x 7 dot-matrix characters printed across the paper.

Plug-in PROM's are available for both the 21 and 31. You can have your favorite programs kept inviolate and ready for use at a moment's notice without tying up the flexible magnetic storage portion of the calculator.

And, finally, a wide range of memory options lets you expand the capability of your machine as your needs expand. For example, in the 31, by simply plugging in IC's and changing a few jumpers you can have up to 8192 program steps and 256 registers or 2048 steps and 1000 registers.

How It Fits Together

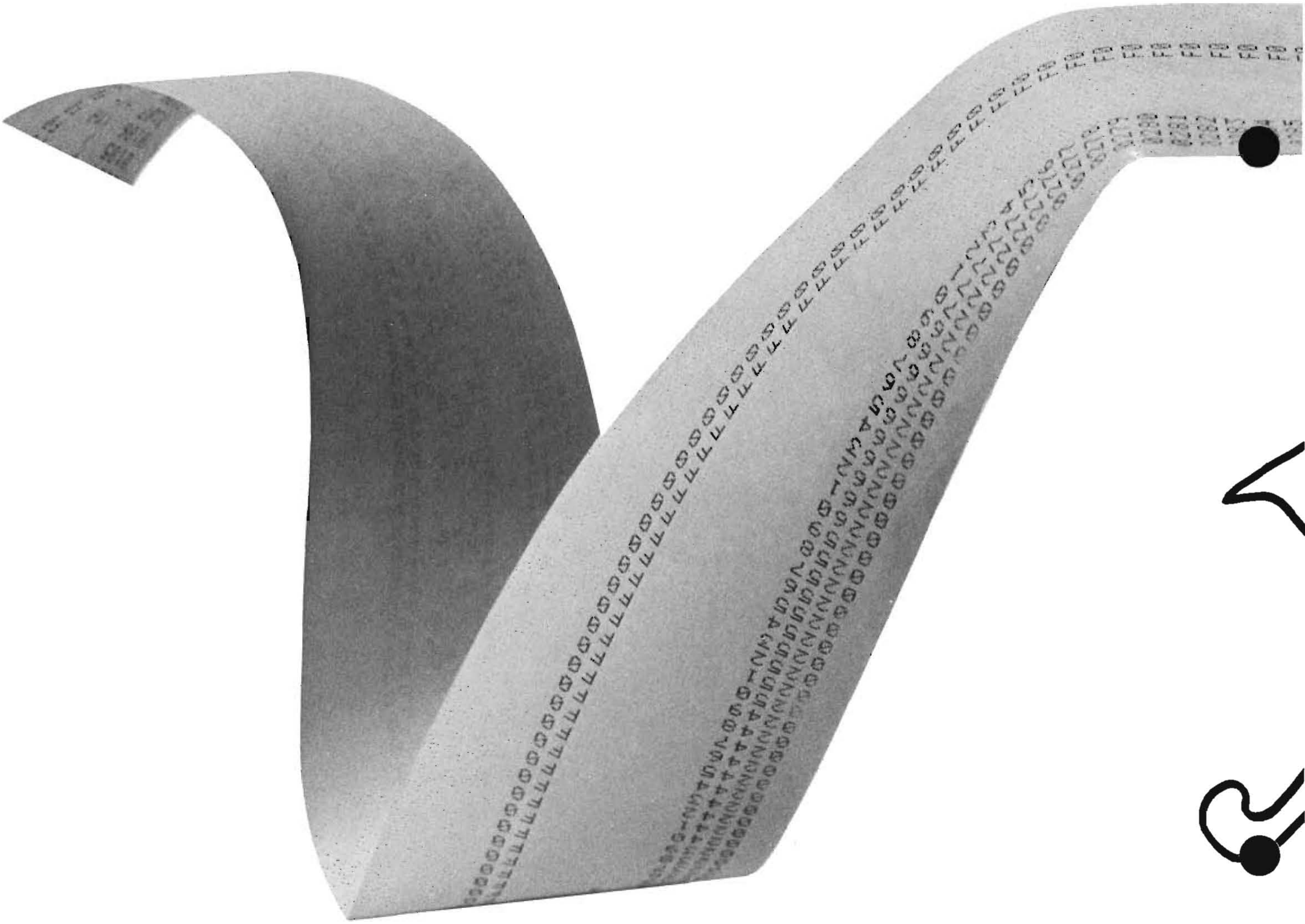
The diagram above shows the main communication paths in the TEKTRONIX 31. In the 31 the ASCII bus can be used for direct memory access as well as for alpha and control. The transfer into and out of the programmer's memory can be at a megabaud rate—comparable to that in the minicomputer and fast enough to make external disk storage feasible. The single I/0 port provides for a variety of peripherals to be connected to the 21 and 31 including the TEKTRONIX 4010 Graphics Terminal.

Summing It Up

Every feature of the TEKTRONIX 21 and 31 is designed to provide you with a high performance, highly reliable, expandable calculator at the most reasonable cost achievable today.

PROGRAMMING—As Easy As Writing a Formula

An important measure of calculator performance is the ease with which you can enter numbers or variables. Equally important is the ease of programming. You don't need a course in computer language to program the TEKTRONIX 21 and 31 Calculators—they understand plain mathematics.



The TEKTRONIX 21

Let's look at how you would program the TEKTRONIX 21 for solving a simple equation.

The problem is:

$$\frac{A}{(1-B)} = C \quad \text{with} \quad \begin{array}{l} A \text{ stored in } K_1 \\ B \text{ stored in } K_2 \\ C \text{ stored in } K_3 \end{array}$$

To program the solution, you would press:

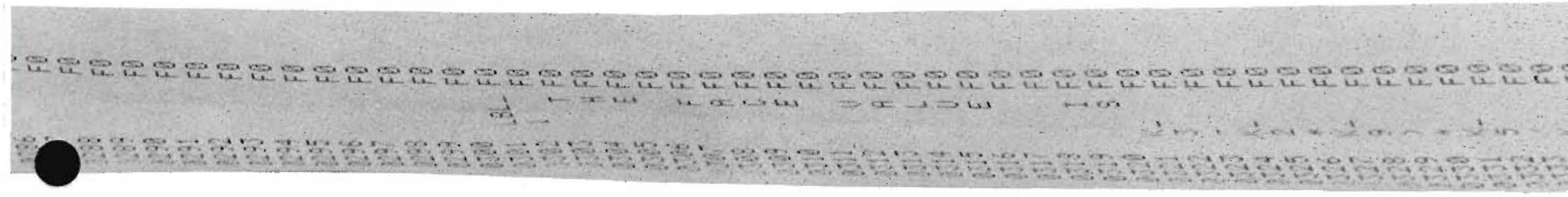
$\boxed{\text{GO TO}}\ \boxed{f_0}\ \boxed{\text{LEARN}}$
$\boxed{K}\ \boxed{1}\ \boxed{\div}\ \boxed{(}\ \boxed{1}\ \boxed{-}\ \boxed{K}\ \boxed{2}\ \boxed{)}\ \boxed{=}\ \boxed{K}\ \boxed{3}\ \boxed{\text{END}}$
$\boxed{\text{LEARN}}$

The $\boxed{\text{GO TO}}\ \boxed{f_0}\ \boxed{\text{LEARN}}$ steps puts the calculator in the LEARN mode at the beginning of block f_0. Then you simply key in the formula. The $\boxed{\text{END}}$ step follows to branch back to the beginning of f_0 and to display the result. The last $\boxed{\text{LEARN}}$ brings the calculator out of the LEARN mode. As you can see, the procedure for programming an equation amounts to little more than just keying it into the machine.

To run this program, you store the values of A and B in K_1 and K_2 and press $\boxed{f_0}$. Storage is done by pressing $\boxed{=}$ and then the register. For example, you press $\boxed{\text{CLEAR}}\ \boxed{6}\ \boxed{=}\ \boxed{K}\ \boxed{1}$ and $\boxed{\text{CLEAR}}\ \boxed{3}\ \boxed{=}\ \boxed{K}\ \boxed{2}$ to store 6 in K_1 and 3 in K_2. Addressing a register without the preceding $\boxed{=}$ recalls the stored contents into the display.

While this simple program lets you solve the equation, you would normally want to do more. You usually perform data entering as part of the program, and, if your calculator has the optional thermal printer, you usually want to print the data and the results. With these additional operations you would key in:

$\boxed{\text{GO TO}}\ \boxed{f_0}\ \boxed{\text{LEARN}}$
$\boxed{\text{CLEAR}}\ \boxed{\text{STOP}}\ \boxed{=}\ \boxed{K}\ \boxed{1}\ \boxed{\text{PRINT}}\ \boxed{\text{CLEAR}}$
$\boxed{\text{STOP}}\ \boxed{=}\ \boxed{K}\ \boxed{2}$
$\boxed{\text{PRINT}}\ \boxed{K}\ \boxed{1}\ \boxed{\div}\ \boxed{(}\ \boxed{1}\ \boxed{-}\ \boxed{K}\ \boxed{2}\ \boxed{)}\ \boxed{=}\ \boxed{K}\ \boxed{3}$
$\boxed{\text{PRINT}}$
$\boxed{\text{PAPER FEED}}\ \boxed{\text{END}}$
$\boxed{\text{LEARN}}$



When the program is being executed, it stops for data A at the first STOP and data B at the second STOP. This data is printed, and then the calculated result C is printed. The PAPER FEED is inserted for formatting the print-out.

To run this program, press:

$\boxed{f_0}$
$\boxed{6}\ \boxed{\text{CONT}}$ (value of A)
$\boxed{3}\ \boxed{\text{CONT}}$ (value of B)

There are eight keys designated f_0 through f_7. Depending on the length and complexity of your programs, these keys can provide direct access to eight separate programs, or, on the other extreme, provide eight programmable branch points in a large program. The basic calculator has 16 steps per f-block; options are available to expand this to 32 or 64 steps per block.

So far we have dealt with an example programmed in f_0 and perhaps extending into block f_1 on the basic machine. On the following page is a typical engineering problem which requires six blocks to program. The program includes conditional branching (the $\boxed{\text{IF} \geq 0}\ \boxed{f_1}$ sequence) and also indirect addressing (the $\boxed{K}\ \boxed{K}\ \boxed{8}$ sequence). The example also illustrates how the solution is translated directly into program steps.

DETERMINANT OF A COMPLEX 2 x 2 MATRIX

Calculating the determinant of a complex 2 x 2 matrix is often performed in engineering, usually as a step in doing parameter conversions. For example, converting 2-port "y", parameters to "z" parameters is a matrix inversion operation which involves calculating the determinant.

This problem is programmed here, not because it is particularly difficult, but because it illustrates some of the programming features that make the Tektronix 21 a powerful, yet simple to use calculator.

The determinant is calculated by the formula-

$$\det \begin{bmatrix} K_0 + iK_1 & K_2 + iK_3 \\ K_4 + iK_5 & K_6 + IK_7 \end{bmatrix}$$

$$= K_0K_6 - K_1K_7 - K_2K_4 + K_3K_5 + i(K_0K_7 + K_1K_6 - K_2K_5 - K_3K_4)$$

In the program, values are first entered into the K-registers. Then the real and imaginary parts of the determinant are calculated as written above and these results are printed and stored.

Example:

$$\det \begin{bmatrix} 1 + i & 2 + i3 \\ 4 + i5 & 6 + i7 \end{bmatrix} = 6 - i9$$

PROGRAM STEPS

		0	1	2	3	4	5	6	7	8	9
f0	00	CLR	=	K	8	PF	f1				
f1	10	CLR	STOP	=	K	K	8	PRNT	K	8	+
	20	1	=	K	8	+/–	+				
f2	30	7	)	IF≥0	f1	K	0	x	K	6	–
	40	K	1	x	K	7	–				
f3	50	K	2	x	K	4	+	K	3	x	K
	60	5	=	K	8	PF	PRNT				
f4	70	K	0	x	K	7	+	K	1	x	K
	80	6	–	K	2	x	K				
f5	90	5	–	K	3	x	K	4	=	K	9
	00	PRNT	CLR	PF	END						

COMMENTS

K_8 is a subscript that is set equal to zero initially.

STOP = K_{K_8} Each matrix element is entered and stored in K_0 through K_7. $K_8 + 1 = K_8$. The subscript is increased by 1.

If ≥ 0 f_1. These steps and the steps just preceding are to test whether K_8 and the remainder of the program can be executed. (If not, the program branches back to the beginning of f_1 so that the next matrix element can be entered).

Program performs the computations just as written in formula above.

With indirect addressing, the contents of one register serves as the subscript of another. For example, if 5 is stored in K_8, then pressing $\boxed{K}$ $\boxed{K}$ $\boxed{8}$ displays the contents of K_5 (K_{K_8} is K_5).

The operations and procedures presented thus far demonstrate how easily you can program the TEKTRONIX 21. In addition, most of the math routines you normally use in problem solving are already in the machine and available at the press of a key.

Supporting the TEKTRONIX 21 are mathematics and statistics program libraries. Mathematics programs range from simple triangle solutions through solutions of third order matrix equations, manipulation of vectors and complex numbers, and numerical integration and solution of differential equations. Included in the Statistics library are programs for means, standard deviations, analysis of variance, tests and distributions (X^2, t, F, etc.), and curve fitting (linear, parobolic, 3-variable curve fitting, etc.).

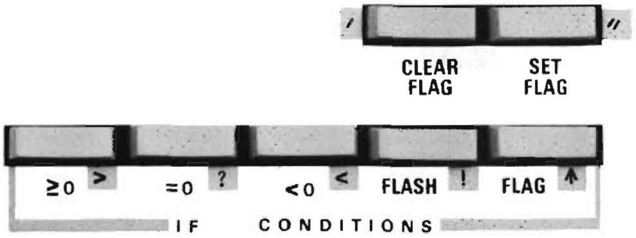
The TEKTRONIX 21, with its programming capability, optional thermal printer and built-in magnetic card reader, can serve the scientific, educational and business communities very effectively.

The TEKTRONIX 31

For those of you with more sophisticated needs, there is the TEKTRONIX 31—one of the most powerful calculators on the market today. It has the same easy-to-use mathematical language and the same mathematical keys as the 21. But the TEKTRONIX 31 offers more capability in several areas.

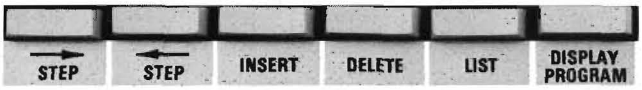
Considerably more program steps and data registers are available to you through options. And continuous-loop magnetic tape cartridges can hold up to 6000 program steps per cartridge for unlimited program storage.

Five "if" conditions provide branching based on whether the condition is satisfied. Three keys detect whether the display is ≥ 0,=0, or <0. Another key de-



tects whether the flag is set, and another detects whether the display is flashing as caused, for example, by taking the square root of a negative number. Thus, the FLASH key can be used to detect whether the roots of a quadratic equation are real or complex.

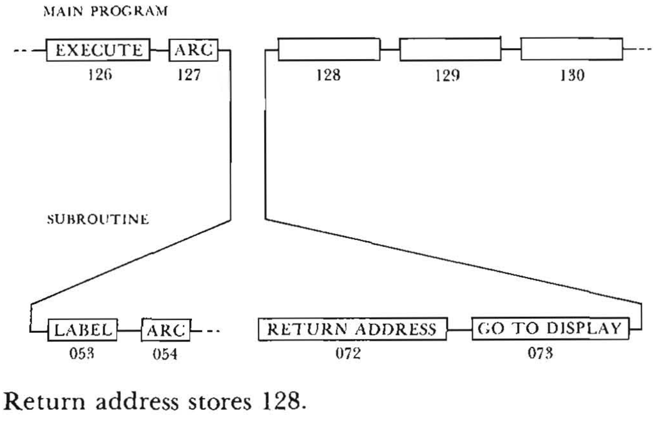
Full editing capability is provided in the 31. You can step forward or backward, delete, insert, list the program, or display the program.



The alphanumeric capability provided by the thermal printer is a powerful programming tool enabling you to include printed instructions in your programs. And you can use alpha to greatly extend the number of program labels available. You can have up to 151 labels in the 31—lots of flexibility for even the most complex programs.

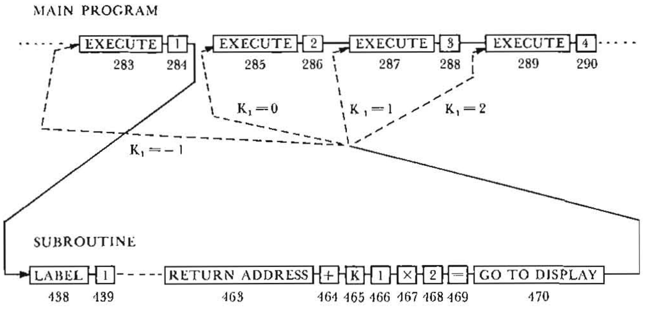
Any part of a program may be labeled by using LABEL and another key for the symbol. This part of the program is then executed by pressing EXECUTE and the appropriate symbol. Labeling provides branch points for "if" conditions or can be used to denote the beginning of separate, independent programs.

You may also use labeling to create subroutines. Usually a subroutine is called from a main program. Upon completion of the subroutine the calculator returns to the main program at the proper location. To accomplish this on the 31, the RETURN ADDRESS GO TO DISPLAY sequence is programmed at the end of the subroutine as follows:



Return address stores 128.

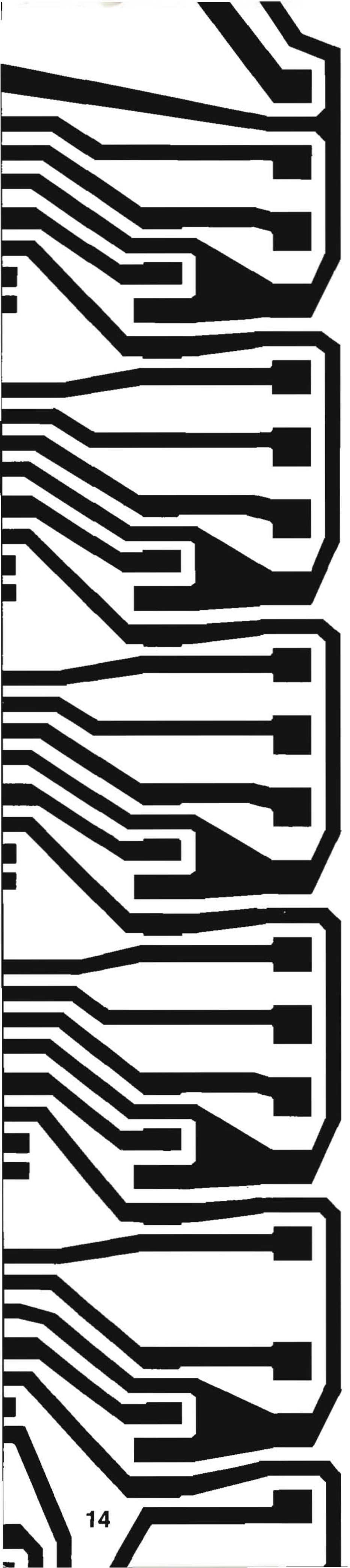
One very useful feature of the TEKTRONIX 31 is that the most recent return address can be displayed, stored in a data register, or become part of a mathematical expression. Even logic within the subroutine can be used to determine where to branch to next. For example, a program may look like this:



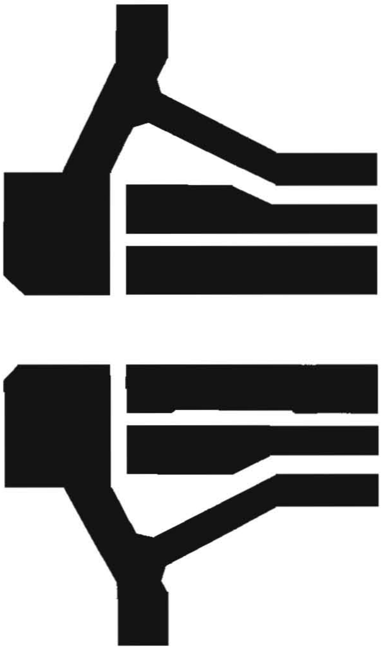
Here the stored return address is 285, but a value of K_1 other than 0, either established before executing subroutine 1 or else established by logic within subroutine 1 causes the subroutine to branch back to the main program at locations other than 285.

Conclusion

The ease with which you can program the TEKTRONIX 31 belies its outstanding problem solving capability. The large program step and register memory, plus the "if" conditions and subroutine capability enable you to do operations on the 31 that were formerly relegated to computers—and for considerably less money. Mathematics and statistics libraries are available to put the 31 right to work for you. With the ability to interface with sophisticated peripherals such as the TEKTRONIX 4010 Graphics Terminal, under program control, the TEKTRONIX 31 can serve as the "heart" of a complete system.



Reliable by Design



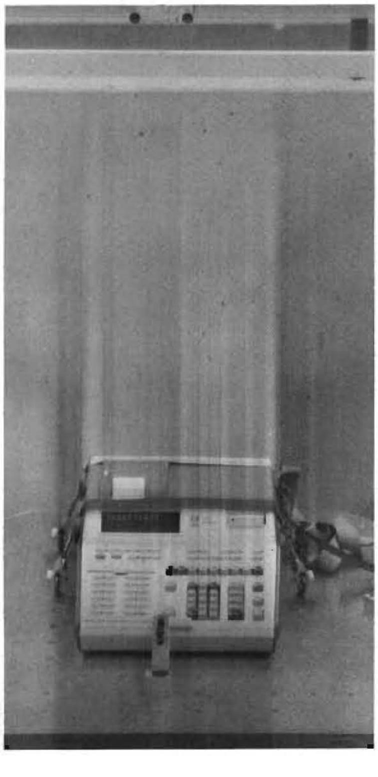
In the early days of electronic equipment, some manufacturers operated under an illusion. They believed users would be nice to their products. So they engineered and built accordingly. But customers had other ideas. Equipment was being carried off to jungle, mountain and desert on plane, truck and pack mule. Product performance was not enhanced by this treatment. Cases cracked, coronas flared, cables broke and connections corroded. Users were unhappy.

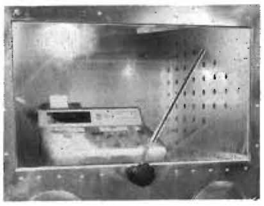
Consequently, the "kick-it-and-maybe-it'll-work" syndrome was born. But kicking didn't help nor did cussing out the manufacturer. It was not the golden age of electronics.

Early in the game, we at Tektronix learned about all the strange places people want to set up shop, and reliability testing became a routine part of the design process for every product. Today, over 5,000 square feet of engineering area are dedicated to punishment, and six engineers and their assistants devote full time to heaping abuse on brand new products. We think our products should operate accurately under all environmental conditions and if there's a design flaw, we want to be the first to know. That's why every new machine is subjected to a series of severe operating conditions. This electronic obstacle course reveals the physical durability of the equipment and the reliability of all operating functions.

Tek's new calculators are no exception.

Because they're not only new products but of a new compact design, the 21 and 31 are prime candidates for rough handling. As a result, they are subjected to the same rigorous reliability testing as our other products. Test parameters involved are heat, humidity, altitude, shipping simulation and just plain old dropping. These take place individually and in combination.





Shake, Rattle and Roll

Features and functions don't mean much without sound structural engineering. The "shake table" highlights undesirable mechanical resonance or flexing. The table provides a 0.015″ vibration from 10 to 50 c.p.s. in three axes. If anything has a tendency to slip or shift it will do it now.

Turn Up the Heat!

Heating and cooling can have a devastating effect on electronic components. Parts could swell, connections crack or circuits short. Thermal cycling in the test oven usually reveals this kind of problem. For thirty hours the calculators endure 0° to 50° C. cycling. During the test, actual machine operation is observed. The engineers can immediately pinpoint any failure or erroneous results. But what if something was weakened but is still operating perfectly? Back to the shake table. A part with hidden thermal damage will usually make itself known during this second vibration test.

Taking a Fall

The survival rate of transported goods is a sometimes thing. Dropping, banging, squeezing and carelessness take their toll. This stage in reliability testing gives our engineers an answer to the question of product self-defense. TEK's drop test plunges the calculators into a fall ending with a 30 G stop. A sample of each model is then secured in its own special packing case and banged up and down on its corners. As if this weren't enough abuse, the packaged products are then dumped into an ersatz truck bed and bumped, shoved and pushed around for several hours as they would be under actual trucking conditions.

Up, Up and Away

Next, a session in the altitude chamber. TEK guarantees flawless product operation up to 15,000 feet. This test provides both you and Tektronix with the confidence. To make sure a non-operating product will survive even higher, chamber air is pumped out til pressure equals that at 50,000 feet. There's a reason. Planes often reach that height and most cargo holds aren't pressurized.

Sweating It Out

Moisture does strange things to electronic devices. It'll carry impulses to the wrong places, fool around with resistance, change voltage levels and give equipment other bad habits. A run through the "Wet Box" socks each calculator with 90% humidity for five days. For variety, a 30° to 50° C. cycle occurs every 24 hours. If the 21 and 31 survive this man-made moisture, they'll survive the stuff from mother nature.

Super Sauna

After a product clears the reliability testing hurdles, proves itself capable of all specs through a range of heat, height and moisture, and does so while staying in one piece, there's still one lingering question. How will it do in actual use? To answer that question as accurately as possible, Tektronix has constructed a special sauna bath. Samples of the new products are operated here at 50% humidity, 50° C., for 24 hours a day, seven days a week. This process is aptly called "accelerated life testing" and can continue for months. What does this mean to you? A TEK calculator in your employ has come off the line with built-in experience. Costly down-time has been designed out.

Beating the System

TEK's insistence on thorough reliability testing has a positive effect on our design engineers. They build equipment to survive the test range. An example? Take a close look at the 21 or 31. To build machines that keep the faith, TEK engineers have replaced many construction/design traditions with a spectrum of innovations.

Innovation: The TEKTRONIX 21 and 31 cases are heavy gauge aluminum, eliminating the possibility of twisting and distortion which sometimes takes place in plastic cases.

Innovation: Components are operated well below their rated capacity giving quality parts an added margin of reliability.

Innovation: TEK-designed thermo-chemical tape printers replace noisy mechanical devices. In addition to providing a quiet operation, these integral printers utilize only 70% of the space previously required.

Not all the calculators rolling off the assembly line get a run at the test series, but each and every 21 and 31 goes through a 96-hour "burn-in" prior to delivery. This session, equivalent to a month's actual operation, eliminates the majority of early failures and prevents you from inheriting those annoying little problems.

Conclusion

We expect the TEKTRONIX 21 and 31 calculators to be valuable tools for your problem solving. We've designed and built them with portability and rough handling in mind. We're confident that they're ready to do the job, anywhere you are.

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committed to
technical excellence

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TEKSCOPE

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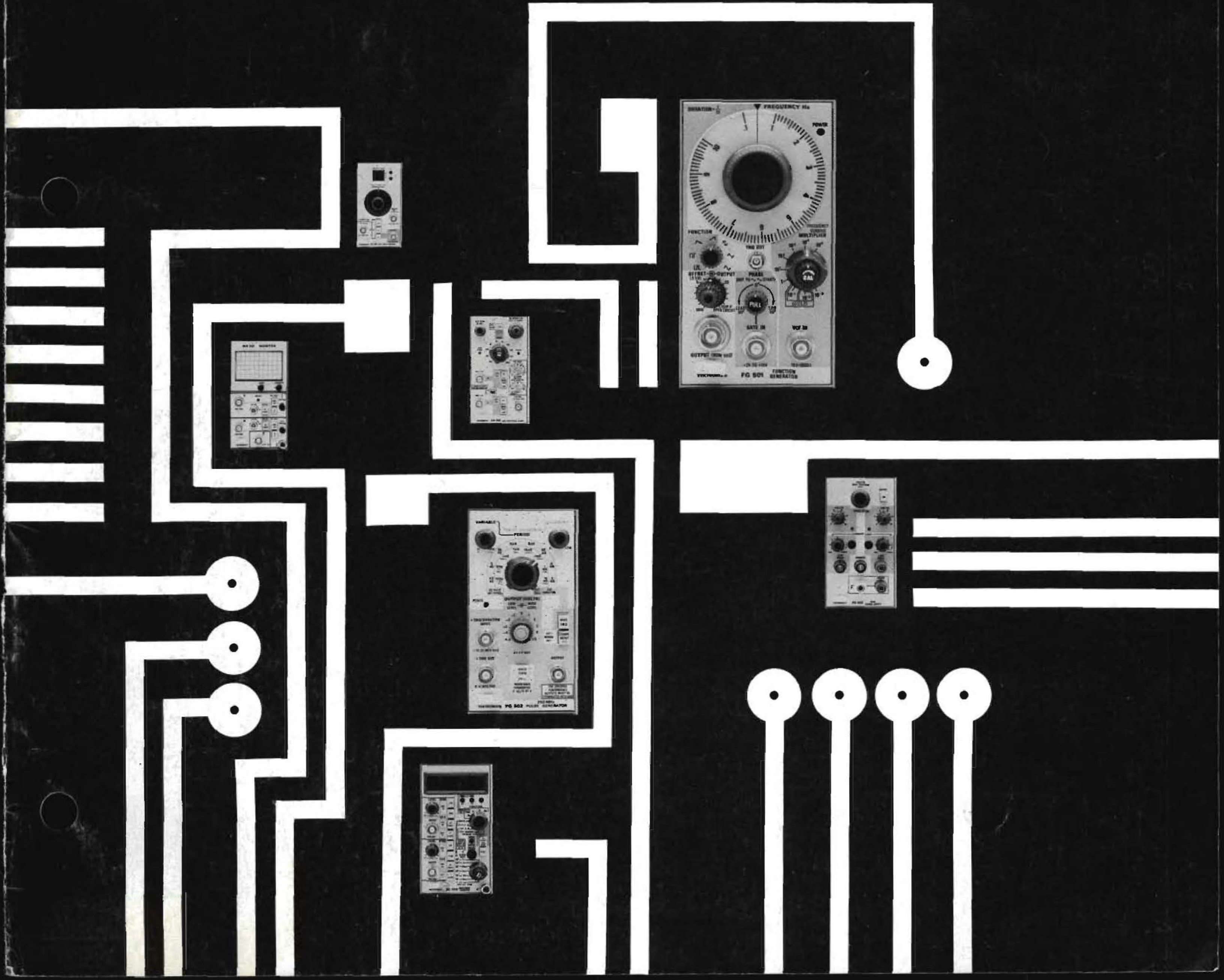

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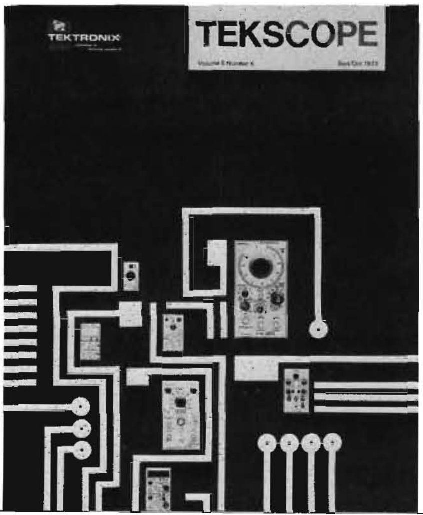
TEKSCOPE

Customer Information from Tektronix, Inc.
P.O. Box 500, Beaverton, Oregon 97005

Editor: Gordon Allison,
Ass't Editor: Dale Aufrecht,
Graphic Designer: Tom Jones

Cover: Some of the newest members of the TM 500 family are pictured on the front cover. It's a distinguished family that includes counters, multimeters, power supplies, signal sources, signal processors, and CRT monitors, with more on the way.



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"Product planning and design must be guided by customer needs—immediate and anticipated."

Philosophy of product design

Undertaking the development of a new product line, or single product, should properly commence after the recognition of one or more user needs that currently are not being met; or, after determining that one or more of his present needs can be met better.

At Tektronix each person is encouraged, and expected, to participate in the initial planning of projects that he or she is likely to be involved in, to contribute ideas or information about these projects. To the degree that people involved in planning are able to correctly ascertain the potential customer's needs, sound judgment may be applied to the relative importance of many factors. These factors must be considered when defining what the product will be. Frequent interchanges with Tektronix Field Engineers and Field Service Technicians; visits directly with present and potential customers, industry forums and trade shows; technical journals and educational programs; all are valuable in enhancing the participants awareness of your needs.

Upon stating what is believed to be a good understanding of present or anticipated customer needs, I believe that all of the suggestions brought forward during the planning process can, and should, be weighed against their relative effects on the primary customer benefits. The decisions regarding these suggestions determine just how well this new product (or product line) will benefit YOU—the customer.

Customer benefits include performance capability, reliability, cost of acquisition, cost of maintenance, ease of operation, versatility, size and weight, appearance, inter-relationship with other equipment and assistance prior to, during and after purchase.

Almost every suggestion initially brought forward is to enhance, or improve, the possible customer benefits in one or more of these areas. Each suggestion needs to be carefully considered for possible detrimental effects in regard to *all* primary benefits. Judgment is applied as to whether any particular suggestion will be incorporated in the plan. This process, of necessity, involves compromises. The result is that some customers still may not have available, equipment which better suits their particular needs. Frequently variations in the form of options (or different models) will be planned and made available to better meet our original goal—providing equipment and service which could benefit you to a greater degree than previously possible. This process of suggesting, comparing and choosing must be continued by all those people involved with executing the plan since the numerous details also affect (favorably or unfavorably) many of the possible customer benefits.

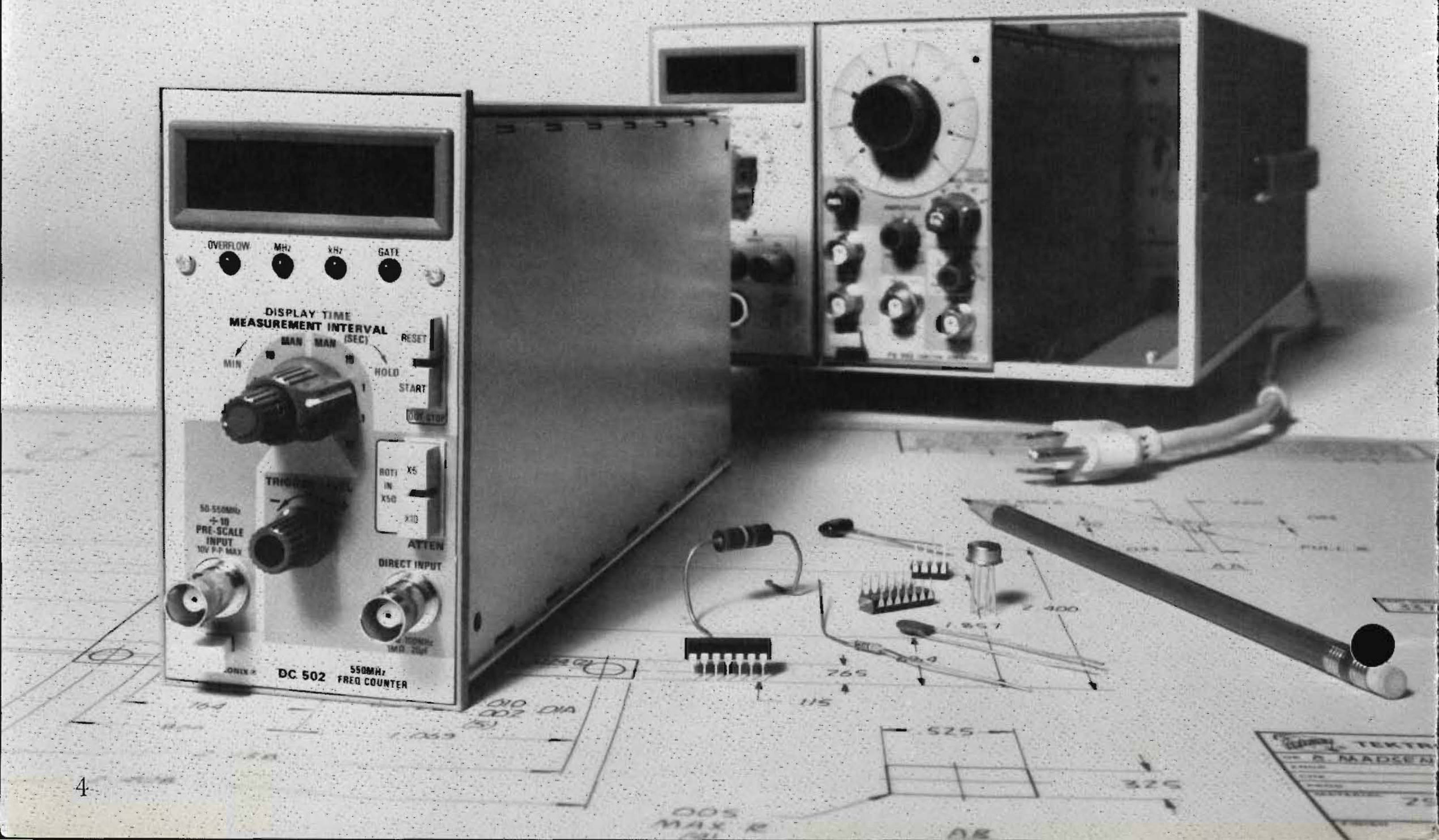
In conclusion, I believe that if one wishes to provide you—the customer—with equipment and service which is better than that now available, one must "join hands" with capable people who have a similar desire. Then, we must work together to provide readily available avenues which encourage and assist the participants in the development of better understanding of your needs. At Tektronix we're striving to do just that.

Jerry Shannon

Engineering Program Manager

A new approach to multi-function instrumentation

"Ten instruments on a bench doesn't have to mean ten cabinets, ten line cords, ten power transformers . . ."
— Bob Metzler



General-purpose test and measurement equipment has traditionally been designed on a one-function-per-box basis. An audio oscillator was one physical entity, a voltmeter was a second, a counter was another, and so forth. Yet, in application, it is relatively rare when a single instrument suffices for a measurement.

A simple volt-ohm-milliammeter may do the job for a small appliance repairman, but the designer, tester, or troubleshooter of modern electronics equipment almost invariably needs multiple functions to satisfy his needs. One or more appropriate signal sources, amplitude measuring devices, frequency measuring devices, signal processors, and variable DC power supplies are frequently required.

An "eyeball estimate" of a typical engineering development laboratory at Tektronix leads to the conclusion that an average of ten instruments (usually not all powered up at one time) are found on a typical engineer's bench. This quantity of instrumentation, often with each instrument being of a different size, shape, and function, with various types of displays, leads to a degree of clutter and confusion which has been accepted as a "fact of life" for years.

Modern trends in technology have dramatically altered the pure electronics end of test and measurement equipment. The progression from vacuum tubes through discrete transistors to integrated circuits (especially large scale integration), has made instruments like counters and digital voltmeters practical, and has permitted size and cost reductions and performance improvements in older types of instruments. Modern digital display technology has permitted miniaturization and increased reliability. However, some portions of the instrument have not yielded similar size or cost reductions nor performance improvements. The tendency, therefore, has been for cabinets, handles, feet, power cords, power transformers, power supply filter capacitors, etc. to represent a larger and larger percentage of the instrument volume and cost.

Most major manufacturers of test and measurement equipment have responded in one of two fashions: they have either designed miniature single-function (traditional concept) instruments for field and portable use and stayed with more conventional packaging for bench use, or they have combined several instrument functions into one package to permit sharing the cost of a common housing, power supply, etc.

One of the shortcomings of combining two or more functions in one package is that often, displays and controls are shared in such a way that both functions cannot be used simultaneously. An example would be a combined counter and digital voltmeter. With only one display, one may count frequency or measure voltage, but not both at the same time. The more serious drawback of the permanently combined multi-function instrument, however, is the lack of ability to alter the configuration when measurement needs change. When a new project demands a different signal waveshape, or operation at a frequency outside the band originally covered, or requires a type of measurement not provided in the fixed multi-function instrument, the user has no choice but to begin stacking additional instruments on or alongside his no-longer-adequate multi-function box.

Another multi-function approach has been to package a basic portion of an instrument, such as the power supply and display, into one unit and then provide a variety of mating "front ends" of varying capabilities. This system provides flexibility in configuring an instrument and is advantageous from a manufacturer's inventory standpoint. But the resultant instrument is still essentially a stand-alone single-function instrument. If it does combine two functions into one "front end", the shared display still limits use to an either/or situation.

When the Tektronix engineering group, headed by Jerry Shannon, looked at the instrument field, the size and cost advantages of multi-function instruments were evident. These engineers had in their backgrounds the benefits of Tektronix' years of experience in designing and building plug-in oscilloscope systems whereby a basic display and mainframe can be configured into dozens of different packages for individual user requirements.

The concept that developed for the TM 500 was a modular, plug-in instrument line in which miniaturized instruments share a common power supply and cabinet, can be internally interconnected as desired for specific applications, but otherwise perform in a totally independent manner (like conventional stand-alone instruments) with no sharing of displays or controls. Instruments can be interchanged in a mainframe almost instantly for purposes of reconfiguring a group of test equipment.

Obsolescence is avoided since new instruments with different capabilities may be substituted whenever needed. Furthermore, test and measurement capability often may be increased by adding an instrument to an existing group rather than making a substitution. This permits a user to start with a limited system and expand it later, rather than being forced to foresee all possible future needs when initially buying test equipment.

An excellent example is found in function generators. With stand-alone single-function instruments, a user must decide before his original purchase whether he will ever want sweep capabilities in his function generator. If he decides he will, he must buy a more expensive model with a built-in sawtooth generator. With the TEKTRONIX TM 500 modular system, however, one may purchase a function generator for manual use, and later add a ramp generator. With the ramp output connected to the function generator voltage-controlled-frequency (VCF) input within the cabinet, these two modules function as a self-contained sweep generator. An X-Y monitor can similarly be upgraded later to a calibrated time base Y-T oscilloscope by adding a ramp generator. Or, a digital voltmeter can become a digital differential-input millivoltmeter and microvoltmeter by adding the calibrated differential amplifier as a preamp.

A number of interesting features were developed as the TM 500 concept was carried forward into actual hardware design. One example is in the design of the mainframe power supplies and voltage regulators. A plug-in oscilloscope system typically has several complete voltage-regulated supplies in the mainframe; each has its output bussed to all plug-in compartments. This system is valid for oscilloscope systems, primarily because the plug-in outputs all interface with mainframe electronics at the same signal levels, and it is, therefore, easy to predefine adequate supply voltages. For a modular general-purpose instrumentation system, however, predefinition of supply voltages is nearly impossible. One instrument may need +15, −15, and +5 volt supplies for optimum operation, while another may require +20 and −6 volts. Predicting the specific requirements of next year's instruments is even more difficult.

Heat dissipation in voltage regulators is also a consideration warranting special attention in a modular system. Heat generated within a plug-in module cannot be carried outside the instrument as efficiently as from a mainframe location, due to additional thermal barriers, interfaces, greater path lengths, and less ventilation. The TM 500 Series solution was a combination of distributed power supplies and floating, raw AC windings. Filtered but unregulated DC at two potentials—+33.5 volts, and −33.5 volts—is bussed from its mainframe origin to each compartment. Two power transistors (one NPN and one PNP) per plug-in compartment, mounted on heatsinks, are located in the mainframe. Each instrument can thus regulate the plus and minus 33.5 voltages down to optimal levels with all significant dissipation occurring in the mainframe. A filtered +11.5 volt, 4-amp supply is also bussed to all compartments. Additionally, two floating 25-volt, RMS windings are available at each plug-in connector. They may be connected in series, parallel, or used independently by each plug-in.

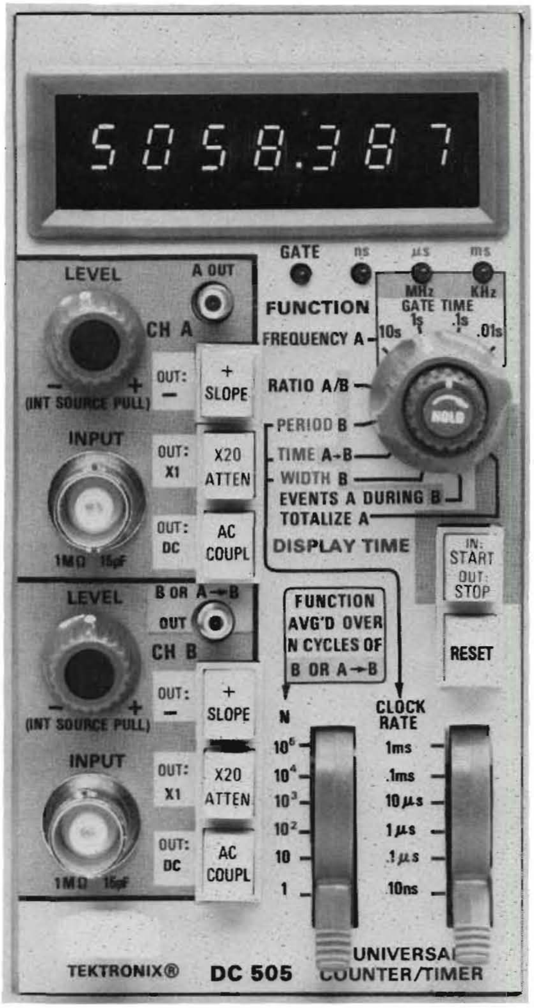
Panel design presents one of the most challenging and most important problems in miniature instrument design. Displays have shrunk in size, and integrated circuits are dramatically smaller than other devices to perform the same functions, but human fingers remain the same size. Combining all the necessary control functions and displays into the thirteen square inches of panel available, without compromising the human engineering aspects, requires real creativity.

The DC 505 Universal Counter is possibly the best example of the challenge, and the result. This counter measures frequency, period, ratio, time interval, pulse width, events A during B, and totalizes. Six choices of averaging factor are selectable in period, ratio, interval, width, and events A during B modes, and clock rate is selectable over five decades in period, interval, and width modes. Completely independent selection of clock rate and averaging factor is possible. Front-panel and rear-interface inputs are switch selectable for both A and B channels, display hold time is controllable, and both channels have selectable trigger polarity and adjustable trigger level. These controls plus two input jacks, gate output jacks, gate and unit indicators, and a seven-digit display are all combined into the 2.6″ by 5″ panel in a very usable manner.

In other instruments, such as power supplies, where panel space is not at such a premium, it was possible to combine two or three supplies into one plug-in. For example, the PS 503 includes a fixed 5-volt at 1-amp regulated supply for digital logic, and separate plus and minus 0 to 20-volt supplies with independently adjustable current limiting.

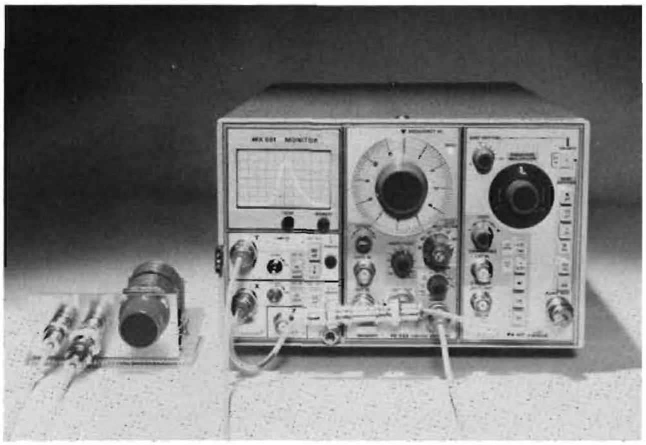
In addition to the benefits of compactness and economy due to sharing of cabinet and power supply components, the modular TM 500 Series permits uncluttered, interconnected, portable, multi-instrument test sets with the internal-interconnect feature. Interconnecting of instruments is facilitated by an option available for the TM 503 Power Module which includes interconnect pins on the interface board at each instrument, a quantity of both shielded and unshielded jumpers, three rear-panel BNC connectors for user wiring for signal input and output, and a 50-pin connector and mating plug for user wiring to control lines, BCD outputs, etc. The internal jumpers may be connected for such simple applications as digital multimeter monitoring of a power supply, or counter monitoring of signal generator frequency.

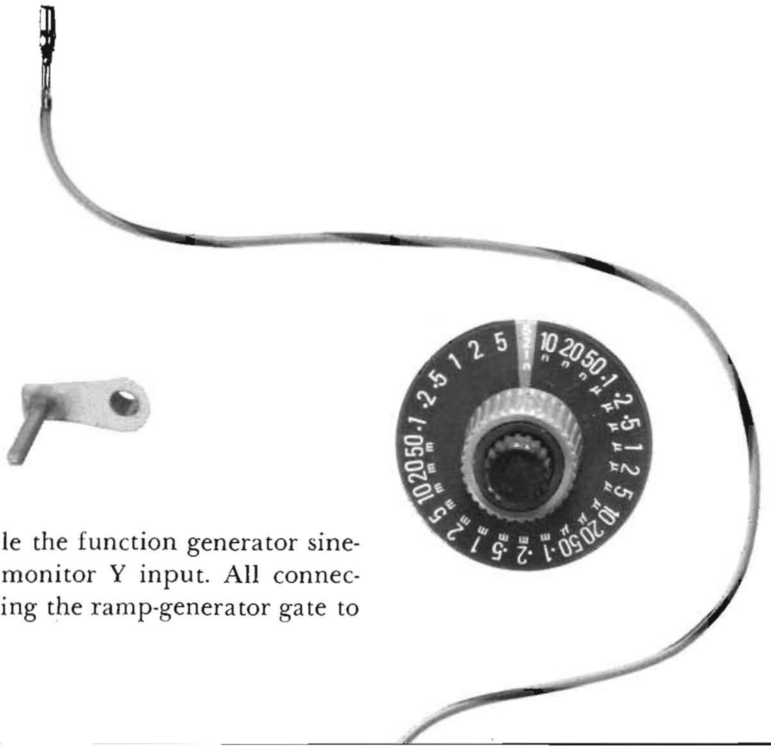
More complex interconnections, still physically simple, permit the user to configure special-purpose test sets in one cabinet, with one handle and one power cord. One such example consists of an FG 502 11-MHz Function Generator, an MR 501 X-Y Monitor, and an



RG 501 Ramp Generator as a filter or IF transformer alignment test set. The ramp generator output simultaneously sweeps the function generator frequency and the monitor X-axis, while the function generator sinewave output feeds the monitor Y input. All connections, including connecting the ramp-generator gate to the monitor Z-axis for retrace blanking, are made internally, and the only external cables necessary are those to the filter under test. The instruments and mainframe are still general-purpose in nature, and may be removed, interchanged, mixed, or matched rapidly into other configurations for other applications.

The TM 500 Series concept of modular intrumentation thus provides an optimum blending of the advantages of independent stand-alone operation with individual displays, and the benefits in size and cost reductions of modern multi-function instrumentation design and manufacturing technology. The added feature of internal interconnections results in increased versatility, less clutter, easier portability, and simpler operation.

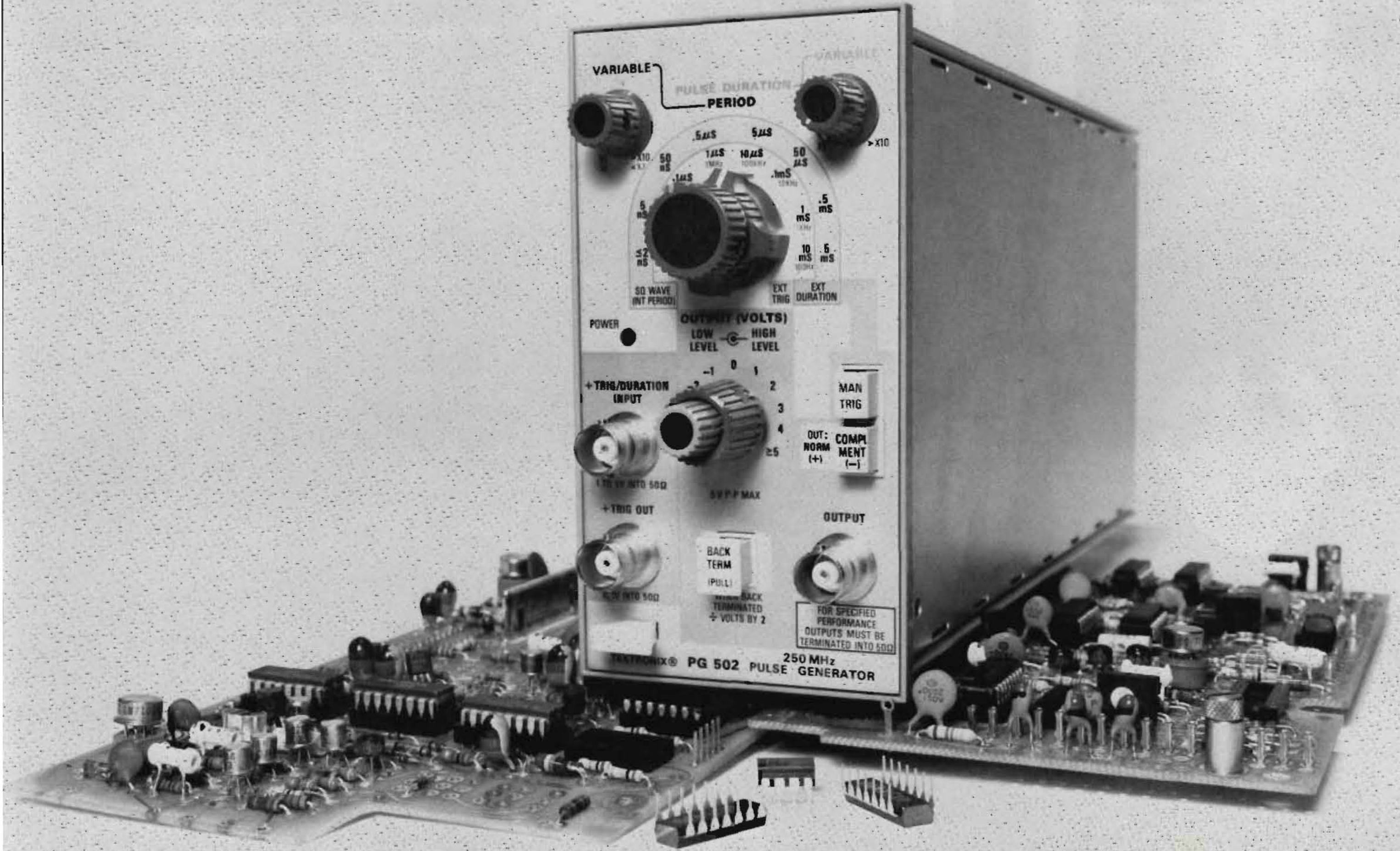




"Application-oriented instruments can save their users dollars, both initially and long term."— **Mark Walker**

A new high speed pulser for logic testing

Did you know that many modern high-speed TTL flip flops will change division ratio when drive levels are changed? Or that the maximum toggle rate depends on the '0' drive level of most logic families? Or even that the ideal input drive levels may not be those supplied by the outputs of IC's from the same logic family? The list goes on and on, but these are some of the things we have found at Tektronix since a new high-speed pulse generator became available.



As the world-wide demand for logic components increases at astounding rates, so does the demand for higher speed, easier to use test and measurement equipment. Most measuring equipment has kept pace with the increased demands; but until now, logic-oriented pulse generators have fallen behind. There just are not many reasonably-priced high performance pulse generators available that will meet today's needs for logic testing, design, or performance verification.

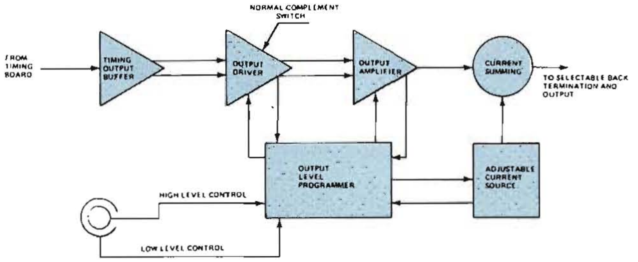
Most conventional pulse generators allow their users to define a pulse with a pulse-amplitude control and a pulse baseline offset control. To properly drive a given logic device with these instruments, the proper value for pulse amplitude and offset must be calculated. Take, for example, driving a 7400 gate. To derive the required pulse amplitude, the low level value of +0.4 volts must be subtracted from the +2.4 volt high level, giving a pulse amplitude of +2 volts. Offset must then be set at +0.4 volts in order to properly approximate the signal out of an assumed preceding gate.

The setup so far is not difficult, however, attempt now to determine the effect of the low level on the performance of the gate, without changing the upper level. This requires duplicating the same set of calculations for every new low level, and necessitates resetting both amplitude and offset controls. This calculating and setting and recalculating and resetting process can even get worse when working with many ECL families.

The new TEKTRONIX PG 502 Pulse Generator was specifically engineered to satisfy just such measurement needs. This instrument, with a maximum frequency in excess of 250 MHz, has separately adjustable pulse high and low levels over a full 5-volt range. This means that any logic family powered within 5 volts of ground can be properly (and if desired, improperly) driven with up to 5 volts of pulse. This includes all of the very popular TTL families as well as faster ECL types. All pulse amplitude and offset combinations that are available with the amplitude/offset system are still available, but without the interaction that can make changes in just one level so difficult. Using the PG 502, thorough evaluation of effects due to changes in only upper or lower logic levels become as easy as turning a single knob. This allows many things to be uncovered that would otherwise go undetected—things like the problems mentioned in the opening paragraph of this article.

The PG 502 introduces this capability at the very high speeds necessary for today's world of logic. At the heart of the PG 502 output stage are two Tektronix-built integrated circuits. The driver IC, in addition to driving the output stage, has current-adjustable amplitude allowing optimum drive and therefore minimum output pulse aberrations. This IC also allows convenient switching for the pulse "normal" or "complement" modes.

The second IC is mounted with the output transistor on a Tektronix-built hybrid circuit, allowing a clean high-speed interconnect for the subnanosecond risetime pulses present in this stage. The pulse leaving this stage is summed with a DC current controlled by the Output Level Programmer (as shown by block diagram, Fig. 1). From this summing mode the combination pulse and DC current, representing the pulse high and low levels selected at the front panel, goes through the selectable back termination switch and on to the output. The back termination switch allows the generator to act essentially as a current source output calibrated into a 50 Ω load, or as a 50 Ω voltage source. However, note that when acting as a 50 Ω voltage source terminated into 50 Ω, the output high and low levels are reduced to one half. The total load on the generator in this position is 25 Ω.



The Output Level Programmer block takes the values of pulse high and low levels requested by the front panel controls and translates this information into the pulse amplitude to be delivered by the output amplifier, and the DC current to be summed with that amplitude to obtain the desired output levels. It also controls the driver so as to optimize the output signals. This Output Level Programmer block minimizes the time consuming setups typical of other instruments, whenever specific and adjustable upper and lower pulse levels are needed.

For pulse testing not requiring this much versatility, the TM 500 Series also includes the PG 501 which can drive all types of TTL logic up to 50 MHz with its ground-referenced outputs.

A time mark generator with error-percentage readout

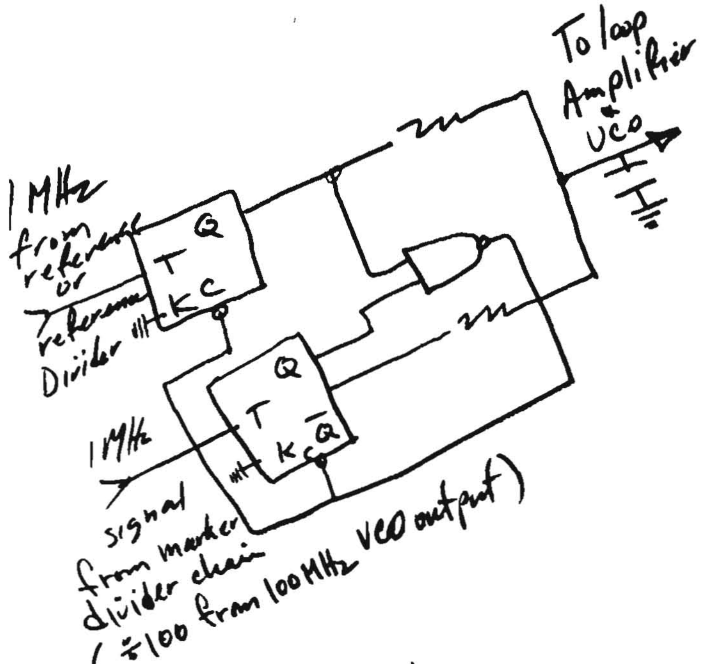


fig. 1
Simple phase detector used in TG 501 Time Mark Gen.

Ever since the introduction of calibrated test equipment, the need for calibration sources has been apparent. And every advance in instrumentation invokes a need for improved calibration equipment. More accurate voltmeters, faster-rising pulse generators, faster time mark generators and higher-frequency sinewave sources are essential for calibrating today's advanced instruments.

In 1952, Tektronix introduced the Type 180 Time Mark Generator for time base calibration. This instrument was rather bulky by today's standards, but did produce very usable time marks. These were counted down from a 1 MHz crystal source by using RC time constant circuits to achieve the desired divider ratio. This ratio was either divide-by-two or divide-by-five, resulting in outputs sequenced 1, 2, 5, 10, etc., from 1 μsec to 5 seconds. Sinewave markers at 200 ns, 100 ns, and 50 ns were obtained by multiplying up from the 1 MHz reference.

With the Type 184, introduced in 1965, came smaller size, transistor and nuvistor circuitry, a 10 MHz crystal reference, and sinewave markers from 50 ns to 2 ns. Calibration needs were changing, supported by the maximum marker jump from 50 ns to 2 ns.

Then, in 1970, the Type 2901 Time Mark Generator was introduced. This instrument simply duplicated the basic Type 184 performance, but with one significant change. It introduced all-digital countdown circuitry using RTL logic, but retained the RF-type multipliers and the 10-MHz reference.

Now with the introduction of the TG 501 Time Mark Generator come several important changes, plus a new feature aimed at relieving much of the time-consuming chore involved in verifying today's equipment.

The TG 501 is only ⅓ the size of its predecessor, has a 1 ns output sinewave, and a 100 MHz basic marker frequency. It can be driven externally by any lab standard at 1, 5, or 10 MHz. The timing of any marker 10 ns or slower can be varied over a limited range by a front panel control, with the deviation from the calibrated position displayed digitally in terms of percentage. This feature permits you to quickly and accurately determine time-base errors.

The versatile TG 501 is made possible by several advances in technology. The standard internal reference frequency is 1 MHz (a 5 MHz reference with greater stability is available). This signal is conditioned at 1 MHz and fed to one side of a phase detector fabricated from a dual TTL flip flop and a single gate (see Fig. 1). The output of the detector drives an amplifier (to increase loop gain), which in turn drives the 100-MHz voltage-controlled oscillator. The output of the oscillator is then buffered and shaped to produce the 10 ns markers. It is also divided down by two for the 20 ns markers and by five for 50 ns. Between 50 ns and 100 ns the transition is made from emitter coupled logic to TTL where the divide-by-two and divide-by-five circuits are again repeated, giving .1 μs, .2 μs, or .5 μs markers. The .5 μs markers are fed to a divide-by-two circuit with the 1 MHz result fed to the other side of the phase comparator. This closes the phase lock loop and insures a stable reference at 100 MHz.

Previous time mark generators repeated the 1, 2, 5 sequencing all the way to their longest marker output; not so with the TG 501. The last divide-by-two or divide-by-five employed gave the .2 μs and the .5 μs markers described above. The remainder of the countdown chain uses only divide-by-ten stages. By simply calling up the desired unit (1, 2, or 5) and the correct power of 10 (10^0 to 10^{-7}), the chain produces the correct marker. This system greatly reduces the amount of logic needed and the switching complexity necessary to pro-

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duce any marker. The output amplifier even has three values of input impedance which are selected together with the 1, 2, or 5 lines. This produces constant duty cycle markers over the entire 1, 2, 5 range with only one marker-shaping capacitor per decade.

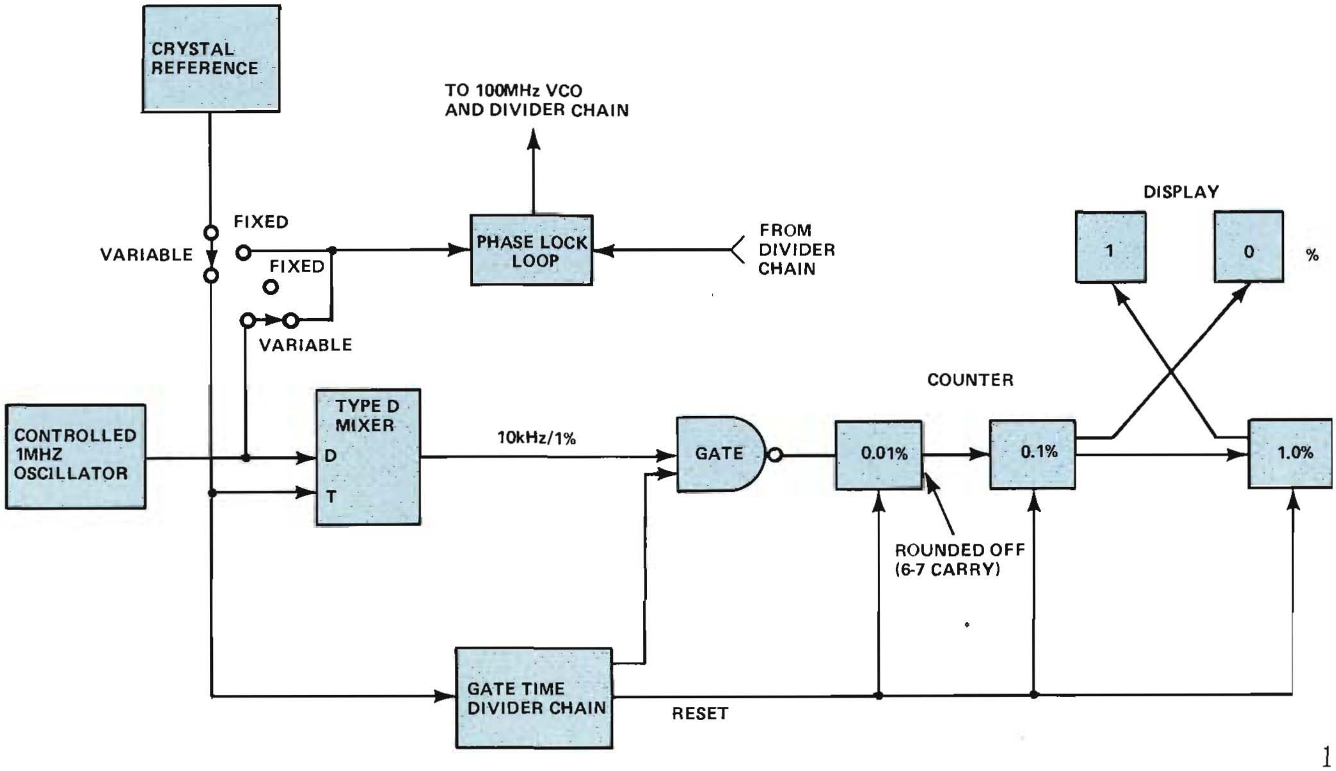
The timing-error readout circuitry also introduces some unique techniques. To change marker timing it is only necessary to change the reference frequency fed into the phase detector, by the desired percentage. The phase lock loop will change the 100-MHz reference by exactly the same percentage, and since all markers are directly derived from this reference, all markers will change by exactly the same percentage. To accomplish this, a front-panel-controlled variable oscillator is inserted in place of the crystal reference as the drive for the phase lock loop. To obtain an accurate digital reading of the percentage of error, it is necessary to produce a signal whose frequency can be counted and read directly in percent. A Type D flip flop is used as a digital mixer to give the difference frequency between the variable reference and the crystal or external reference. For a 1% change in timing, the 1-MHz frequency will change 10,000 cycles. By counting the 10^4 bit and the 10^3 bit this reading would be 1.0%. To display this reading introduces counter error of ±1 digit in the last, or the 0.1% digit. By also counting the 10^2 bit and using it to round off the 10^3 bit as displayed, this counting error is reduced by 10 times, yielding a very accurate indication of timing error. This is shown in Fig. 2.

Since timing, when in error, can be either fast or slow, it is necessary to indicate the direction of error on the digital readout. This is done by again using a simple phase detector like that shown in Fig. 1. Since the detector output indicates direction of frequency difference by its output voltage level, the signal that is faster is easily determined. The fast LED is lit when the variable sequence oscillator is above the crystal reference in frequency. All pertinent information is therefore read out when the TG 501 is used in the variable timing mode, with the entire readout going dark when the unit is operated in the calibrated position.

Another point in the design of this instrument deals with the main phase lock loop for marker generation. If this loop should fail for any reason, it would be possible to have markers generated which were not, in fact, locked to the reference source. To prevent this condition from occurring, the out-of-lock conditions of the loop are monitored. If lock is lost, the instrument output is automatically disconnected, indicating the need for servicing.

On the high end, sinewave markers of 5, 2, and 1 ns are generated. These markers are generated by taking the outputs from the RF-type multipliers and filtering them through comb-type filters. These filters are printed directly on the circuit board, and are used to eliminate both the harmonics and subharmonics which are generated in the multiplying process. This technique allows good filtering characteristics, requires little volume, and gives consistent filtering results. All markers are at 1 volt P-P amplitude up to 2 ns, with the separate 1-ns output delivering 0.5 volt P-P into a 50 Ω load.

For application of the TG 501 and other new calibration aids, see Service Scope in this issue.



Teknique

Operational amplifier applications

"Good design combined with simplicity, flexibility and reliability yields a high return on your instrument investment."
— **Warren Collier**

Although op-amps in a variety of physical forms are usually thought of as components buried within an instrument or system block, there are many applications where a free-standing op-amp can serve as a signal conditioner or interfacing device.

We've just added this valuable tool to the TEKTRONIX TM 500 Test and Measurement family. The AM 501 is an operational amplifier packaged and configured for use as an instrument. You can readily define the characteristics of the AM 501 to suit your particular application, through convenient front panel connectors, or you can install the feedback components inside the unit if desired.

The AM 501 features high input impedance, a slew rate of at least 50 V/μs and output range of ± 40 volts and ± 50 mA. It can withstand input voltage as high as 80 volts. These broad performance characteristics make the AM 501 well suited for a wide range of analog processing applications.

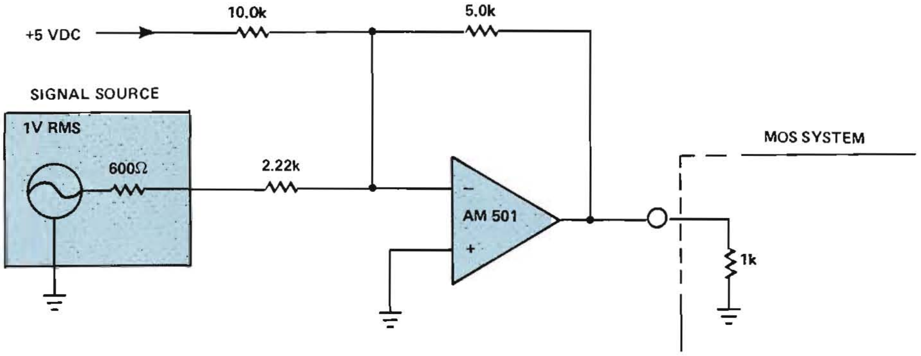
Before detailing a few very specific types of interfacing applications, it may be well to list the general kinds of things an op-amp can do, utilizing the classic feedback configurations. The op-amp can act as:

1. A buffer stage with nearly ideal follower characteristics.
   - A. Output is in phase with input.
   - B. Gain is unity, within a close tolerance; no adjustment required.
   - C. Input impedance is high; output impedance is low.
2. A voltage amplifier capable of a wide range of accurate and arbitrary gain factors.
   - A. If amplification is in phase, the input impedance may be kept very high; this configuration is best suited to a single input signal.
   - B. If used as an inverting amplifier, input impedance will be lower, but many AC and/or DC voltages may be summed, with almost no interaction. Also, the gain factor for each input may be different.
3. A precision differentiator, producing a well-defined output voltage which is proportional to the rate-of-change of the input signal.
4. A precision integrator, producing an output signal which has a well-defined rate-of-change proportional to the input voltage.
5. A Schmitt trigger with well-defined and easily adjusted hysteresis.

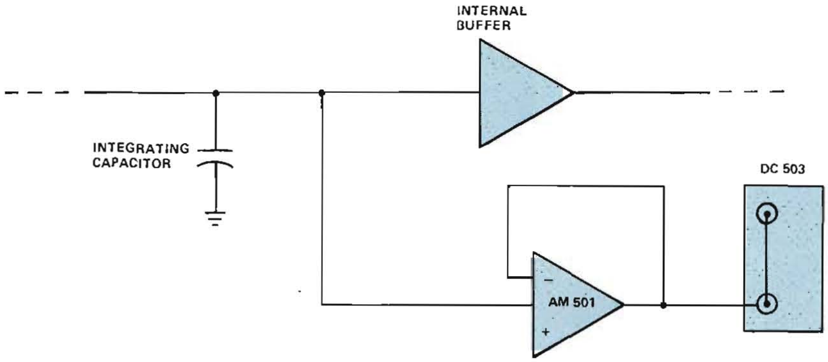
In addition to performing each function separately, several op-amps may be interconnected to perform more complex functions. For example, using one AM 501 as an integrator, and a second as a Schmitt trigger, triangle and ramp waveforms of unusual linearity may be generated.

In summary, any time you want to change the amplitude, invert the phase (or polarity), and transform the impedance or shift the DC level of a low-frequency signal, one or more op-amps will do the job for you. Additionally, they can be used to operate on the derivative or integral of the input signal. The main limitations are that very high gains or very low input levels are not suitable, high speed signals are generally not suitable, and because of the op-amp's "slew rate" characteristics, bandwidth and risetime depend on signal amplitude. On the positive side, accuracy and stability are excellent, and there is very little offset between input and output DC level, except as intentionally introduced.

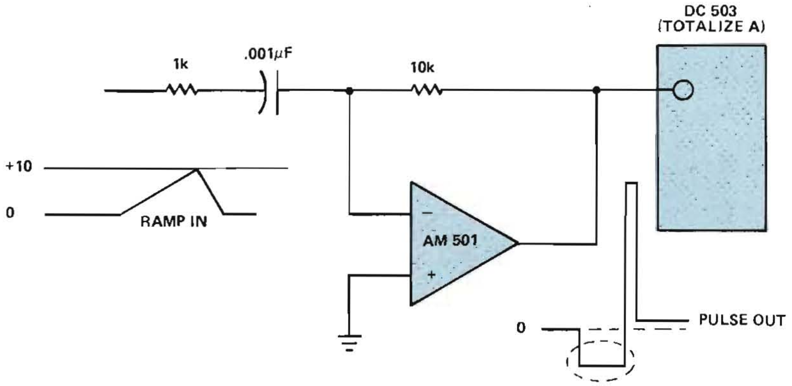
To proceed with more specific application examples, consider the following interface problems and their op-amp solutions:



Problem 1.—A sinewave source needs to be clocked into an MOS system. The amplitude is insufficient (one volt RMS behind 600 Ω) and the DC level is wrong (centered at ground). The signal has to swing between zero and at least five volts minus.
Solution—Interface the signal with an AM 501 connected as a summing amplifier. Introduce the necessary offset by summing the signal with a DC voltage from a power supply.



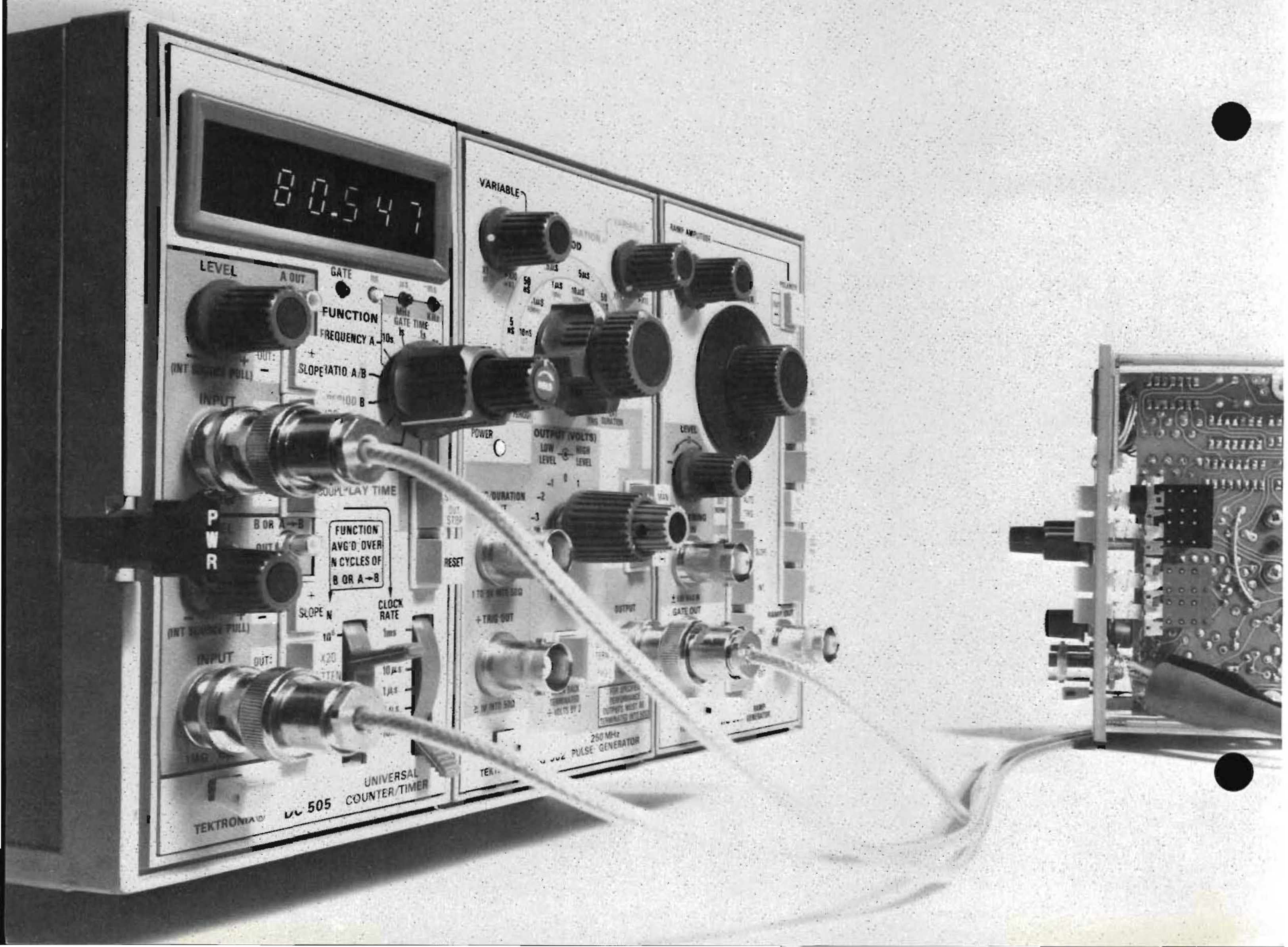
Problem 2. You want to connect the signal on an integrating capacitor to a time-interval meter (TIM). The signal amplitude is several volts, and only a few nanoamps of load current can be tolerated; the one megohm input impedance of the TIM is too low. The circuit under test has an internal buffer, but it shifts the DC level to an unsuitable value. Capacitive coupling will introduce signal aberration or excessive load current.
Solution—Interface the signal with an AM 501 connected as a follower. Input current is less than one nanoamp at room temperature; output signal is nearly identical to input signal.



Problem 3. A system generates ramps at random intervals. The ramps are of uniform amplitude, but are of two different durations. You want to count the number of fast ramps only, which occur in one hour. Both ramps have a 10 V amplitude; the slow ramp has a duration of 50 μsec and the fast ramp lasts 10 μsec.
Solution—Using the AM 501, differentiate the ramps so that only the fast ramp generates an output voltage adequate to trigger the counter.

"Today's IC's let the counter designer concentrate on application-oriented instruments."
— **Jim Geddes**

A new 225-MHz Universal Counter/Timer



A 100-MHz clock rate for high resolution single-shot measurements of interval and period, time interval averaging for still better resolution, two identical input channels permitting measurements on extremely narrow pulses, independent selection of clock rate and averaging factor, and a new capability called EVENTS A DURING B: these are some of the outstanding features of the new DC 505 225-MHz Universal Counter Timer. This high performance counter adds important new measurement capabilities to the TEKTRONIX TM 500 Series of test and measurement equipment.

Two input channels are characteristic of universal counters, in contrast to the single inputs found on simpler frequency counters. But there is something special about the two inputs on the DC 505. Typically, the B channel of a counter has much less bandwidth than the A channel. The TEKTRONIX DC 503 is representative of this with a 10-MHz B channel and a 100-MHz A channel. The new DC 505 boasts a 225-MHz bandwidth in both channel A and B.

In making time interval and pulse width measurements, channel A starts the counter and channel B stops it. With a wide bandwidth in both channels, the DC 505 permits interval and width measurements on much narrower pulses than most other instruments. For example, an instrument with a 10-MHz stop channel is typically limited to 100-ns minimum-width pulses. The DC 505 can make interval (TIME A → B) measurements on signals as narrow as 5 nanoseconds.

Pulse Width Measurements

Pulse width can be measured on any universal counter with a TIME A → B capability by using a "tee" connector and two cables to feed the signal to A and B inputs simultaneously. One channel's controls are then set to trigger on the leading edge, the other on the trailing edge, and the width measurement is made. Some instruments provide some simplification by a switch which parallels both channels to one input jack. This eliminates the need for the "tee" connector, but the input impedance is still cut in half. In either case (and in all TIME A → B measurements), any mismatch in propagation delay through the two channels adds to the measurement error.

The DC 505 provides simpler operation, more accuracy, and narrower pulse capability by its WIDTH B mode. The unknown pulse is connected to the B channel with one cable, where it sees the full 1 Megohm input resistance. Triggering level is set by one control and no channel match error (mismatched propagation delay) occurs since the B channel both starts and stops the measurement. The stop automatically results when the signal passes through the selected trigger level again, with the opposite polarity to that selected by the front panel SLOPE switch. Since less circuitry is involved in the path in WIDTH mode, the DC 505 can make measurements on pulses as narrow as 2 nanoseconds (absolute accuracy will be ±3 nanoseconds).

Time Interval Measurements

The need for better accuracy and (particularly) better resolution of time interval measurements is one of the significant trends in counter applications. Range determination by radar and lasers, determination of time of flight of sub-molecular particles, and propagation delay through logic circuits are only a few of the important areas where improved time interval resolution is desirable.

Resolution on a single-shot time interval measurement is determined strictly by the clock rate; a 1-MHz clock gives 1 microsecond resolution, 10 MHz gives 100 nanoseconds, and so forth. The quartz crystals used as the time bases in virtually all modern counters operate somewhere between 1 MHz and 10 MHz since achievable stability is optimized there. The DC 505 has a 1-MHz crystal standard or an optional 5-MHz temperature-compensated crystal with divide-by-five circuitry to provide a 1-MHz output. This 1-MHz signal is then multiplied to 100 MHz using a phase locked loop, yielding a 10 nanosecond resolution for single-shot measurements.

While the 10 nanosecond clock period and resultant resolution limitation is essentially the state-of-the-art for single-shot measurements, large improvements are achievable through averaging techniques when the interval to be measured is repetitive. The resulting improvement in resolution is a factor of $1/\sqrt{N}$ where N is the averaging factor; so 10,000-times averaging with the 10 nanosecond clock produces a minimum of 100-picosecond resolution, unless the counter clock and the external pulse rate are synchronous (see below).

Internal averaging, unlike period averaging, is a statistical process. A thorough mathematical analysis of the process, including confidence levels in the displayed results, is beyond the scope of this discussion; but one important potential limitation in the interval averaging process should be noted. The improvement in resolution occurs only when the counter clock and the repetition rate of the interval being averaged are not harmonically related. If the rep rate of the system being measured is adjustable, a good test is to make the averaged interval measurement at several different rates. The answers should agree unless a synchronous counter-clock and system-clock situation exists at one of the rates.

Absolute Accuracy of Time Interval

Absolute accuracy in time interval measurements is a function of four factors: resolution, time base error, triggering error, and channel delay mismatch. When making single-shot measurements of intervals less than about one millisecond, resolution is normally the largest contributor to error. Time base error with the temperature-compensated Option 1 time base will virtually never be a factor in interval measurements. Triggering error and channel delay mismatch, lumped together, will not exceed 6 nanoseconds on fast rise and fall pulses where interval measurement is commonly used.

Since time-interval averaging can reduce the ±1 count resolution ambiguity from 10 nanoseconds (assuming the fastest clock rate) to 100 picoseconds, the ultimate absolute accuracy when averaging becomes limited by the triggering and channel mismatch errors. External cables of finite length must be used for any measurement, so the overall channel mismatch error consists of both internal mismatch in the instrument (2 nanoseconds maximum) and mismatch in the electrical length of the external cables. For any given instrument the internal mismatch will be constant and could be calibrated out of the system by trimming the proper external cable length while measuring an accurately known interval. The ±4 nanosecond triggering error, thus, is the accuracy limit in time interval averaging measurements.

Independent Rate and Averaging Factor

A unique feature of the DC 505 is the completely independent selection of clock rate and averaging factor. Clock rates are selectable from 10 nanoseconds (100 MHz) through 1 millisecond (1 kHz), and averaging factors from 1 (single shot) through 10^5. For most interval, width, or period measurements of relatively clean, stable signals, one would normally select the fastest clock rate and an averaging factor limited either by display overflow or the length of time the operator is willing to wait for an answer. With noisy or jittering signals, the operator may wish to deliberately select a large averaging factor. If the duration of the interval (or width or period) being measured is such that the value of averaging factor selected results in display overflow, a slower clock rate may be chosen. This useful operating feature led to an unusual circuit requirement within the counter. Since the location of the decimal point and the units indicators (ns, μs, ms) depend on both clock rate and averaging factor, they could not be controlled in the usual simple fashion by contacts on a rotary function selector switch. The solution to the problem was a simple discrete-transistor read-only memory (ROM) in the form of a 6 X 7 matrix.

EVENTS A DURING B Mode

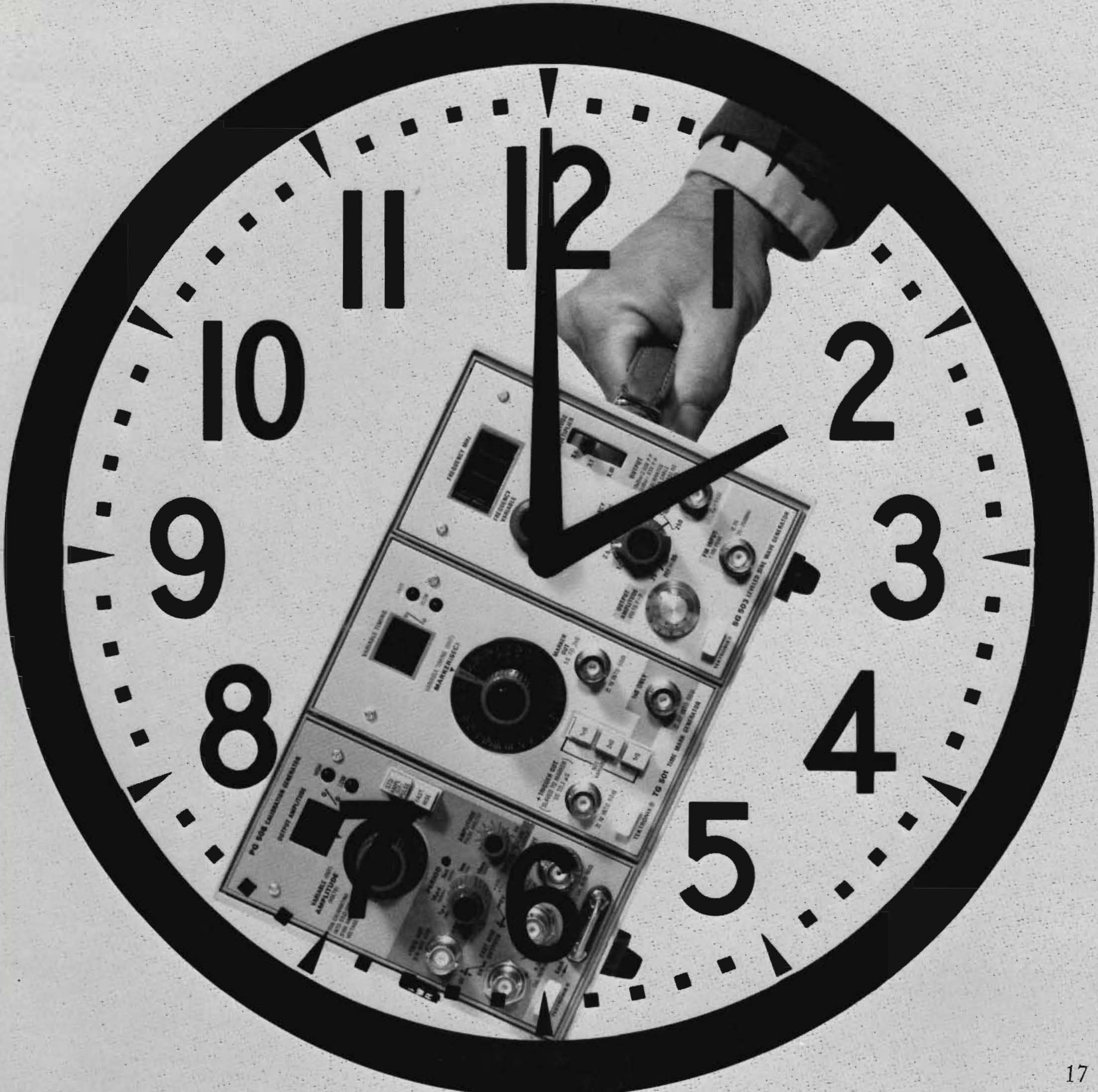
In addition to the unusual characteristics already discussed and the fairly conventional modes of operation like frequency, totalize, period, and ratio, a new functional capability called EVENTS A DURING B exists in the DC 505. The display will show the number of events appearing at the A input during the width of a pulse at the B input. This feature can be selected over a range of 1 to 10^5 B input pulses by means of the averaging factor switch. Direct verification of the division ratio of counters on a single-shot basis can be made using this mode of operation. It would also be useful for counting computer clock pulses occurring during some operation, or could be used simply as a remotely-gated totalize function.

The DC 505 packs an amazing amount of measurement capability and flexibility into one TM 500 module. In conjunction with other instruments like the PG 502 250-MHz pulse generator, the DM 501 4½-digit multimeter, and a Tektronix high performance oscilloscope, it provides an extremely powerful tool for work in modern digital and high frequency systems.

Servicescope

Verification or Calibration? A time-saving decision

With the announcement of the TM 500 "Cal Package", a powerful new tool is available to instrument calibration personnel to reduce the cost and improve the accuracy of oscilloscope calibration. The key to improvement lies in on-site verification rather than full, and often unnecessary, calibration in the metrology lab.



To properly contrast the improvements available, let's first consider typical calibration practices now in use. In many facilities, procedures for calibration of test instruments involve physically collecting the instruments from their usage points and transporting them to the metrology lab. This collection and transportation involves the risk of physical damage in handling and the loss of use of the instrument for at least a few days. The instruments are, of course, turned off during transportation and while awaiting calibration. They thus are cooled down and then warmed up again in the calibration facility. If the time allowed for thermal stabilization in the cal lab is inadequate, if the lab ambient temperature is different than that at the usage point, or if the room ambient is the same but the immediate thermal environment is different (as when a normally rackmounted instrument is removed from a factory test station and calibrated on an open bench), a less than ideal situation prevails. While the instrument is normally specified for operation over a reasonably wide temperature range, best accuracy is achieved if the thermal environments are identical for calibration and actual use.

Following the stabilization period, the instrument performance is usually verified before calibration takes place. This practice is particularly useful in determining whether calibration intervals should be lengthened or shortened. With conventional calibration equipment, verification requires both visual interpolation and calculation. The calibration technician sets his time mark generator or standard amplitude calibrator to the appropriate range and reads the deviation of the resultant display from the scope graticule divisions. Interpolation is generally necessary, so both subjective judgment and possible parallax errors can become significant factors. The technician then calculates, by longhand, slide rule or other means, the percentage deviation of the instrument from exact accuracy.

Even if the deviation is within specifications, verification is typically followed by full recalibration. In this procedure, the technician feeds the standard calibrating signal (time marks or amplitude) to the oscilloscope and "tweaks" the appropriate controls until the display is exactly aligned with the proper graticule divisions.

Finally, appropriate record keeping is done, and a new calibration sticker is affixed to the instrument.

Now let's consider a new approach using the TM 500 oscilloscope "Cal Package". The package typically consists of the TG 501 Time Mark Generator, the PG 506 Calibration Generator, and either an SG 503 or SG 504 Leveled Sinewave Generator, all contained in a TM 503 Power Module.

With this highly portable calibration system, verification moves from the cal lab to the user's work site. The calibration technician carries the TM 503 with instruments (approximate weight, 18 pounds) to the oscilloscope and powers up the Cal Package. The oscilloscope is neither turned off nor moved.

If the time base is to be checked first, a cable connection from the oscilloscope input is made to the TG 501, and the scope time base and TG 501 are set to corresponding ranges. With the time-variable knob on the TG 501 set to its outer position, the technician turns the knob until the time marks exactly align with the graticule and then reads the scope timing error in percent fast or slow, from the two-digit readout on the TG 501 front panel. Other ranges can be verified just as rapidly, with the deviation percentages recorded by the technician if that is part of the established procedures. No interpolation is required, no computations are necessary, and the entire operation takes place with the oscilloscope in its normal environment.

Vertical sensitivity verification is done in a virtually identical fashion using the PG 506 Calibration Generator. The two-digit readout on the PG 506 panel indicates percentage deviation of the generator output, high or low, from the switch-indicated (standard range) value. High generator output, when adjusted for squarewave alignment with the graticule, corresponds to low oscilloscope sensitivity and vice-versa. This contrasts to the Time Mark Generator case, where a fast generator and fast time base correspond.

The key parameters of vertical and horizontal accuracy have thus been verified "on location" in a matter of minutes. The bandwidth can be quickly checked with the SG 503 or SG 504, as appropriate for the instrument bandwidth. If all parameters have been verified as falling within acceptable deviations from perfect accuracy, the technician can re-sticker the oscilloscope, unplug his TM 503, and move on to the next location. No unnecessary recalibration needs to take place, and the instrument is ready for use in less time than a typical coffee break, rather than being shut down for hours. If a parameter was outside spec but within "tweak-in" range, both the TG 501 and PG 506 can function as normal fixed calibration sources simply by pushing the variable knob in. The digital readout is then disabled and the generator output is set only by the indicator-range switch.

With verification and minor calibration performed at the user's site, the metrology lab, as far as oscilloscopes are concerned, now becomes only a place for troubleshooting and repairing instruments which have actually failed.

You who are familiar with earlier generations of Tektronix oscilloscope calibration instruments will find the TG 501 Time Mark Generator similar to the 2901, with operation extended to one nanosecond (1 GHz) and the error readout feature added; however, the TG 501 does not permit "stacking" (combined operation of two markers to create time marks at two different rates). The PG 506 Calibration Generator combines the features of the 106 Pulse Generator and the Standard Amplitude Calibrator. The SG 503 Leveled Sinewave Generator is functionally similar to the 191, but extends coverage to 250 MHz and provides frequency readout by a built-in autoranging 3-digit counter rather than a dial with attendent problems of accidentally reading the wrong range. It also replaces the 067-0532-00 Calibration Fixture. The SG 504 functionally replaces the upper portion of the range of the 067-0532-00 and extends coverage to 1050 MHz.

The TM 500 Series

Test and Measurement Instruments

SIGNAL GENERATORS

FG 501 Function generator; 0.001 Hz to 1 MHz, five waveforms

FG 502 Function generator; 0.1 Hz to 11 MHz, 25 ns rise and fall, five waveforms

PG 501 Pulse generator; 5 Hz to 50 MHz, 3.5 ns rise and fall

PG 502 Pulse generator; 250 MHz, 1 ns rise and fall, independently controllable logic 1 and 0 levels

PG 505 Pulse generator; 100 kHz, 80-V floating output, independently variable rise and fall times

PG 506 Pulse generator; 0.5 ns rise time output, 60 V output, and voltage calibrated output for oscilloscope calibration (measures amplitude errors with 0.1% resolution over error range of ±7.5%)

RG 501 Ramp generator; 10-μs-to-10-s ramp, with four scope-type trigger controls

SG 502 RC oscillator; 5 Hz to 500 kHz, sine and squarewaves, 0.1% distortion

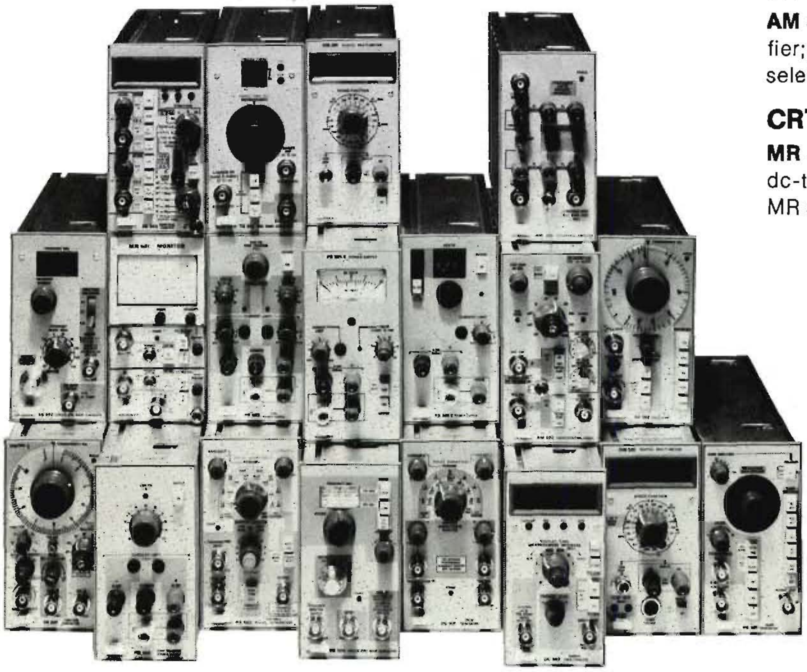
SG 503 Sinewave oscillator; 250 kHz to 250 MHz, 50-kHz reference output

SG 504 Sinewave oscillator; 245 MHz to 1,050 MHz, 50 kHz reference

TG 501 Time-mark generator; 1-ns-to-5-s markers, measures timing errors with resolution within 0.1% over timing-error range of ±7.5%

DIGITAL MULTIMETERS

DM 501 4½-digit multimeter; voltage accuracy to within 0.1% with temperature-measuring capability



DIGITAL COUNTERS

DC 501 Seven-digit, 110-MHz counter and totalizer

DC 502 Similar to DC 501 with ÷ 10 pre-scaler for counting to 550 MHz

DC 503 Seven-digit, 100-MHz universal counter with dual channels

DC 505 Seven-digit universal counter, 225 MHz on both channels

POWER SUPPLIES

(all also provide + 5 volts, referenced to ground)

PS 501 Floating output of 0 to 20 V, 0 to 400 mA

PS 501-1 PS 501 with 10-turn-potentiometer readout

PS 501-2 PS 501 with dual-range meter readout

PS 502 Dual-tracking supply ±10 to ±20 V or 20 to 40 V

PS 503 Dual supply, 0 to ±20 V or 0 to 40 V

MAINFRAMES

TM 501 Powers one module from standard line voltage

TM 503 Powers three modules; dual rackmount kit available

MOBILE TEST STATIONS

203 Option 1 SCOPE-MOBILE® Cart mounts TM 503, stores four modules

204 Option 1 SCOPE-MOBILE® Cart mounts TM 503, stores five modules

SIGNAL PROCESSORS

AM 501 High-power, high-voltage op amp; 5-MHz bandwidth, 50 V/microsecond slew rate into 800-ohm load

AM 502 Dc-coupled, high-gain differential amplifier; 1 to 100,000 gain, dc-to-1-MHz bandwidth, selectable—3 dB points

CRT MONITOR

MR 501 X-Y monitor; 10 mV to 10 V per division, dc-to-2-MHz bandwidth (RG 501 also converts MR 501 to oscilloscope)

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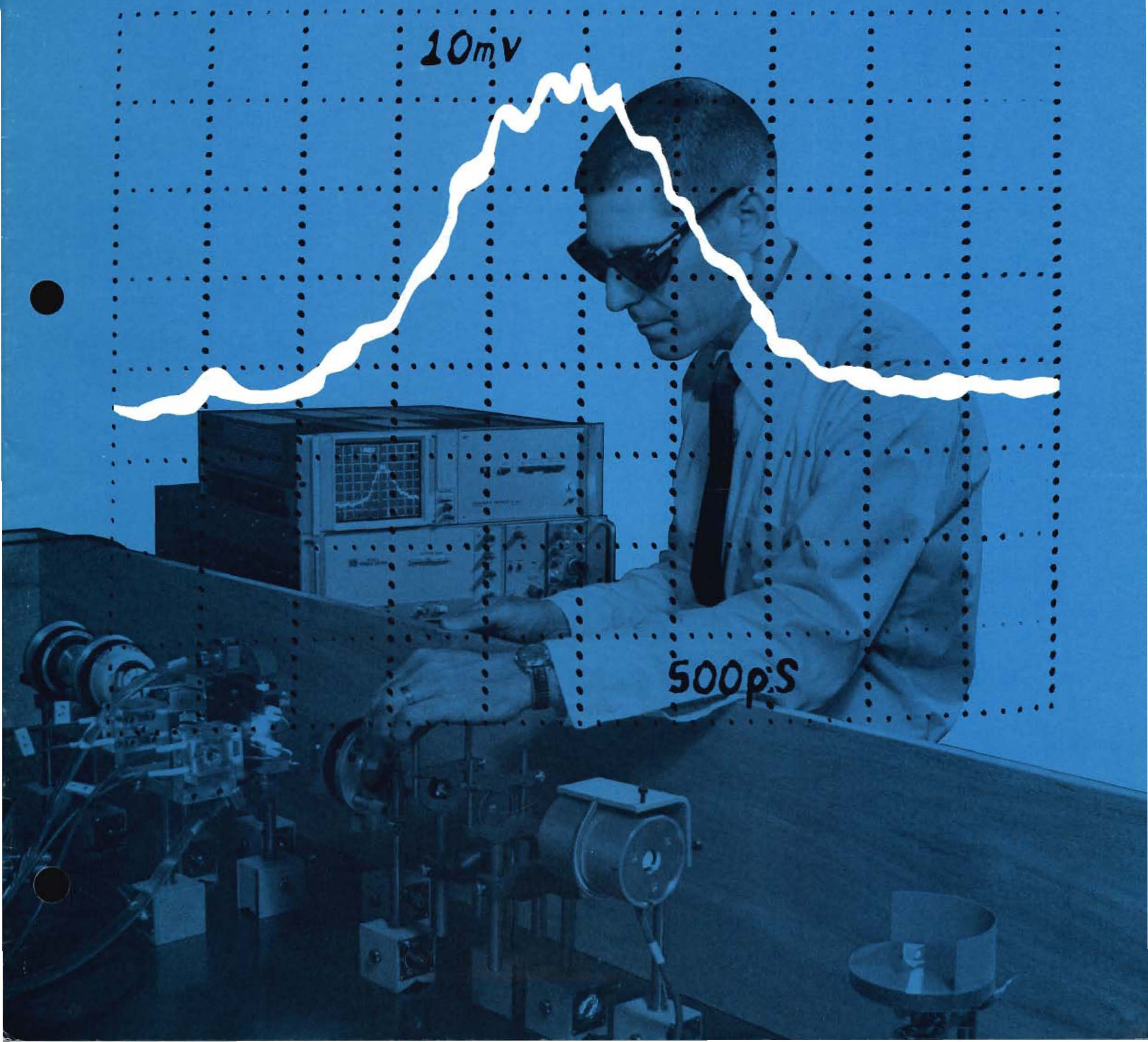

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TEKSCOPE

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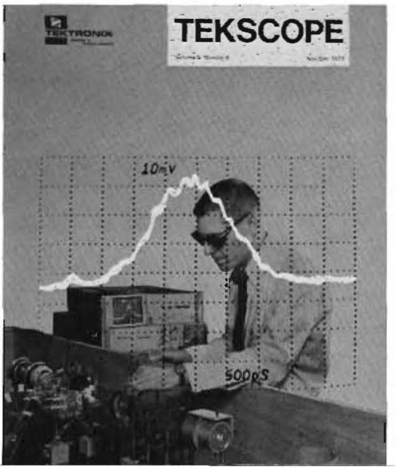
Cover: Dr. Gail Massey of the Oregon Graduate Center makes adjustments to a Q-switched neodymium YAG laser using the R7912. The dot pattern is the electronically-generated graticule and the waveform is typical of a detector output from a pulsed laser.



A new way to look at transients

Carlo Infante

The display and analysis of fast, single-shot pulses has long been one of the most challenging problems in oscillography. These pulses result from measurements in a wide variety of fields such as laser research, nuclear research, computer design and service, stress analysis of components, and others. In the past, the only way to view fast transients, which may be a nanosecond or less in duration, has been to use an oscilloscope with a viewing hood or the very best scope/camera combination. These methods have been quite successful as proven by the many thousands of TEKTRONIX oscilloscopes in installations of this kind, but there are some obvious disadvantages. One is the need to dark-adapt one's eyes before attempting to view a fast transient. Another is the time required to develop and analyze the photograph containing the waveform. Still another is the expense and inconvenience of using film, particularly when the waveforms need to be digitized for computer processing. Many of the present methods for digitizing waveforms from film involve hand processing with resultant time-consuming delays and possibility for errors.

The TEKTRONIX R7912 Transient Digitizer solves these problems in a unique and novel way, and in addition, provides features not available on earlier instruments. The functions of writing and reading, which in a normal oscilloscope are carried out by the same CRT beam, are accomplished by two separate electron beams in the R7912; waveform display is handled by a third beam in an associated monitor. This allows optimizing the design of each function to achieve the overall goal of large, bright, high-resolution waveform displays. The waveform can be displayed on a TV monitor such as the TEKTRONIX 632 to provide a bright, large-screen display easily viewable in room-ambient light; equivalent photographic writing rate in this mode is 30,000 div/μs. In addition, the waveform can be automatically digitized; i.e., the waveforms are processed into a computer-compatible format so they can be analyzed by a computer. Or, if desired, the waveforms can be stored in a self-contained memory (optional) and displayed on an X-Y monitor; an equivalent stored writing rate of 8,000 div/μs can be achieved with no limitation on storage time. (If display area is 8 by 10 centimeters stored writing rate is equivalent to 8,000 cm/μs.)

Instrument Description

Fig. 1 shows a block diagram of the instrument. The writing section of the R7912 is similar to a conventional oscilloscope. The input signal is acquired, conditioned, and amplified by vertical plug-ins from the TEKTRONIX 7000-Series family. Any of the 7A-Series plug-ins can be used, allowing a wide choice of vertical capabilities from high gain (as low as 10 μV/div with the 7A22 Differential Amplifier) to maximum bandwidth (1 GHz with the 7A21N Direct Access Unit). Horizontal sweep and sweep gate are generated by a 7B-Series time base plug-in.

The input signal is applied to the CRT writing gun. Design and operation of the CRT is described in a special feature section of this article. The waveform written on the target by the writing gun is read out by the reading gun. With the instrument operating in the NON STORE mode, the reading beam scans the target linearly in a TV format and operation is quite similar to that of a conventional TV camera. Each time the reading beam crosses a written point, a small current pulse is generated in the target lead. This pulse is amplified and processed to provide the video output signal.

Synchronizing signals for the Read System and the associated video monitor are generated by the Sync Generator. The X and Y Ramp Generator and Scan Amplifier produce the waveforms required to drive the X and Y deflection plates of the Read System.

In the DIGITAL mode, the read sequence is changed while the write sequence remains as already described In this mode, the target is scanned in steps in a 512 by 512 matrix rather than linearly. Also, fast scanning occurs vertically in the DIGITAL mode which is opposite to the NON STORE mode where fast scanning is done in the horizontal direction as in conventional TV. Fig. 2 illustrates these two scan modes using simplified waveforms and scan lines. The NON STORE mode, being similar to conventional TV, will not be explained further here.

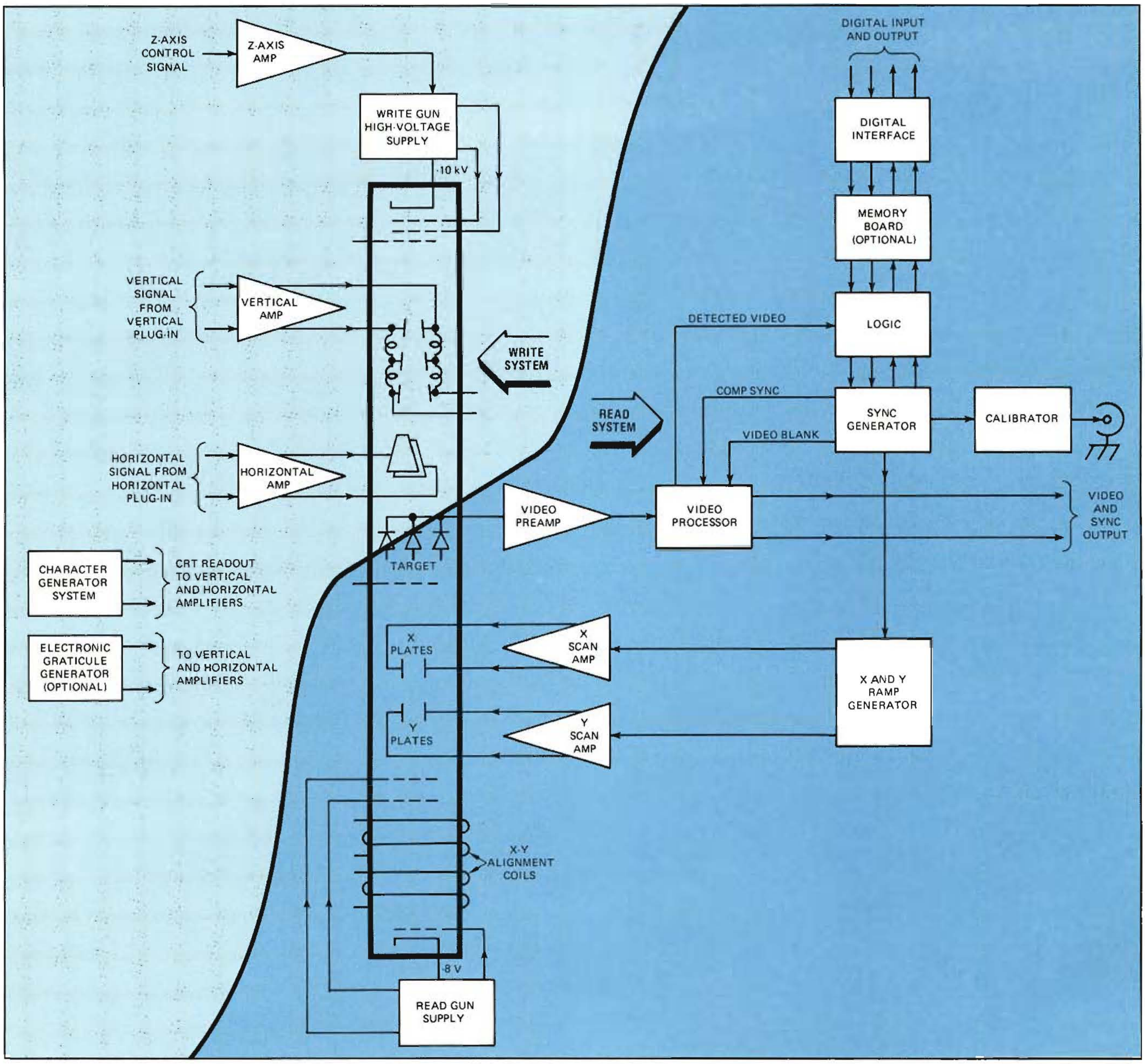


Fig. 1. R7912 Block Diagram.

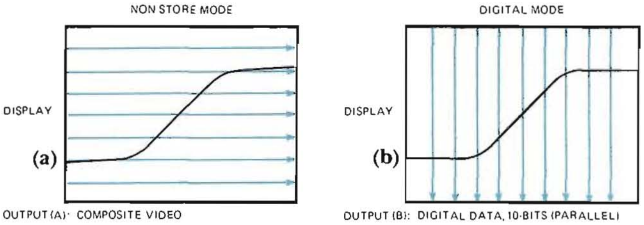


Fig. 2. Target scanning modes.

Vertical scanning is used in the DIGITAL mode due to the nature of the waveforms normally digitized. Notice that for the simplified scan shown in Fig. 2B, each vertical scan line intersects the waveform only once. In this mode, addresses of points on the target are transferred and stored in memory only when a trace has been written at that point on the target. This results in the fastest readout of information needed to define a waveform, and requires less storage space in memory for the waveform. In actual operation, the trace is several samples wide and circuitry is incorporated in the instrument to reduce the amount of information which must be communicated to define a trace. The counters and logic circuits required for digital operation are contained in the Logic circuit. The optional Memory allows waveforms to be stored in the DIGITAL mode for later transfer to a computer, or for display on a storage display unit through a display interface.

The R7912 uses the CRT READOUT SYSTEM pioneered in the TEKTRONIX 7000 Series to display measurement parameters along with the waveform. These characters are written on the diode target by the writing beam on a time-shared basis and become part of the output signal in the NON STORE mode. An optional converter is available for use in the DIGITAL mode to take the readout information directly from the plug-ins and convert it into an ASCII coded format which becomes part of the data communicated to the computer.

The optional Electronic Graticule Generator produces a dot array similar to the graticule on a conventional oscilloscope CRT. The electronic graticule is written on a time-share basis with the input signal and, like the CRT READOUT signal, becomes part of the output signal from the Read System. This electronic graticule eliminates parallax associated with overlay graticules and minimizes errors due to non-linearities or drift in the amplifiers or CRT deflection system.

Novel Circuitry—The Key to Performance

As you would expect in a state-of-the-art instrument, many novel circuits make up the R7912. These include a highly stable −10 kV power supply, an electronic graticule generator, low-noise amplifiers, and unique logic circuits. Let's look at several of these circuits in more detail.

Ramp Generator. A block diagram of the Ramp Generator is shown in Fig. 3. Two of these circuits are used in the R7912; one for the vertical and one for the horizontal. In the NON STORE mode, the Integrator generates a highly linear ramp (waveform A) whose amplitude is precisely set by two stable discriminators which define the upper and lower end points of the ramp. This waveform is synchronized by the action of the Phase Detector which compares the end of the ramp with the sync pulses. If there is an error, it changes the timing, or charge current, of the integrator to insure proper timing.

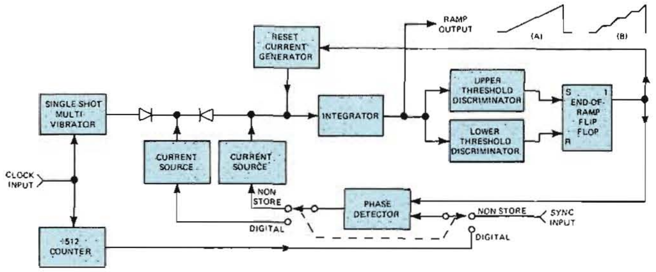
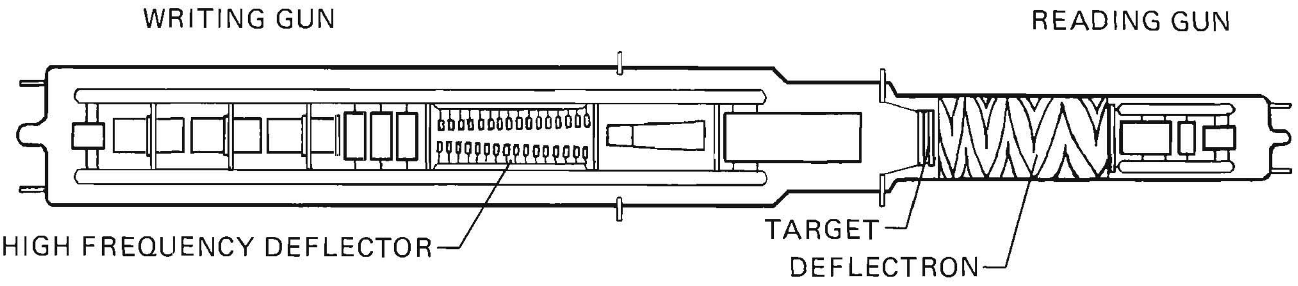


Fig. 3. Ramp Generator.

In the DIGITAL mode, 5-MHz clock pulses are connected to a Single-Shot Multivibrator and to a ÷ 512 Counter. Each time the Multivibrator fires, a small amount of current is injected into the Integrator, resulting in a step at its output. The voltage of the output step remains stationary during the Multivibrator's quiescent period. After a number of ramp and hold steps have been accomplished, the Upper Threshold Discriminator resets the End-Of-Ramp Flip Flop causing the Integrator to reset. The circuit is then ready to produce a new staircase waveform. The output of the End-Of-Ramp Flip Flop and the ÷ 512 Counter are compared by the Phase Detector. If these pulses do not occur simultaneously, a correction signal is generated by the Phase Detector and the charging current of the Integrator is suitably adjusted. In this fashion, the Phase Detector insures that precisely 512 steps are generated for each vertical or horizontal scan, resulting in a stable digitized waveform.

One of the features of this circuit is that the period of the staircase can be changed without affecting the accuracy of the staircase. This occurs in the operation of the R7912 when a point is addressed on the target where a waveform has been written. Normally, the staircase holds at each step for about 100 nanoseconds while the signal on the target lead is checked for a change in state since the previous sample. If there is no change, the staircase is advanced to the next step. How-

A close-up look at the crt



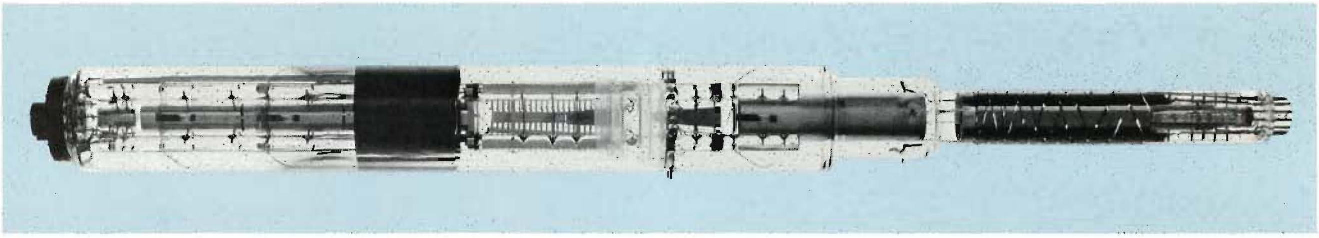


Fig. A. R7912 CRT.

The outstanding performance of the R7912 is due, in large part, to the TEKTRONIX-developed scan-converter tube forming the heart of the system. Fig. A shows a drawing of the tube along with a photograph of the final product. The tube is double-ended with the write gun and read gun facing each other axially. These guns and their associated deflection structures are separated by the target, where scan conversion occurs. The design parameters of the tube were optimized by means of a computer program to provide the best trade offs in gun structure and accelerating potential for the required resolution and scan area at the target.[1]

The input signal from the vertical amplifier is applied to the high-frequency deflector which consists of two helical delay lines assembled into a balanced deflection system. The entire writing-gun structure is operated at −10 kV to provide small spot size and fast writing rate.

The target consists of an array of diode junctions formed on a silicon wafer using integrated-circuit techniques. Fig. B shows a detailed view of the silicon target. A density of 2000 diodes per inch yields the desired resolution for the ½-by-⅜-inch scanned area. The center 0.75-inch diameter of the target is thinned to about 10 microns to facilitate operation in the double-ended mode (by comparison, the thickness of this page is about 100 microns).

The read gun produces a low-velocity electron beam with minimum shading and good resolution. Shading is caused by off-normal landing of the beam on the target and results in errors in the readout signal. This is particularly objectionable in a precision measurement instrument such as the R7912 and becomes even more of a problem when the output signal is converted into digital form (see Fig. C).

To accommodate the variable scan rates required of this instrument, electrostatic deflection was chosen for the read gun rather than the electromagnetic methods normally used for vidicons. However, if electrostatic focusing is used along with electrostatic deflection, poor shading

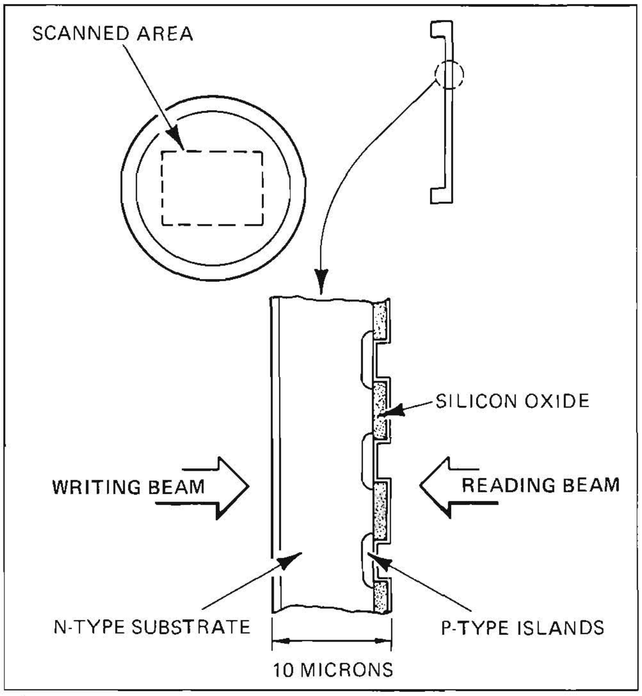


Fig. B. Target detail.

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[1] For a complete discussion of the design considerations that went into the CRT for the R7912, refer to "Storage Tube With Silicon Target Captures Very Fast Transients" by Raymond Hayes, Robert G. Cutler, and Kenneth W. Hawken, *Electronics*, pp. 97-102, August 30, 1973.

characteristics result. To solve these problems, a hybrid design was developed consisting of an electrostatic deflection system surrounded by an axial magnetic focusing field. The deflection plates actually consist of a cylindrical electrode pattern photo-etched on the interior wall of the tube (see Fig. A). The axial magnetic field is provided by an external solenoid. This configuration is called a deflectron deflection system.[2]

As the reading beam is scanned across the target, it charges the target negatively towards the read-gun cathode potential and the target diodes are reverse biased. High-velocity electrons from the write gun bombard the back of the target, creating electron-hole pairs which diffuse through the target. This causes the diodes to conduct and discharge in the written area. When the reading beam next scans the written area, it recharges the diodes, producing a signal current in the target lead. Amplification and processing of this signal provides the video or digital output signal.

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[2] For a complete discussion of the deflectron system, see "Electron Trojectories in Twisted Electrostatic Deflection Yokes" by E. F. Ritz, *IEEE Transactions on Electronic Devices*, November 1973.

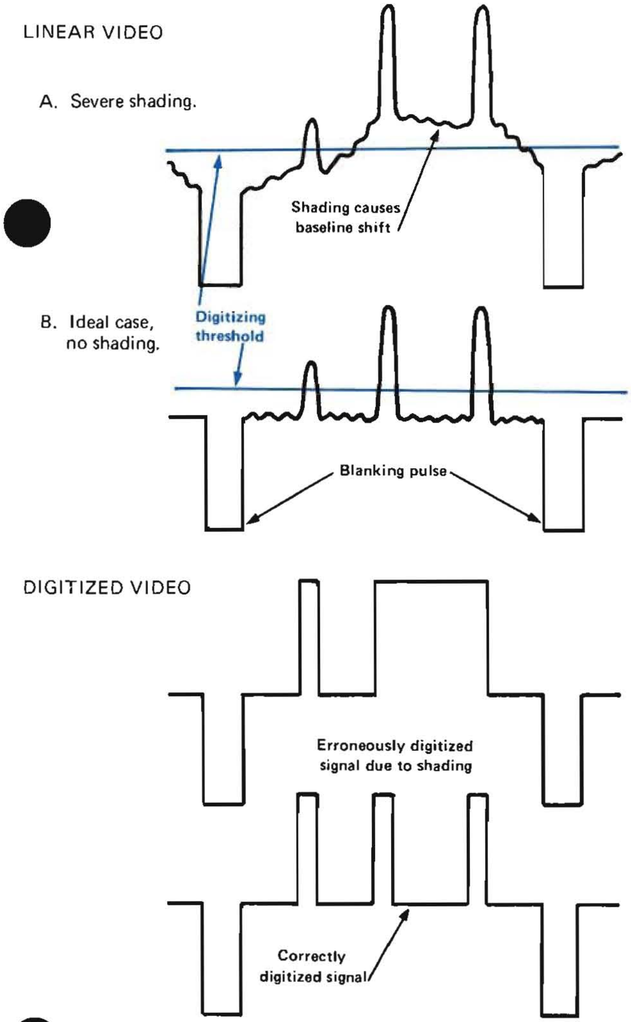


Fig. C. Effects of shading on digitized video.

ever, when a change is detected, the staircase holds at this step for about 1.6 microseconds to allow time for the address of this data point to be transferred to the computer or stored in memory. As a result, each staircase may have a different duration since the number of these pauses for address transfer will vary depending on the nature of the waveform written on the target. In a conventional feedback-stabilized circuit, this would result in timing variation and an inaccurately digitized waveform. To prevent this, the clock input pulses are interrupted during the address communication time. Both the Single-Shot Multivibrator and the ÷ 512 Counter remain inactive until the clock resumes. Highly stable circuitry in the Integrator holds the step level very constant during the pause. The overall result is that when normal operation resumes, the outputs of the End-Of-Ramp Flip-Flop and the ÷ 512 Counter have been delayed by the same amount of time. Therefore, no error signal is generated at the input of the Phase Detector and the ramp generator remains stable and phase locked even though the period of the staircase has changed.

Each of the vertical and horizontal steps has a BCD-coded address associated with it which is stored in the optional memory or transferred to a computer when valid waveform data is detected on the target. Both a vertical and a horizontal address is required to define a point on the target. Since the dot raster is a 512 by 512 matrix, there are over 250,000 addressable points on the target. The average waveform normally requires about 1500 points for complete definition. However, under some conditions such as dual-trace operation, two waveforms may be stored in memory simultaneously. To provide adequate storage, a 4000-word memory has been provided as an option for the R7912.

Electronic Graticule. Another interesting circuit is the Electronic Graticule Generator as shown by the block diagram in Fig. 4. This circuit generates all of the information needed to write the graticule on the target, along with the waveforms and readout. At the end of each sweep, this circuit is activated to begin producing the graticule. The master clock signal provides a precise reference for accuracy; all output signals are derived from the clock.

The electronic graticule is defined on the screen by a series of dots 0.2 division apart for the minor divisions and 1 division apart for the major divisions. When the electronic graticule is activated, fast ramps are produced in the vertical direction. Since the first ramp at the left side of the graticule must define both the major and minor divisions, 41 dots must be displayed to produce eight major divisions. During this ramp the master clock input is connected directly to the Dot Multiplexer which produces one Z-Axis intensifying pulse for each clock input.

The Vertical Dot Counter (÷ 45) produces an output after 45 clock pulses, which serves as a reference to the phase-locked Vertical Integrator. Operation of this ramp generator is similar to the Ramp Generator described previously. As the vertical ramp is reset, it triggers the Horizontal Staircase Generator which moves the next trace one step or 0.2 division to the right. At the same time, the output of the Major Division Counter (÷ 5) changes state, causing the Dot Multiplexer to switch from the direct vertical dots input to the Vertical-Dots-Divided-by-5 Input. During this vertical ramp, a dot is displayed every fifth clock pulse to define a major division.

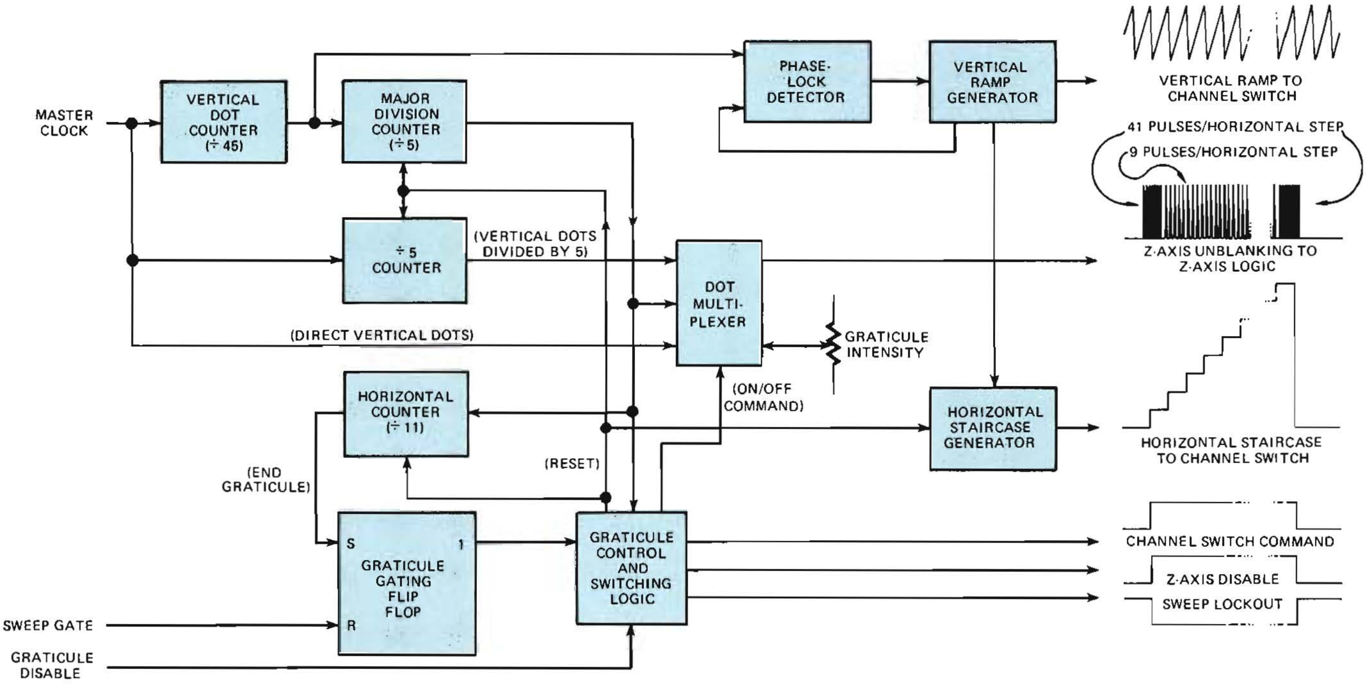
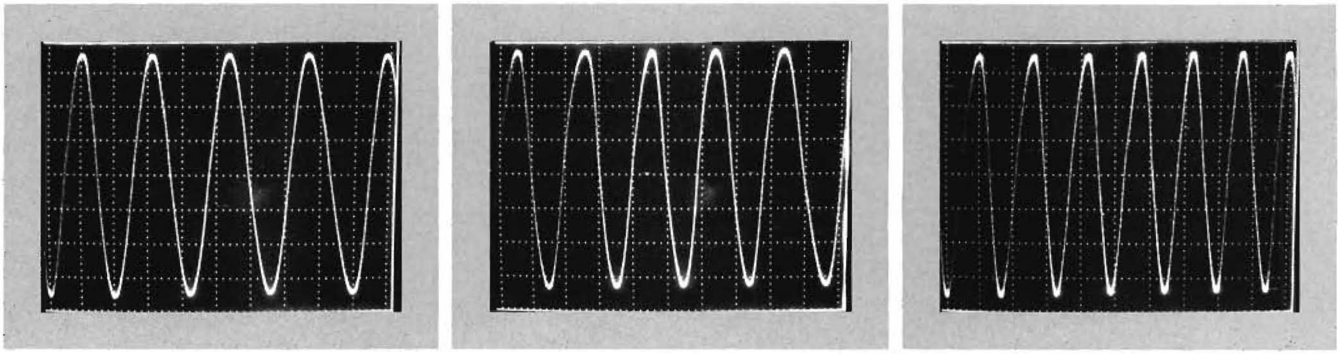


Fig. 4. Block diagram of Electronic Graticule Generator.



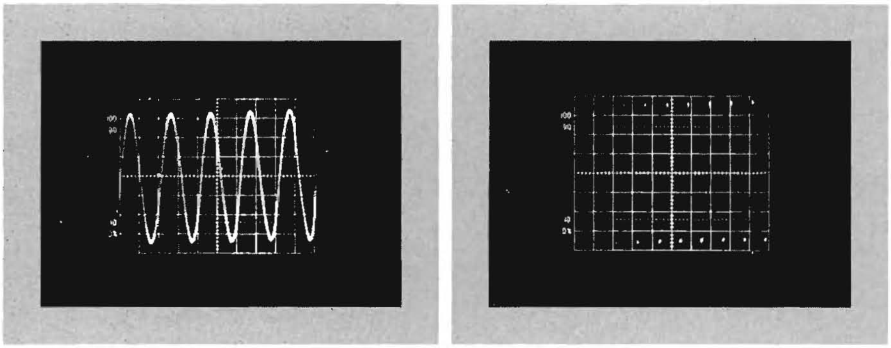


Fig. 5. Performance of R7912 (top waveforms) compared to fastest conventional oscilloscope (bottom waveforms). No waveform is shown for the conventional oscilloscope at 2.4 GHz since it could not display this signal.

Three more vertical ramps are generated in this manner. Then, the output of the Major Division Counter switches so that dots are again displayed every 0.2 division. Action continues until the graticule is complete. When the Horizontal Counter (÷ 11) has received 11 inputs from the Major Division Counter (÷ 5) the graticule is complete and it resets the Graticule Gating Flip Flop. This action turns off the Graticule Control block and halts operation of this circuit. About four milliseconds are required to write the complete graticule.

The Proof Is In The Performance

Performance of the instrument is best shown by the accompanying photographs. Fig. 5 shows continuous sinewave signals as displayed by both an R7912 Transient Digitizer/TV monitor (NON STORE mode) and a TEKTRONIX 7904 Oscilloscope. Identical plug-ins were used for both measurement systems. Fig. 6 shows the reconstructed display of a single pulse that was digitized by the R7912. The digital information was fed to a computer through the instrument's optional memory and interface circuits. It was then reconstructed and displayed on a TEKTRONIX storage display monitor.

Acknowledgments

This instrument, as many state-of-the-art projects, is the result of the dedicated effort of many people. These include: Carlo Infante, Program Manager; Jim Cavoretto, Project Engineer who also provided valuable assistance in compiling this article; Al Allworth, Don Roberts, and Stu McNaughton, Electrical Engineers; Walt Lowy, Engineering Technician; Ray Hayes, Ken Hawken, Bob Culter, Hal Cobb, Ed Ritz, and Bo Janko, CRT Engineering; Loyal Strom, Helene Albright and Ken Nesvold, Prototype Support; Doug Giesbers, Larry Pearson and Phil Lloyd, Mechanical Engineering; Nick Hughes and Ray Blohm, Instrument Manufacturing. The list would not be complete if special recognition were not given to these marketing people whose inputs and support were always very valuable: Bob Hightower, Bob Johnson, and Bill West.

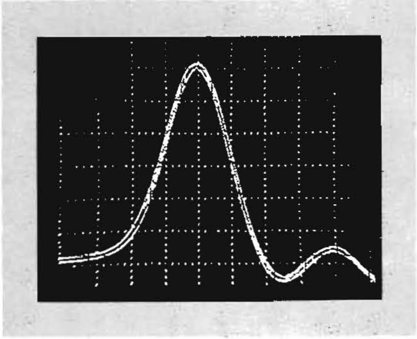
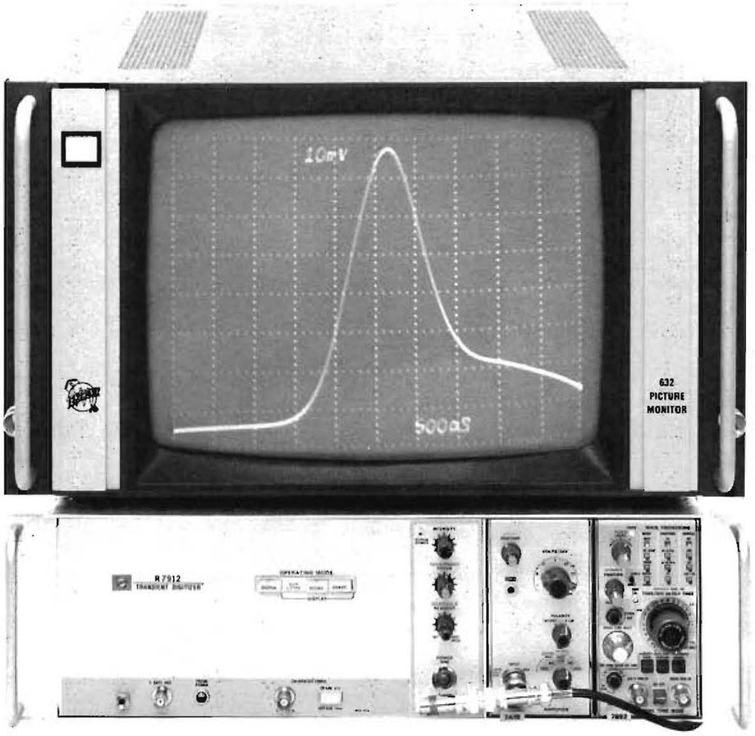
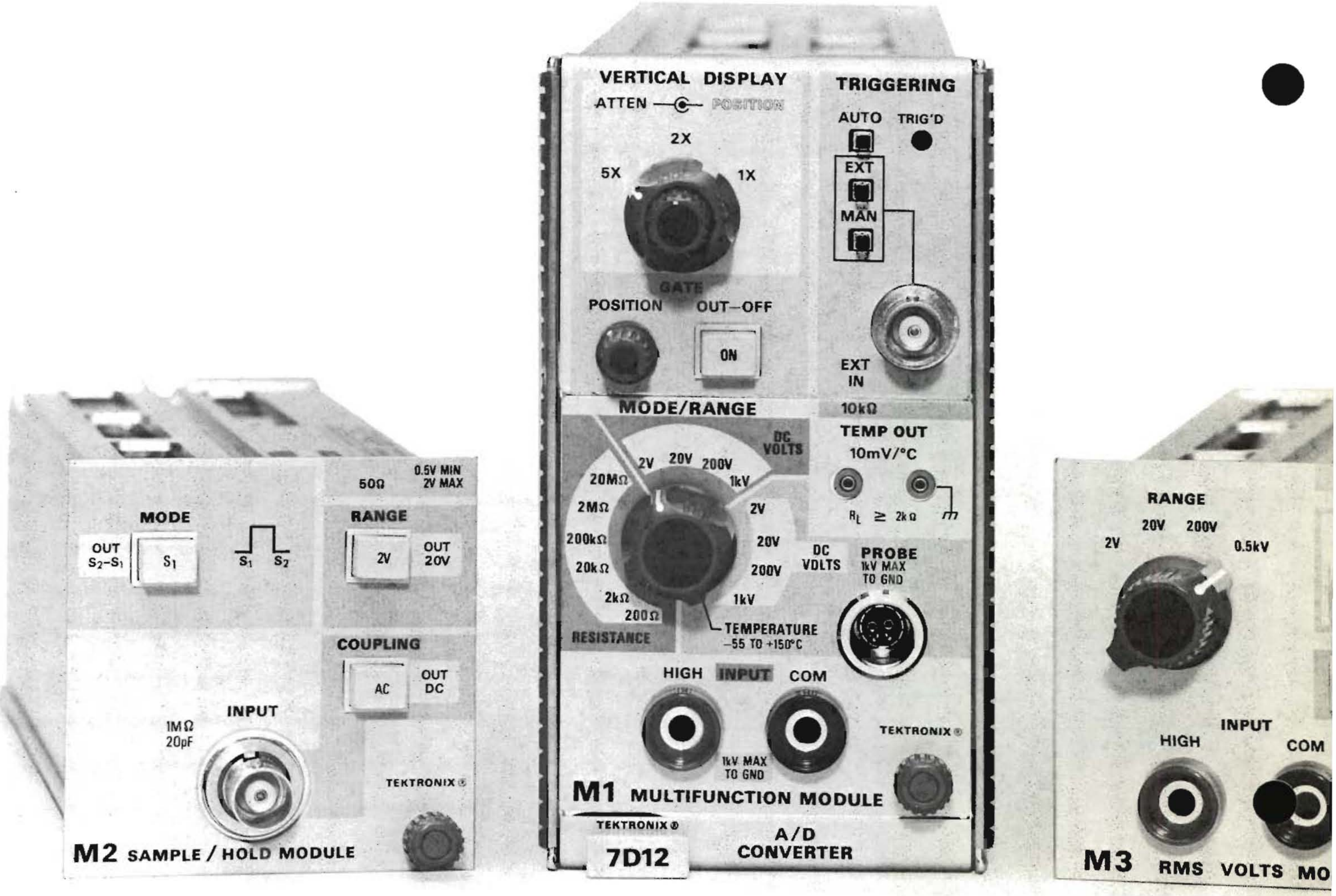


Fig. 6. Digitized waveform, reconstructed and displayed on a TEKTRONIX 603 Storage Monitor.



Hideki Iwata Ken Sternes

A fast A/D plug-in for the oscilloscope



One picture is worth a thousand words. And sometimes even a thousand words can't adequately convey the information. We might paraphrase this to say, "One waveform displayed is worth a thousand voltmeter readings." And sometimes even a thousand voltmeter readings can't adequately portray the waveform. It's true, however, that often a picture, or waveform, doesn't tell the complete story. The addition of a few words, or figures, can impart a lot of valuable information.

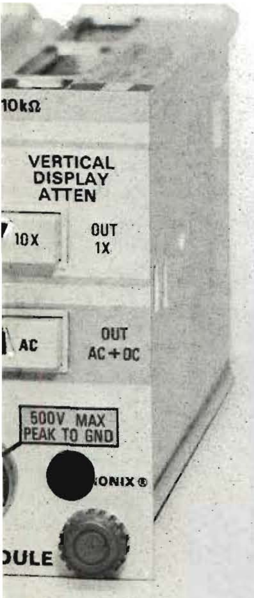
The introduction of the TEKTRONIX 7000-Series Oscilloscope with CRT READOUT brought us the powerful measuring capability afforded by displaying both waveforms and alphanumerics on the CRT at the same time. To many, this seemed to be merely a convenience for recording deflection factors along with the trace when photographing the screen. It *has* proven to be a convenience—and much more, for it has broadened the role of the oscilloscope to include counters, DVM's, computer-aided measurements and the like. Now a new analog-to-digital converter plug-in for the 7000-Series adds several highly useful measurements to your oscilloscope's repertoire.

The 7D12 Plug-in

The 7D12 A/D Converter plug-in is designed for use with any 7000-Series Oscilloscope containing CRT READOUT. The unit consists of two basic sections: the plug-in mainframe, which contains a fast, 4½-digit, A/D converter, inverter power supply, dual-trace 100-MHz vertical amplifier, readout control section and trigger circuit; and a smaller module which plugs into the front of the 7D12. Three modules are currently available—the M1 Multifunction Module for measuring DC volts, resistance and temperature; the M2 Sample/Hold Module for measuring voltage from ground to a selected point, or the difference voltage between any two selected points; and the M3 RMS Volts Module for making true RMS voltage measurements. We will discuss each of these in some detail; but first, let's take a closer look at the 7D12 mainframe.

The block diagram in Fig. 1 shows the major sections of the 7D12 and the modules. The modules process various analog signals—peak voltage, RMS voltage, resistance, temperature, etc., and produce a DC voltage which the 7D12 converts to digital readout information for the 7000-Series Oscilloscope. The M2 and M3 also provide an analog signal for display.

The function of each block in the 7D12 is readily apparent except, perhaps, for the inverter power supply. This supply permits floating the A/D converter, enabling us to make measurements with the input elevated as high as 1 kV. Triggering of the 7D12 can be accomplished internally from a unijunction transistor oscillator, externally thru a BNC connector, or manually by a front-panel push button.



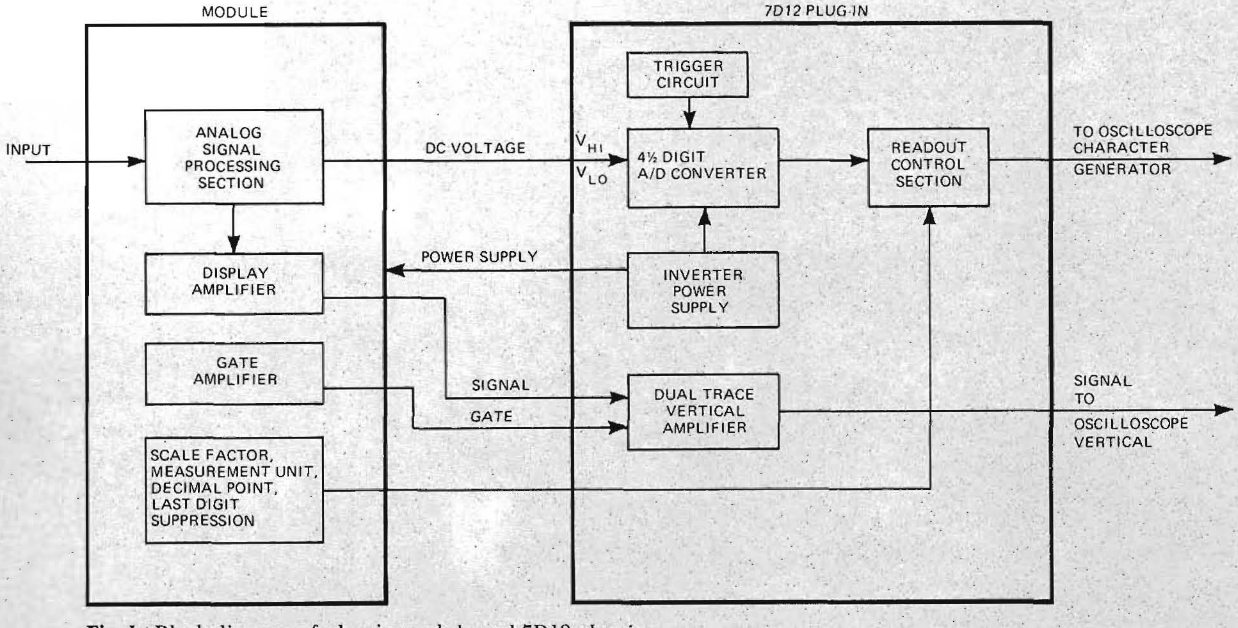


Fig. 1. Block diagram of plug-in module and 7D12 plug-in.

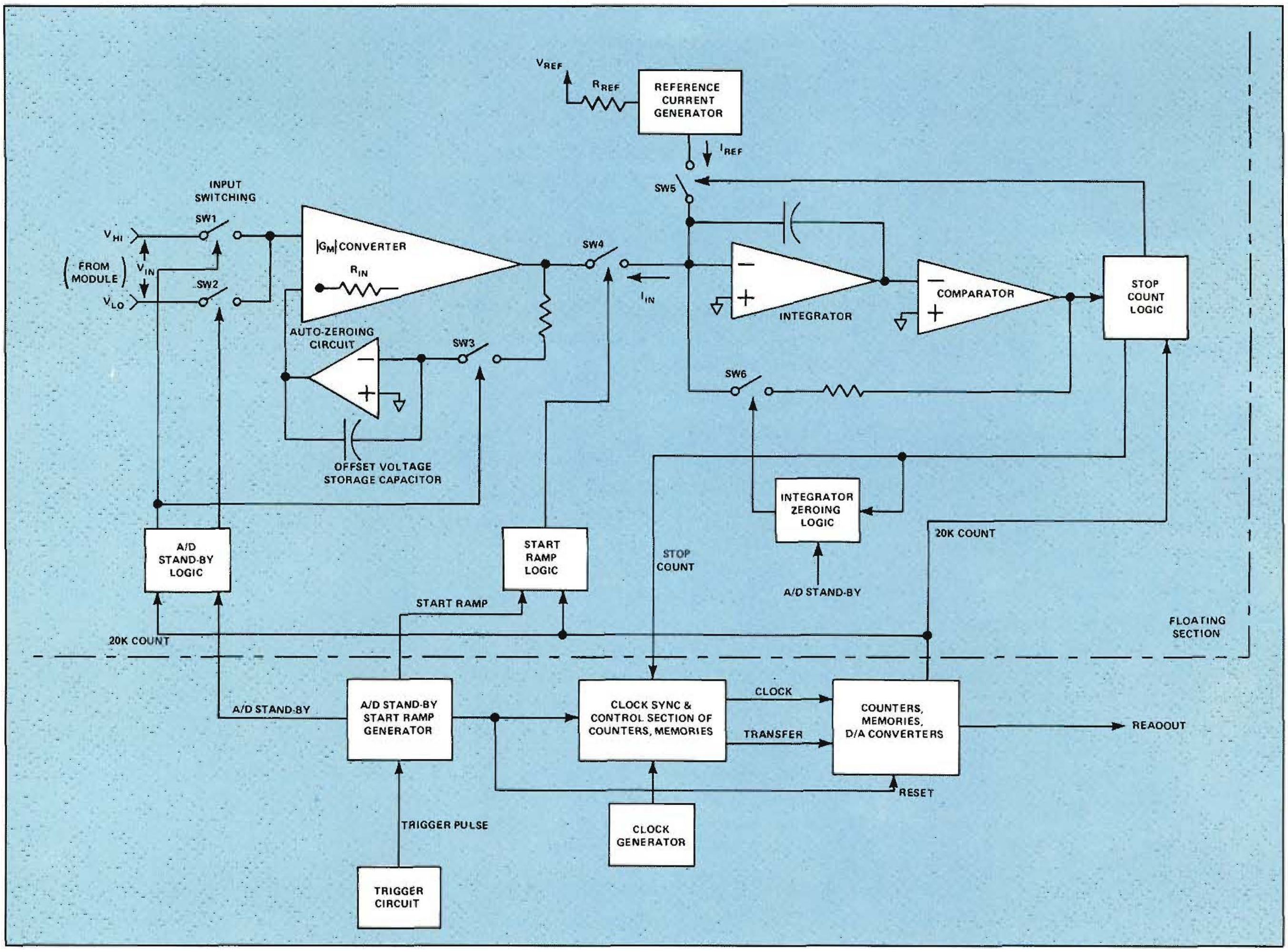


Fig. 2. Block diagram of the 7D12 A/D Converter.

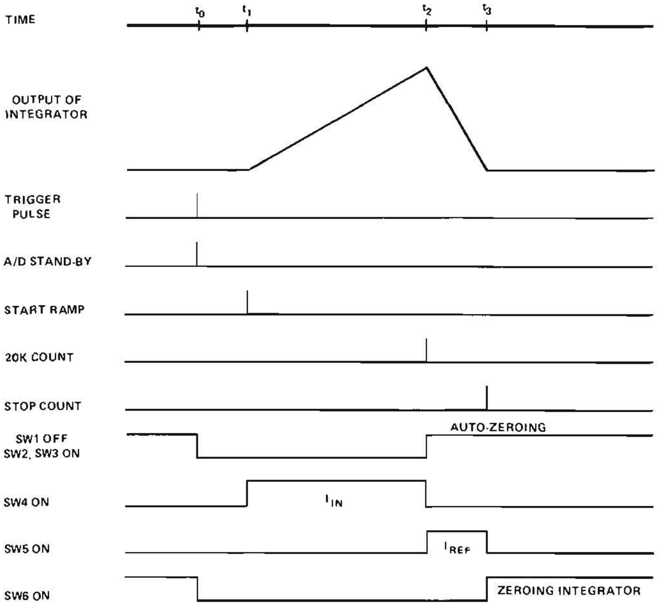


Fig. 3. Timing diagram for A/D conversion process.

The A/D Converter

The block diagram of the converter is shown in Fig. 2, and the associated timing diagram in Fig. 3. The converter produces 4½ digits with an accuracy of 0.01%. Basically, it is a dual-slope A/D converter with an auto-zeroing circuit. All of the switches shown in Fig. 2 are electronic switches such as MOS-FETs, JFETs and diodes. The circuitry enclosed by the dotted line is a floating section powered by the inverter power supply.

To help in understanding how the converter works, let's go through a normal sequence of events:

Before T_0—Before the trigger pulse arrives at the 7D12, SW2 and SW3 are closed, and SW1 is opened. The input to the $|G_M|$ converter, which has a current rectifier, is connected to V_{LO}. The $|G_M|$ converter and auto-zeroing circuit are nulled, and a capacitor in the circuit memorizes the input offset voltage of an input amplifier in the $|G_M|$ converter. SW6 is closed so that the integrator will start integrating at the proper voltage.

t_0 - t_1—When a trigger pulse arrives at t_0, the A/D Stand-by Start-Ramp Generator produces an A/D stand-by pulse to switch the states of SW1, SW2, SW3, and SW6 through the A/D Stand-by Logic circuit. The input of the $|G_M|$ converter is now connected to V_{Hi}. The input voltage V_{IN} is equal to V_{Hi} minus V_{Lo}.

t_1 - t_2—After 2 milliseconds, a start-ramp pulse is produced at t_1 to turn SW4 on through the Start Ramp Logic, to start integrating the input current, I_{IN}, and the counter is started by the clock pulse from the Clock Synch. and Control Section.

t_2 - t_3—At 20,000 counts of the counter at t_2, SW4 is opened, and SW5 is closed to start integrating down by the reference current, I_{REF}. At t_2, the auto-zeroing circuit is activated again by turning SW1 off and SW2 and SW3 on through the A/D Stand-by Logic.

After t_3—When the output of the integrator reaches the zero level, a stop-count pulse is produced, and the reference current is turned off at t_3. The counter stops. The content of the counter is then transferred to memory where the output is converted to an analog readout signal. SW6 is turned on again to prepare the integrator for the next measurement. The digital readout is equal to $(I_{IN}/I_{REF}) \times 20{,}000$. I_{IN} is equal to $|V_{IN}|/R_{IN}$ where R_{IN} is a discrete resistor in the $|G_M|$ converter, and I_{REF} is equal to V_{REF}/R_{REF}. The readout can be expressed by the following equation:

$$\text{Readout} = \left(\left(|V_{IN}|/R_{IN} \right) / \left(V_{REF}/R_{REF} \right) \right) \times 20{,}000 \quad \ldots \quad \text{Eq. 1}$$

With the use of the auto-zeroing circuit, the $|G_M|$ converter cannot drift more than 100 microvolts for the instrument's operating range of +15°C to +40°C. By using a precision input amplifer with high gain and high common-mode-rejection, V_{IN} in Eq. 1 is made equal to the voltage input to the 7D12. V_{REF} is a temperature-compensated zener diode with a temperature coefficient of 5 p.p.m./°C. The ratio of R_{IN} and R_{REF} can be tightly controlled by using matched resistors whose temperature tracking is better than 2 p.p.m./°C. Therefore, total maximum temperature coefficient is 7 p.p.m./°C. The required accuracy of ±0.01% over a ±5°C temperature range is easily achieved.

Now let's take a closer look at the plug-in modules.

The M1 Multifunction Module

The M1/7D12 combination forms a 4½-digit voltmeter and ohmmeter, and a 3½-digit temperature indicator. The DC voltmeter measures from 0 to 1000 V in four ranges with a resolution of 100 μV on the 2 V range. System accuracy is ±0.03% of reading ±0.005% of full scale over the ambient temperature range of 20°C to 30°C, or ±0.04% of reading ±0.005% of full scale from 15°C to 40°C. Either input connector can be elevated 1 kV above ground, and the input impedance is 10 MΩ on all ranges.

Resistance from 0 to 20 MΩ is measured in six ranges, with a resolution of 10 milliohms on the 200 Ω range. The accuracy is ±0.09% of reading plus ±0.01% of full scale from 15°C to 40°C.

Both temperature and DC voltage can be measured using the convenient P6058 voltage/temperature probe. Temperature from −55°C to +150°C can be measured with a resolution of 0.1°C and an accuracy of ±1°C up to 125°C and ±2°C up to 150°C. A pair of terminals on the M1's front panel provides an analog output of 10 mV/°C (0°C = 0 volts). This output is available regardless of the Mode/Range switch setting.

The M2 Sample/Hold Module

The M2/7D12 combination provides a unique measurement capability for the 7000 Series. You can measure voltage amplitudes from ground to a selected point, or the difference voltage between any two selected points with an accuracy of ±0.35% or better. The sample points can be triggered automatically, manually, or externally, with one of the most convenient sources being the delayed gate from a 7000-Series Time Base. With the delayed gate applied to the trigger Ext In connector, the leading edge of the gate determines the S_1 sample point, and the trailing edge determines the S_2 sample point. Fig. 4 shows a typical measurement using the S_2-S_1 mode. The reading at the upper left is the voltage difference between S_2 and S_1, upper center is the TIME/DIV, and the lower left reading is the vertical deflection factor for the displayed signal. The signal display is intensified during the delayed gate; however, at sweep rates of about 100 ns/div and faster, the intensified portion will not coincide with the displayed gate because of the delay line in the oscilloscope vertical amplifier. The time interval between S_1 and S_2 can be as short as 30 ns and as long as 5 ms. For single-shot S_2-S_1 measurements, the time interval must be 150 μs or longer.

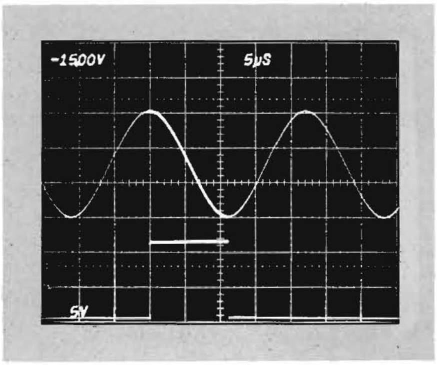


Fig. 4. Typical S2-S1 measurement showing peak-to-peak voltage of AC waveform. Reading is at upper left.

10 Nanosecond Aperture Time

One of the unusual features of the M2 is the 10 ns aperture time. This makes it useful for measuring high dv/dt signals such as the fast A/D converter waveform pictured in Fig. 5. Accuracy of the measurement is typically better than ±0.25% if 40 ns is allowed for settling time following an input signal step-function.

Fig. 6 illustrates an application of the M2/7D12 teamed up with a 7D15 Universal Counter/Timer plug-in to make accurate rate-of-rise measurements on a ramp signal. The M2 is operated in the S_2-S_1 mode. The delayed gate from the time base plug-in is used to gate both the M2/7D12 and the 7D15. The +2.35 V reading in the upper left corner is the change in amplitude during the brightened portion of the trace. The time interval as measured by the 7D15 is 20.92 µs and the 1X indicates the reading was taken during a single event rather than an average of several ramps. Accuracy of the M2/7D12 in this mode is ±0.35%. The linearity of the ramp can be quickly checked by moving the delayed gate along the ramp and noting any change in the amplitude reading provided by the M2.

The M3 RMS Volts Module

The M3/7D12 combination brings another unique measurement capability to the oscilloscope—measuring true RMS voltages. The M3 measures DC, the true RMS voltage of signals from 40 Hz to 100 kHz, and the true RMS value of AC + DC. The maximum input is 500 V RMS or 1000 V peak. Voltages are displayed digitally on the CRT with 3½-digit readout, with a resolution of 1 mV achievable on the 2 volt scale. Accuracy of the M3 is ±0.25% of full scale up to 40 kHz on the 2 V and 20 V ranges, derated to ±0.5% above 40 kHz. The maximum permissible crest factor $(\frac{E_{PEAK}}{E_{RMS}})$ is 5. Response time of the M3, that is the time required for the readout to reach its stated accuracy after a step voltage is applied, is less than 2 seconds.

The M3 can measure distorted sinewaves such as the outputs from SCR circuits, or non-sinusoidal waveforms such as pulse trains with duty cycles as low as 4%. The photograph in Fig. 7 shows the measurement of the RMS voltage from a silicon controlled rectifier. The RMS value of the displayed waveform is the reading at

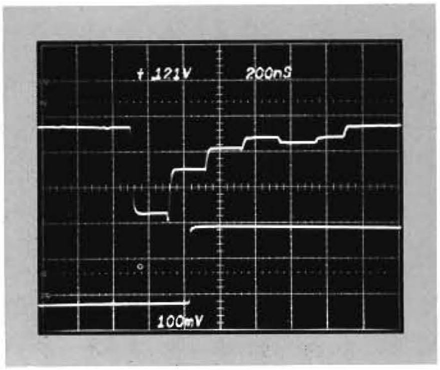


Fig. 5. Voltage level at any point on this A/D waveform can be made by positioning the gate to start at the desired point.

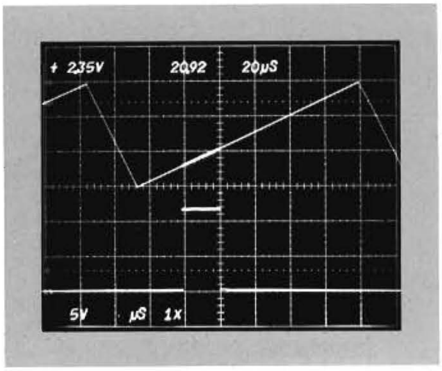


Fig. 6. The S2-S1 mode being used to accurately measure rate-of-rise on a ramp signal. The voltage difference is+2.35 V and elapsed time 20.92 µs.

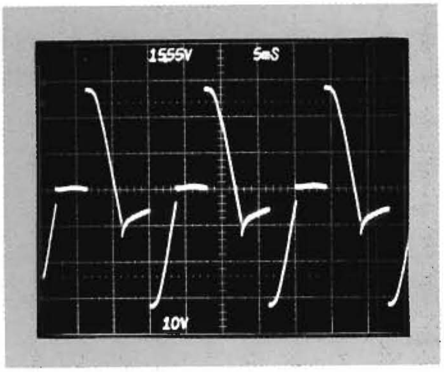


Fig. 7. True RMS value of SCR is measured by the M3/7D12.

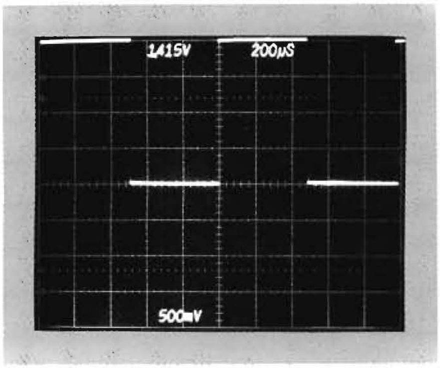


Fig. 8A. Measuring true RMS value of AC+DC waveform.

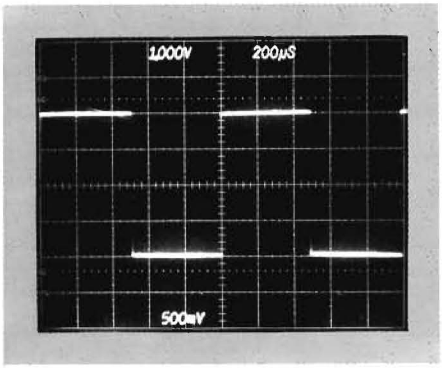


Fig. 8B. Measurement of same waveform with DC component removed by AC coupling.

upper left, and the lower reading is the vertical display sensitivity. Another example, showing the effect of DC on the RMS measurement is shown in Fig's. 8A and 8B. The waveform in Fig. 8A is a 2-volt pulse with a 1-volt DC component. Fig. 8B is the same pulse with the DC component removed by AC coupling the M3. If the pulse were symmetrical, the RMS value in the DC-coupled reading would be $\sqrt{2}$ times the AC-coupled reading since $E_{RMS} = \sqrt{(DC)^2 + (AC_{RMS})^2}$ and, in this instance, $AC_{RMS} = DC = 1$ volt.

Now, let's take a look at how the M3 functions. The block diagram of the M3 is shown in Fig. 9. Following the input attenuator, the signal progresses through two separate channels. The lower channel is an amplifier for conditioning the signal for display as an analog signal, or waveform, on the CRT. The modulator allows the floating input to be transformer coupled to the chassis-referenced 7D12 display amplifier. Bandpass of the analog channel is DC to 700 kHz.

The upper channel converts the input signal to a DC voltage equivalent to the RMS value, for driving the A/D converter in the 7D12. The operational rectifier and voltage-to-current converter, although shown as two separate blocks, are difficult to separate physically. A simplified circuit diagram of the two is shown in Fig. 10. When the input is a positive signal, the current path is through Q_1, R and CR_2; when negative, it is through Q_2, R and CR_1. The voltage across R is Ke_{IN} and you will note that the current flows unidirectionally in the output. The output current is thus proportional to the absolute value of the input voltage. To prepare the signal for squaring, the output current is divided into two equal parts for driving the multiplying circuit. These two equal currents then pass to the gain cell which squares, averages and takes the square root of the input currents. The output of the gain cell is equal to the RMS value of the input voltage to the M3, but is referenced to some positive voltage rather than the common buss. By using a summing amplifier this positive voltage is subtracted, bringing the output back to the common reference for driving the 7D12.

Summary

The 7D12, with its plug-in modules, adds important new measurement capability to your 7000-Series Oscilloscope. And, it is measurement capability with digital accuracy. True RMS voltage, DC voltage, resistance, temperature, and voltage difference between any two selectable points on a waveform are all measurements available to you using the 7D12 plug-in.

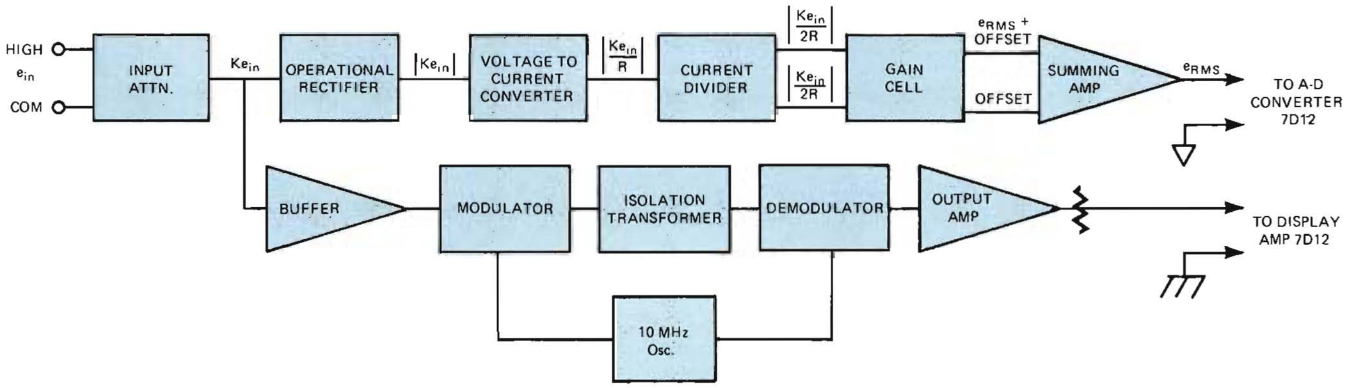


Fig. 9. Block diagram of the M3 true RMS volts module.

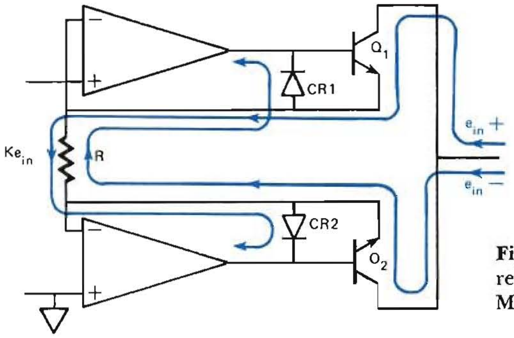


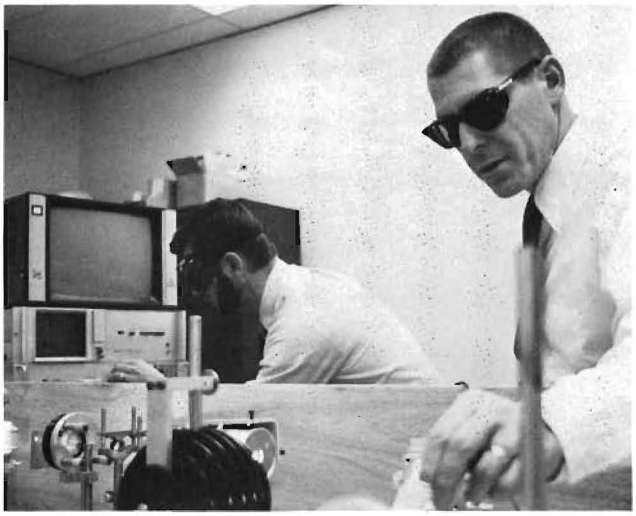
Fig. 10. Simplified block diagram of operational rectifier and voltage-to-current converter used in M3.

Teknique

Digitizing and displaying fast pulses

Hale Farley

Did you know that high-speed signals can be quickly made computer compatible? Or that they can be displayed on a large screen TV monitor in real time or stored on an X-Y monitor in a refreshed mode? The TEKTRONIX R7912 Transient Digitizer can digitize signals that occur in a few tenths of a nanosecond. The signal is captured on a diode-array target at sweep rates up to 500 picoseconds per division. In the DIGITAL mode, it is scanned off at a rate slow enough for a minicomputer to handle, with a maximum writing rate equivalent to 8,000 div/μs. The NON STORE mode provides bright, large screen displays at writing rates equivalent to 30,000 div/μs.



Dr. Gail Massey of the Oregon Graduate Center making adjustments to a pulsed neodymium YAG laser, using the R7912.

Just how fast is 500 picoseconds? The fastest entity known is light. In 500 picoseconds, light travels about six inches. One source of light pulses which is receiving increasing attention in many research laboratories is the laser. A laser (light amplification by stimulated emission of radiation) is a source of energy that occurs within a very short time frame.

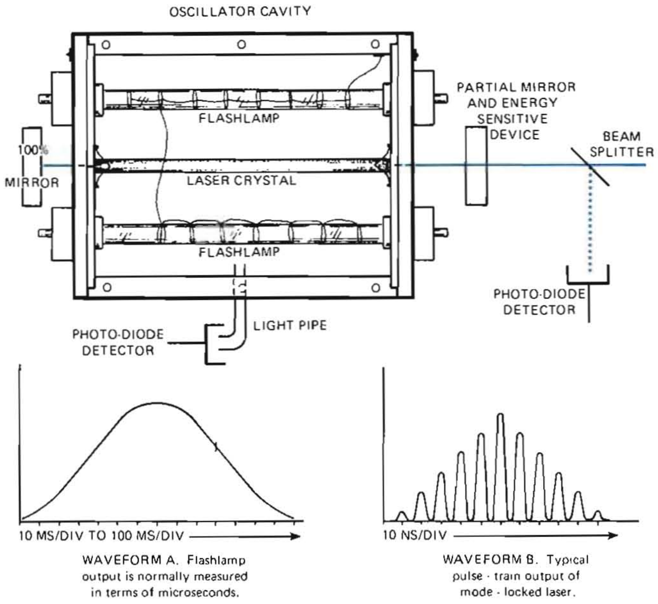
The pulse train produced by a mode-locked laser often has fast pulses that are separated by only a few nanoseconds. A switching method such as a dye cell is used in conjunction with a mode-locked laser to permit only a single pulse train to leave the laser cavity. The individual pulses within the train can be as short as five picoseconds. The ability to capture and display a single pulse is limited by the response of the detector and the measurement instrument. With the R7912 and the 7A21N Direct Access Plug-in, instrument risetime is 350 picoseconds at a sensitivity of 4V/div or less.

Fig. 1 shows a very simple mode-locked laser which produces two basic waveforms which can be analyzed with the R7912. Response of the flashlamps can be measured with the R7912 by either of two methods. One is to place a current-sensing resistor in series with the power lead for each lamp. A drawback of this method is that multiple signal channels are needed, one for each lamp. A preferred method of measuring flashlamp response is with a light pipe and photo-diode detector. Now, the display shows the actual flashlamp output on a single channel. The R7912 can be operated in the NON STORE mode to provide a real-time display for adjusting the flashlamps and setting the pumping power. In the DIGITAL mode, the R7912 digitizes the waveform to allow computer action on the signal or for automatic computation. Some of the data that can be obtained from this setup is:

- Total light output.
- Duration of light pulse.
- Peaks, breaks, or other irregularities in the power curve.
- Area under the curve for indication of power (may be determined automatically by the computer).
- Auto-feedback calibration of the pumping power to maintain desired light output (under computer control).

Waveform B shown in Fig. 1 is the pulse-train output of the mode-locked laser. Normally, this signal is obtained using a beam-splitter mirror and a photo-diode detector. Again, the R7912 can be operated in the NON STORE mode to produce a real-time display which makes system setup easy. The large screen TV monitor allows you to view the detector output easily, even from across a brightly lighted room, while you make system adjustments. This waveform can also be computerized for measurement of output power, Fast Fourier Transform computations, or many other computer-aided functions.

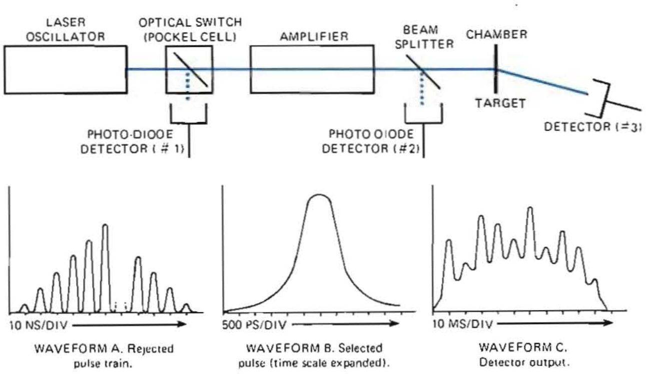
A typical laser system is shown in Fig. 2. Some of the points where measurements could be made with an R7912 are identified by the detectors shown in this diagram. Typical waveforms that would result at these measurement points are also shown. A Pockel cell is a typical optical switch used in laser systems. It switches fast enough to select an individual pulse out of the mode-locked pulse train. The rejected portion of the pulse train can be sensed by photo-diode detector #1 and compared with the amplified output at photodiode detector #2 to see if a complete single pulse came through the optical switch and how cleanly this pulse was extracted from the pulse train.



WAVEFORM A. Flashlamp output is normally measured in terms of microseconds.

WAVEFORM B. Typical pulse - train output of mode - locked laser.

Fig. 1. Mode-locked laser.



WAVEFORM A. Rejected pulse train.

WAVEFORM B. Selected pulse (time scale expanded).

WAVEFORM C. Detector output.

Fig. 2. Measurements in laser system.

A variety of detectors could be used to measure the effect of the pulse at the target. Choice of the detector would be determined by the phenomenon you desire to measure at the target. Some typical detectors used are:

- Photo diode—measures photon flux; i.e., photons of various energies and X-rays.
- Faraday cup—measures charge of particles.
- Energy/charge analyzer—measures energy versus charge.
- Beta spectrometer—measures electrons of various energies.
- Secondary electron detector—measures work-function characteristics of various materials.
- Neutron detectors—measures neutron activity.

Waveform C is a typical output waveform produced by any of the above detectors.

As in the previous measurement, the R7912 can be used either in the NON STORE or the DIGITAL mode. For system setup and alignment or real-time analysis of measurement results, the NON STORE mode used with a TV monitor provides a good display. However, some high-powered lasers must allow several minutes to elapse between pulses. In that circumstance, the DIGITAL mode used with a storage monitor provides the best display. This setup allows the display to be viewed and analyzed for extended periods. Also, new information can be written over the previous trace for direct comparison.

We mentioned previously that the output signal from the detectors can be digitized for computer analysis. It is not feasible in these limited pages to describe in detail the computations that can be made on these signals by the computer. The operating capabilities are mainly limited by the abilities of the programmer and physical limitations of the computer.

In this article, we have given only an over-view of the measurement capability of the R7912 Transient Digitizer. While we have not answered all of the questions you may have regarding measurements to be made with this system, we hope to have implanted the seeds of a few ideas which will germinate into solutions for your individual measurement problems.

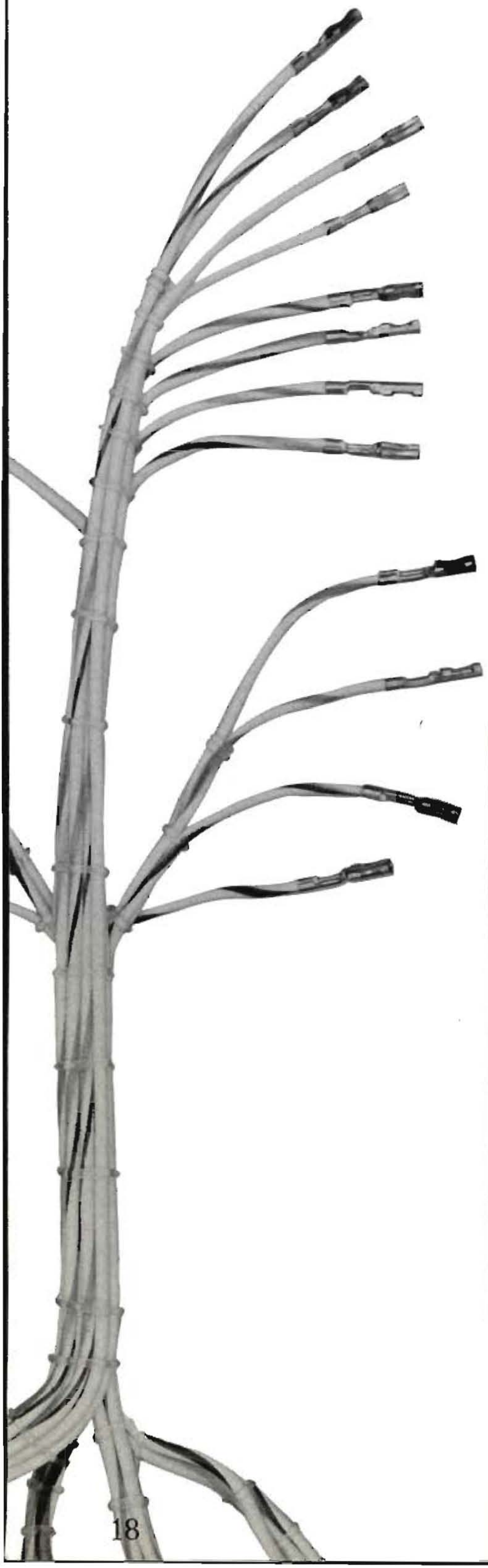
Servicescope

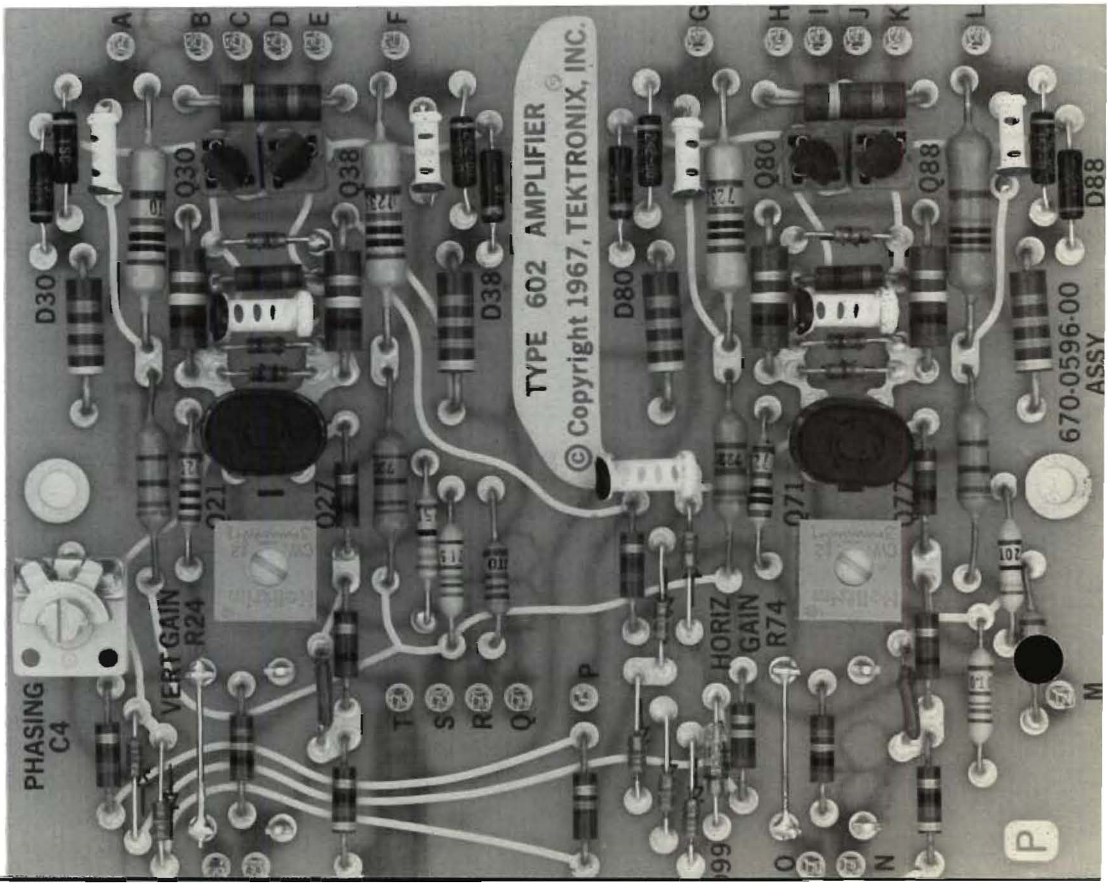
Getting around in Tektronix Instruments

Most electronic equipment is pretty complex inside. Especially when it comes to locating specific components and circuitry while troubleshooting the unit.

Serviceability has always been an important design consideration at Tektronix. Beginning with our first instrument, the Type 511 Oscilloscope, we endeavored to make components easy to locate and replace. And leads were soldered in, in a manner allowing them to be easily lifted for troubleshooting. The notched ceramic strips used in later instruments such as the 535 and 545 made servicing almost a pleasure.

Now, with the use of printed circuit boards and the automatic insertion and soldering of components, servicing has become a bit more difficult. Components are reduced in size and component density is vastly increased. Locating and replacing specific components on a crowded circuit board can be a real problem. Here are some of the things we are doing at Tektronix to make it easier for you.





Printed Circuit Board Marking

Much can be done to accommodate component marking if proper attention is given to this when designing the circuit board. With space limited, we assign priority to marking active devices such as transistors and IC's, adjustable components, plugs and connectors, and danger points. Both the circuit symbol and control name are usually shown for adjustments. Markings follow the A.S.A. code for component symbols—"Q" designates transistors, "U" integrated circuits, "CR" diodes, "K" relays and so forth. Incidentally, you will find most active devices mounted in sockets rather than soldered on the circuit board.

The location of the number one pin for IC's, and the proper orientation for multi-lead connectors are also noted on the printed circuit board. Some of the most useful markings are test points denoted by "TP". These correspond to test points shown in the manual schematics and usually have provision for easily attaching a probe. The instruction manual also contains photos of each printed circuit board with all components and adjustments labeled.

Connectors Play an Important Part

It's easier to take things apart if leads and cables terminate in connectors. You'll find some real innovations by Tektronix engineers in this area. The Peltola connector provides a compact, inexpensive means of connecting shielded leads to the printed circuit board. Harmonica connectors accommodate ten-lead ribbon cable in a minimum of space and are easy to put on or disconnect. And unique inter-board connectors provide direct connection between circuit boards without the need for cabling.

Color Coded Wires

This year Tektronix applied color-coding stripes to over 75 million feet of wire for use in our instruments. Another 6 or 7 million conductor feet of ribbon cable, also color coded, is supplied by outside vendors. These brightly colored leads enhance the internal appearance of Tektronix instruments, but that isn't the primary purpose for color coding. It serves a very useful function in building the instrument and in servicing it.

The color-coding scheme is basically in accordance with MIL-STD-681B. The color of the wire insulation identifies the function of the lead as follows:

Black — Grounds
Brown — Heaters and filaments
Red — B+ power supplies
Violet — B− power supplies
Gray — Internal AC Power
White — Signal leads

Color stripes are added to these solid-colored backgrounds to further identify the lead. For example, a floating ground is black with a white stripe. The red and violet power supply leads are coded to denote their deviation from ground or zero voltage as follows (the numbers corresponding to the standard resistor color code) :

+	4th supply	2-4 & 2-4X Series
	3rd supply	2-3 & 2-3X Series
	2nd supply	2-1 & 2-1X Series
	1st supply	2-0 & 2-0X Series
0		
	1st supply	7-0 & 7-03 Series
	2nd supply	7-1 & 7-1X Series
	3rd supply	7-2 & 7-2X Series
−	4th supply	7-3 & 7-3X Series

For example, the 2-0 and 2-0X series are used for the first, or lowest, positive power supply. The 2-0 lead is the regulated bus. The 2-01 is the decoupled 2-0 supply. If another lead is needed the 2-03 code is used. The most unregulated lead in this supply is coded 2-09, and if another lead is needed, the next most unregulated lead is coded 2-08.

The gray base color is used for internal AC wiring. Conductors for the line (hot) side, starting at the AC input, are color coded 8-0, 8-01, 8-02 in sequence. The black stripe corresponds to the black lead in the power cord.

Conductors for the neutral (cold) side are color coded 8-9, 8-19, 8-29 in sequence; the white stripe corresponding to the white lead in the power cord.

Signal leads have a white base color. The stripes are used only for lead identification and have no significance.

The use of ribbon cable complicates the use of color coding to code wires according to function. In fact, it becomes a practical impossibility considering the variety of ribbon cables used. There is a practical coding scheme that is useful, however. Color can be used to denote the lead position in the cable. For example, all leads in a ribbon cable have a base white color. The first lead, which will be connected to slot number one in a connector, has a brown stripe; the number two lead has a red stripe and so on. This color scheme is used on ribbon cables with two or more conductors.

Summary

Getting around in electronic instruments can be frustrating and time consuming. Well-marked chassis and printed circuit boards, color-coded wiring, and innovative connectors are all designed to make it easier to get around in your Tektronix instruments.

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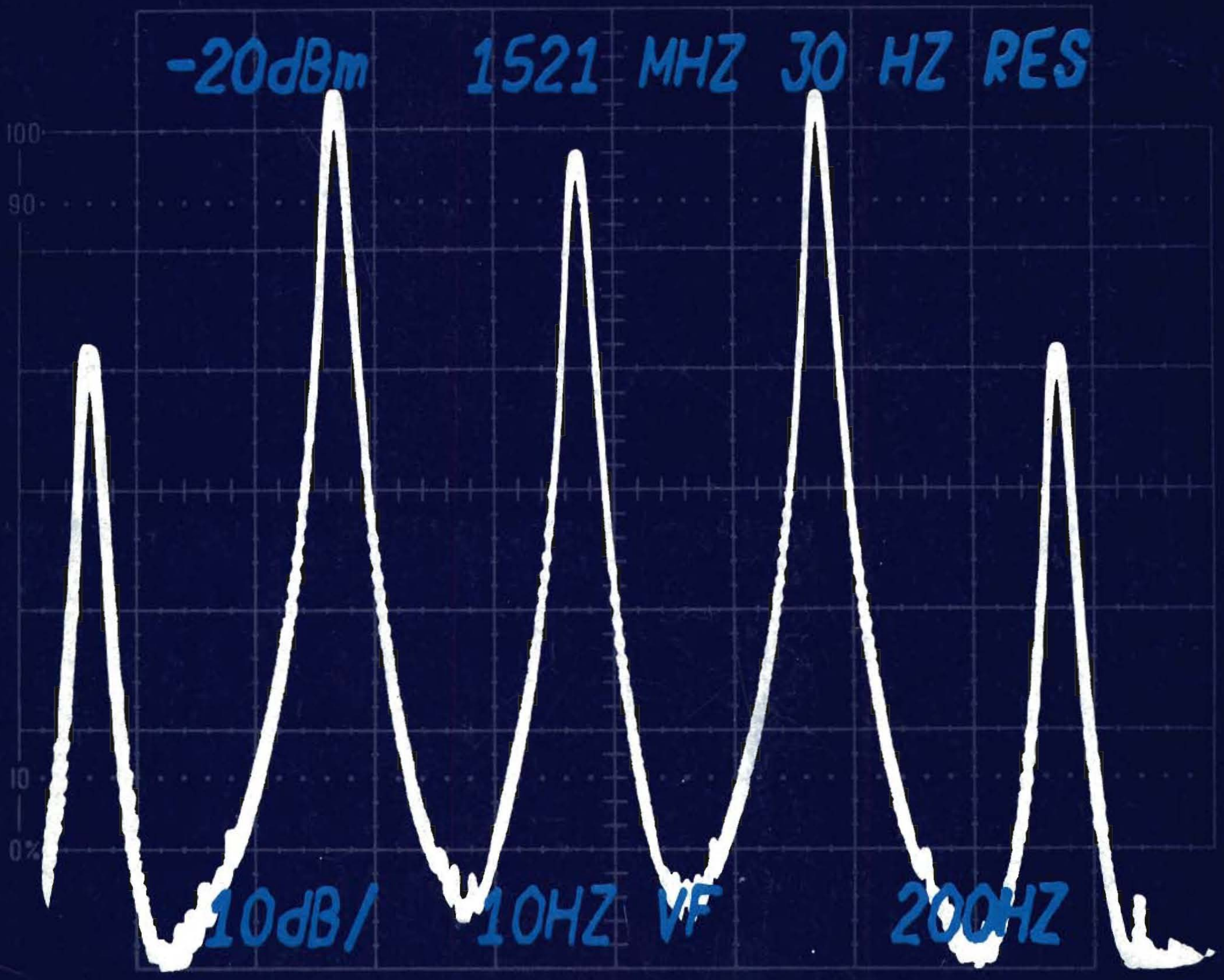

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TEKSCOPE

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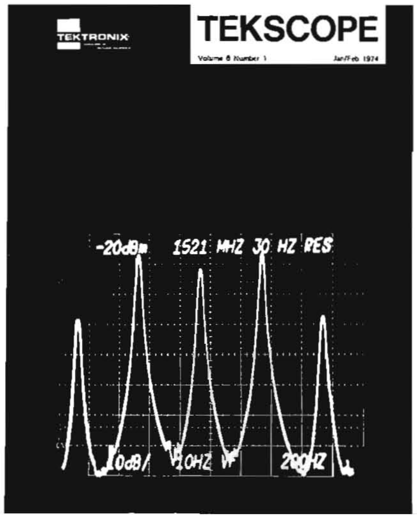
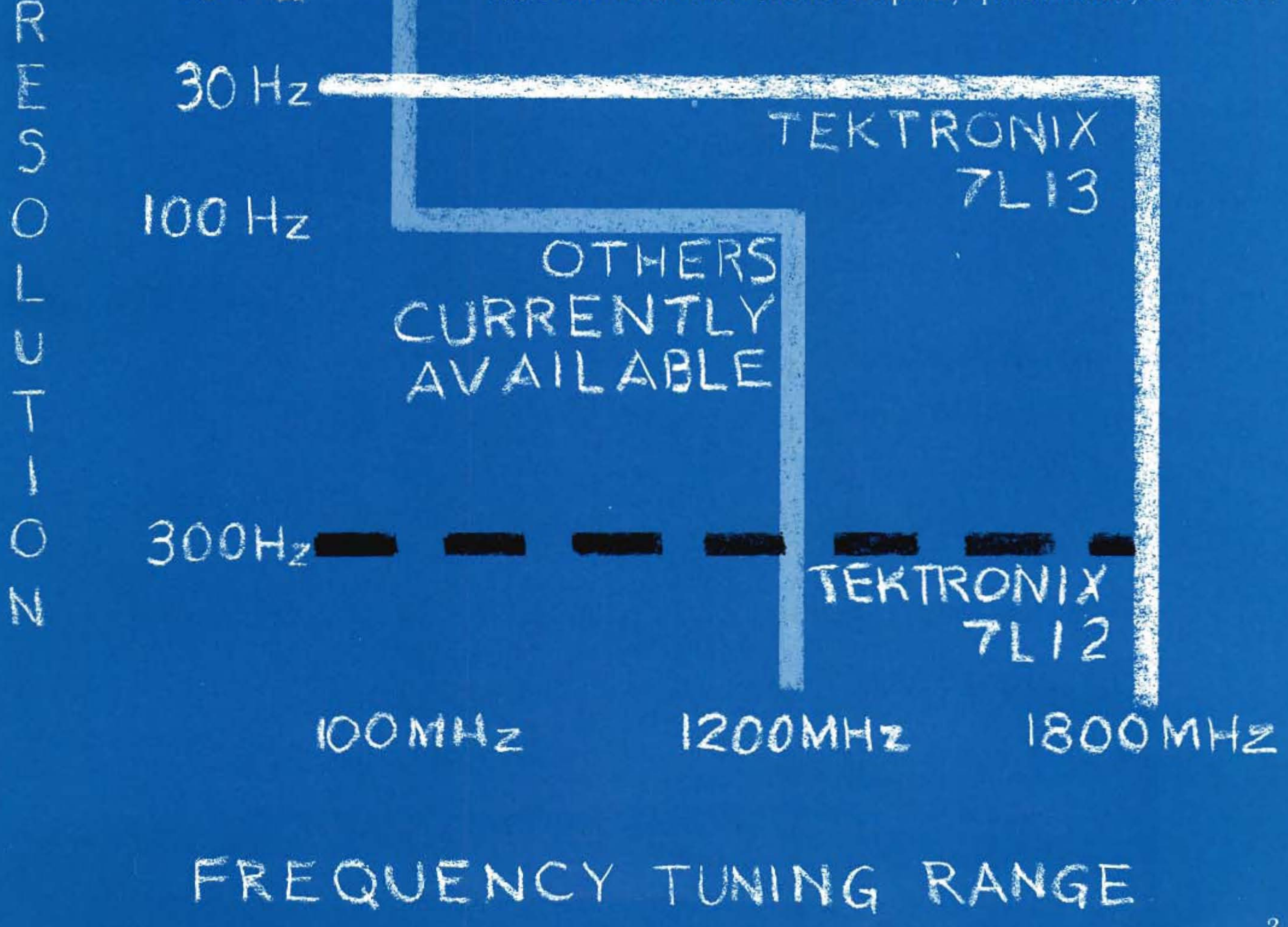
Cover: A close-up view of the display of the 7L13 Spectrum Analyzer. The CRT Readout displays the Spectrum Analyzer control settings. Center frequency is 1521 MHz, frequency span is 200 Hz/div, resolution is 30 Hz and the video filter is set at 10 Hz. The reference level at the top of the screen is −20 dBm and the vertical deflection factor is 10 dB/div.

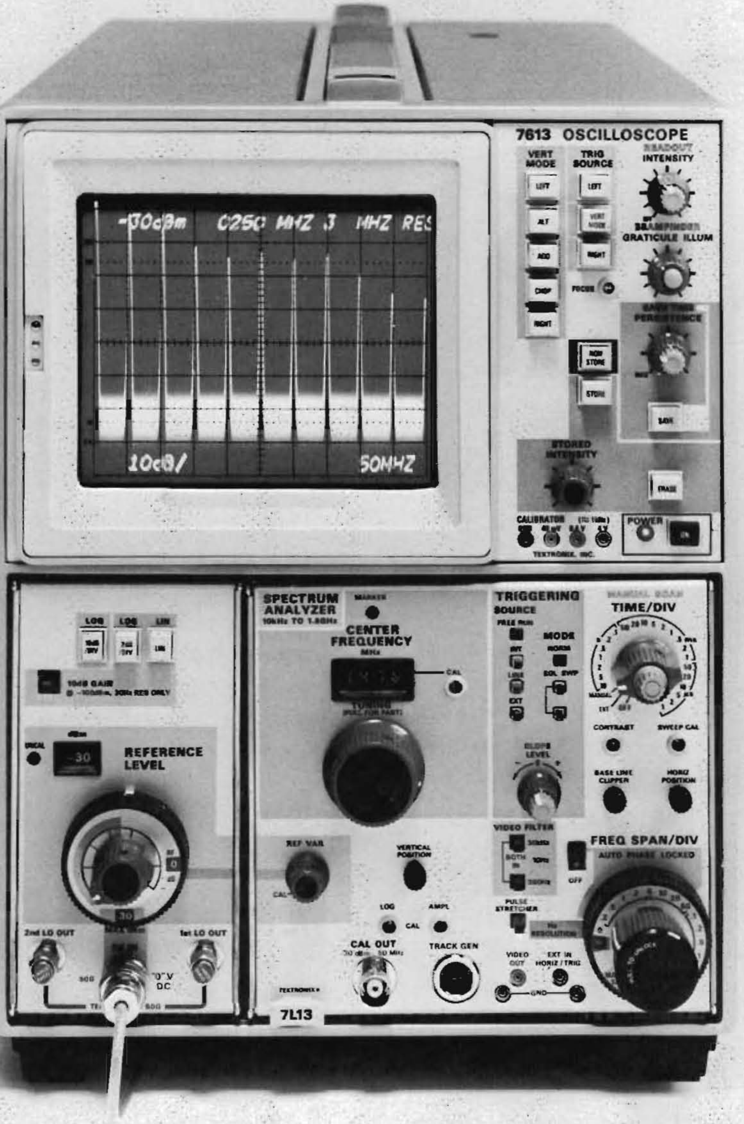


F. Telewski

30 Hz resolution at gigahertz frequencies— a new direction in spectrum analysis

For some years the needs of high-frequency spectrum analysis in the area of DC to 2GHz have been satisfied by a number of instruments whose incidental FM was in the order of 200 Hz. While these instruments have served well they do not permit exacting measurements in the areas of spectral purity and close-in distortion. As a result, the user is often compelled to adopt alternate test procedures which require the use of down-converters and low-frequency spectrum analyzers or wave





analyzers. The cumbersome nature of these measurement systems coupled with the tightening of signal specifications by governmental regulatory agencies has created a need for a high performance, high-frequency spectrum analyzer.

Performance Goals

At inception, the 7L13 program aimed at reducing internal FM and drift by an order of magnitude with commensurate improvement in resolution capability. Keeping in mind that most spectrum analyzers are already somewhat difficult to operate, these improvements could not be accomplished at the expense of operational ease. Indeed, additional improvements in operational simplicity should be sought.

First Local Oscillator

It is the local oscillator system that determines the performance achievable in most spectrum analyzers. An examination of the oscillator system reveals that there are basically two oscillators under consideration. These are the 1st L.O. (2.1 - 3.9 GHz) and the 2nd L.O. (2.2 GHz) as shown in Fig. 1. The 3rd L.O. being crystal-derived at 95 MHz contributes negligible FM (<<1 Hz p-p) to the system.

It is common practice, as the frequency span is reduced, to phase lock the 1st L.O. to a fixed crystal reference oscillator, thus stabilizing it while shifting the sweep function to the 2nd L.O.[1] The rate of the crystal reference oscillator determines the range over which the 2nd L.O. must be swept in order to complete the frequency coverage between the discrete lock points. Hence, a low-frequency reference is desirable from the viewpoint of design ease in the 2nd L.O. system.

The choice of a crystal reference rate is compromised by the high phase noise associated with low-frequency references. The increase in noise arises from the requirement for a higher multiplication rate of the fundamental oscillator, whose behavior is characterized by the following equation:

$$\mathrm{DEG}_{dB} = 20 \log M,$$

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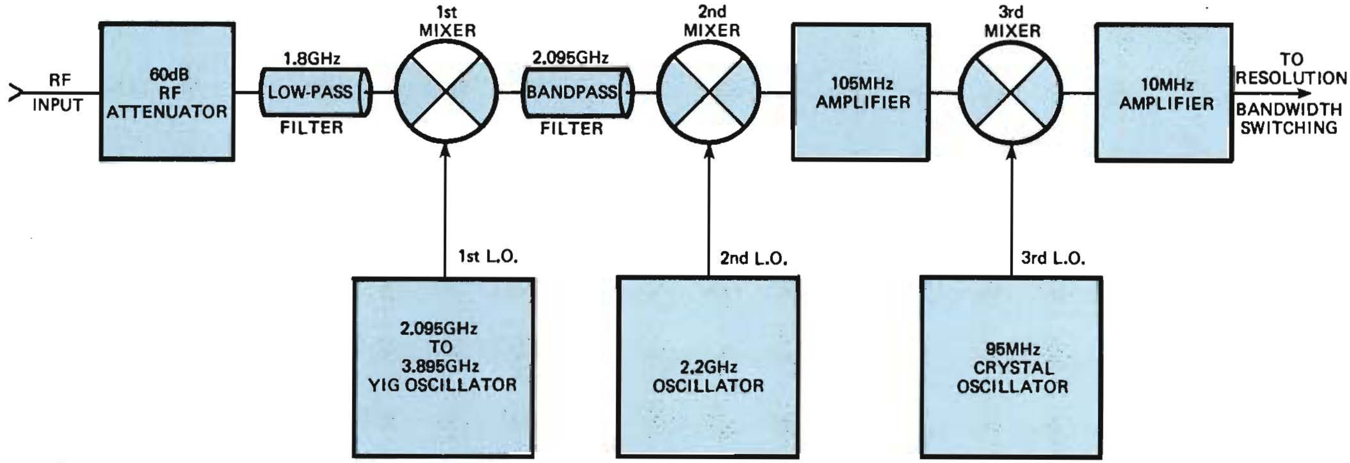

Fig. 1. Frequency conversion system of the 7L13.

Where: DEG is the degradation in spectral purity in dB and M is the multiplication factor. From the standpoint of phase noise it is desirable to choose a high rate for the crystal reference oscillator; however, conflicting requirements result. A 1-MHz reference rate is chosen as medium ground for the 1st L.O. reference. This permits a reasonable 2nd L.O. tuning range of 3 MHz as well as satisfying the phase noise constraint.

There is a unique bandwidth for any oscillator servo system which will yield optimum spectral purity. This bandwidth is determined by considering the relative spectra of the reference oscillator and the voltage-tuned oscillator (VTO) which is to be locked. In the 1st L.O. servo loop, the loop bandwidth is chosen such that the excellent line-width properties of the crystal reference are translated to the YIG VTO. The broad noise pedestal associated with the same reference is rejected in favor of the faster falling noise sidebands of the YIG VTO. The FM performance of this system, when operating in the lock mode, is in the 1 Hz p-p area.

2nd Local Oscillator

The 2nd L.O. usually consists of a varactor-tuned oscillator operating in the region of 1.5 to 2.5 GHz. Examination of the properties of this oscillator type indicates that under reasonable circumstances, 200 Hz is the minimum residual FM that can be expected as guaranteed performance without resorting to external stabilization techniques.

Improving the performance of the 2nd L.O. becomes a problem of designing an oscillator at a frequency where the desired stability and tuning range can be achieved. In this case a voltage-tuned oscillator operating from 16 to 19 MHz, and whose residual FM is approximately 1 Hz p-p, meets the requirements of a reference for the 2nd L.O. system. The stability properties of this reference oscillator are translated to 2.2 GHz by a type-two frequency servo system as indicated in Fig. 2. The unstable 2.2 GHz oscillator, collector tunable over a ±1.5 MHz range, is heterodyned with a crystal-derived 2182.5-MHz (FM <1 Hz p-p) signal. The product at 17.5 (±1.5) MHz is phase compared with the 16 to 19 MHz reference oscillator and the resultant error signal is amplified and fed back to the collector of the 2.2 GHz oscillator. Thus, the 2.2 GHz L.O. is synthesized in such a manner that it replicates the product of the 16 to 19 MHz oscillator and the 2182.5 MHz crystal-derived source within the bandwidth of the servo system. The complete 2nd L.O. system of the 7L13 exhibits a typical incidental FM of 1 Hz p-p.

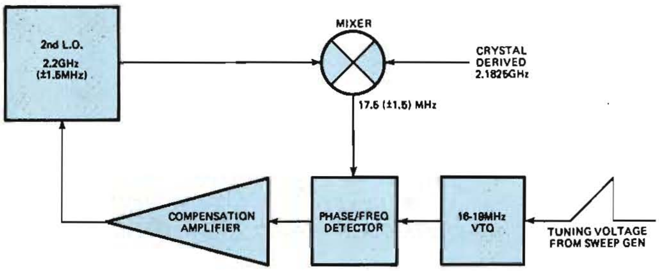

Fig. 2. Second L.O. stabilization system.

A major distinction in the operation of the 2nd L.O. servo system (as opposed to the 1st L.O. loop) is that it is functional in all modes of 7L13 operation. The 2.2 GHz oscillator is never allowed to assume a free running mode and is under the control of the 16 to 19 MHz VTO from the time the instrument is turned on. Consequently, there is no mention of a 2nd L.O. lock mode on the analyzer front panel, and the stabilization of the 2nd L.O. in no way complicates the use of the instrument.

30 Hz Resolution Filter

In order to exploit the extraordinary stability of which the 7L13 local oscillator system is capable, a 30-Hz resolution position was made available to the user. In light of the fact that the widest resolution bandwidth in the instrument is 3 MHz, a center frequency of 10 MHz is chosen for the final IF. In order to keep system complexity to a minimum, this requires that the 30-Hz resolution filter be at 10 MHz as well.

This filter is of the well known lower sideband ladder design (Fig. 3). It employs three quartz resonators whose unloaded Q is in excess of one million and has a nominal 60:6 dB shape factor of 10:1. These resonators, when exposed to temperature variations encountered in the instrument (0°>50°C), are prone to alter their center frequency by a large fraction of the filter bandwidth. In order that the 30 Hz filter be able to maintain its bandpass characteristics under conditions of varying temperature, the quartz resonators are required to have matched temperature-versus-frequency properties.

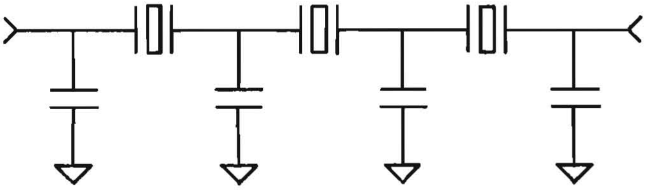

Fig. 3. Simplified circuit of the 30-Hz crystal filter.

Frequency Readout and Tuning

The availability of high linearity (typically .1%) YIG-tuned oscillators prompted the use of a digital frequency readout. This is accomplished by a digital voltmeter (DVM) which monitors the tune voltage of the 1st L.O. The frequency information obtained from the DVM is multiplexed and displayed both on the front panel, by a light-emitting diode display, and on the analyzer screen via the Tektronix CRT READOUT system. This permits the user to measure frequency to an accuracy of ± (5 MHz + 20% of the frequency span per division); 20% of a division being as close as one can typically judge the signal position, taking into account the effects of observation and the geometry of the display.

Simplification of operation was achieved through the development of a single-knob tuning scheme. Previous analyzers have often had two or more tuning knobs; and depending upon what mode the analyzer was operating in, inadvertent adjustments of the wrong tuning knob could cause severe frequency disturbances in the instrument. This problem is eliminated in the 7L13 through a mechanism employing two magnetic clutches and a self-centering potentiometer. When this system is operated in spans where the 1st L.O. is stabilized, the 2nd L.O. potentiometer clutch is engaged. Starting from a centered position, it prohibits one from achieving lock with the 2nd L.O. tuning control against one stop. Further, access to the 1st L.O. potentiometer is denied the user by disengaging the 1st L.O. potentiometer clutch so that he cannot mistakenly tune the 1st L.O., break lock, and lose his display. When returning to spans which do not require 1st L.O. stabilization, the clutches alternate state returning the 2nd L.O. potentiometer to its centered position and permitting tuning of the 1st L.O.

Convenience Features

We have come to expect such user conveniences as absolute amplitude calibration, freedom from spurious, automatic frequency stabilization, coupled span and resolution controls, display warning indicators and such in our high performance spectrum analyzers; and indeed they are all present in the 7L13. The 7L13 goes a step beyond and introduces the concept of full parameter readout to spectrum analysis (Fig. 4). All pertinent information, i.e., center frequency, resolution bandwidth, span, video filtering, vertical scale factor and power reference level may be viewed at a glance or permanently recorded by a photo of the display.

Performance

The graph of frequency tuning range versus resolution on page 3 shows the performance of the 7L13 and other instruments currently available. As is evident, the 7L13 represents a significant breakthrough in the area of high resolution, high-frequency spectrum analysis. The 7L13 has achieved a high degree of synergism with respect to spectral purity, resolution and drift. The instrument is not limited by the cleanliness of its oscillator system, as is so often the case with other high-frequency analyzers. As Fig. 5 shows, the shape of the 30-Hz resolution filter is clearly defined for well over 60 dB. This performance, familiar to users of low-frequency spectrum analyzers, is uncommon above a few hundred megahertz and due largely to the very conservative 10-Hz FM specification of the 7L13.

Resolution is a significant feature of a spectrum analyzer. Fig. 4 illustrates a 1476-MHz carrier, amplitude modulated at 50-Hz rate with both sidebands distinctly resolved. Fig. 6 shows the same carrier modulated at a 400-Hz rate along with residual 180-Hz line-related modulation on the carrier source 60 dB down.

The question of how long a given stable signal will remain on the display may be resolved by the drift specification. Just how well the 7L13 conforms to its 2 kHz/hr drift specification is evident in Fig. 7. This time-lapse photograph, made at hourly intervals, reveals a total drift of 4 kHz in 6 hours with 1.2 kHz occurring in the first hour.

All of the foregoing performance features of the 7L13 would lose much of their impact if the analyzer were not highly immune to intermodulation distortion. It is this property which in large part determines whether the display on the analyzer is real. Returning to Fig. 5, one can see that, in this 2-tone test at 1555 MHz with 500-Hz tone separation, there are no visible 3rd-order intermodulation products.

In general, it is instruments like the 7L13 which will ease the burden of making critical spectral measurements at high frequencies. And this ability will set the direction for future improvements in communication equipment performance.

Acknowledgments

As with any program embodying the complexity of the 7L13, there are more people involved than can be listed. All should feel a sense of satisfaction from their role in the development of this instrument. The principle contributors, other than the author as project manager, were electrical design: Mike McMahon and Jack Reynolds; mechanical project engineer: Leighton Whitsett; mechanical design: Jack McCabe and Jim Wolf.

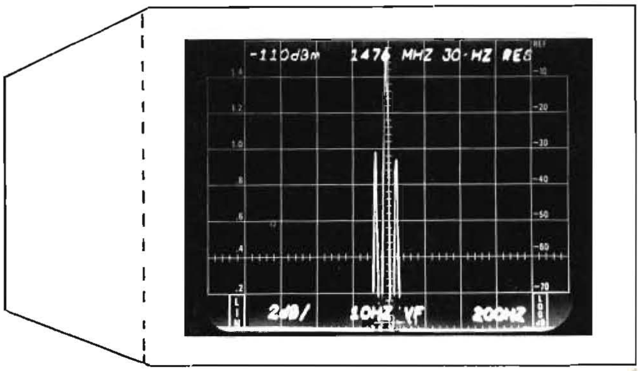

Fig. 4. 1476-MHz carrier modulated at 50 Hz. Note full parameter readout.

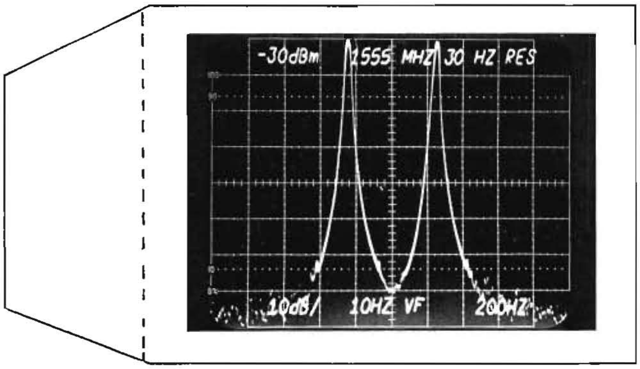

Fig. 5. Two-tone test at 1555 MHz shows freedom from distortion along with spectral purity and resolution filter shape.

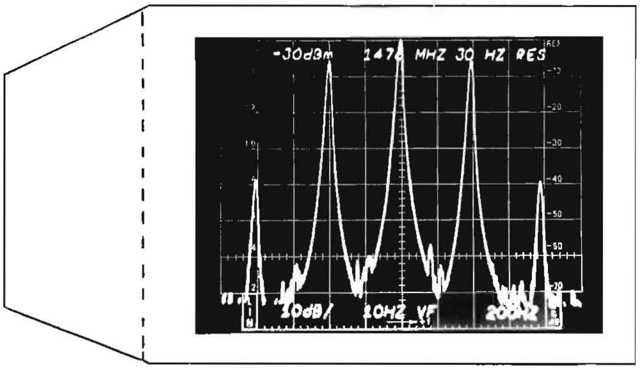

Fig. 6. 1476-MHz carrier 100% AM modulated at a 400-Hz rate.

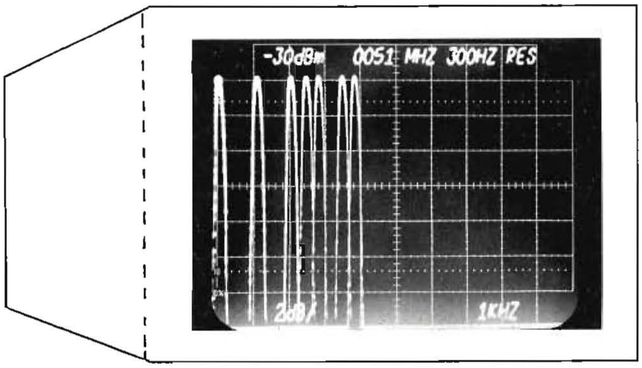

Fig. 7. Time-lapse photo taken over a 6-hour period shows excellent drift characteristics of the 7L13.

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[1] Telewski, "Freq. Stab. Tech.," TEKSCOPE, Jan. 72, pp. 10-11.

CRT READOUT– nicety or necessity?

When the 7000-Series Oscilloscopes were being conceived much discussion centered around a scheme to present alphanumeric information on the CRT along with the waveform. Would the benefits derived justify the engineering effort required? What about the added cost to the customer who didn't need or want readout? These and related questions consumed hours of discussion.

The question of added cost for those not needing readout was neatly resolved by placing the bulk of the readout circuitry on a single printed circuit board. Easily installed or removed, readout could be included at the time the instrument was ordered, or added later at the customer's preference. Only time could adequately answer the question of whether the benefits would justify the effort required.

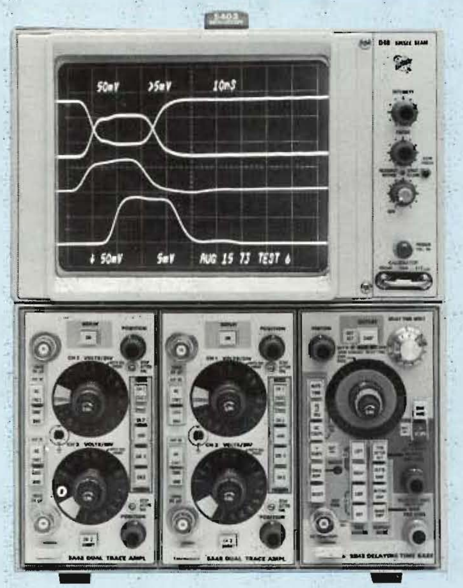
How It Works

Here, briefly, is how the readout system works. The system uses an electronic character generating circuit which time shares the CRT with the normal scope functions. The characters are formed by a series of X and Y analog currents developed by Character Generating I.C.'s. A set of 50 different characters are provided, with the capability to add others as the need arises. Included are all of the numerals, most of the alphabet in upper case, the symbols, p, n, μ, m and other special symbols.

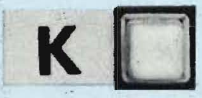
To minimize coding complexity an analog coding scheme was developed in which data is encoded by means of resistors and switch closures. This data is generated in the plug-in by connecting these resistors between time-slot pulses and data output lines via the appropriate switch. The coding scheme includes two channels for each plug-in so that dual trace amplifiers and delaying/delayed time bases can be accommodated. A maximum of eight words can be displayed, corresponding to two channels for each of four plug-ins. The position of each word on the CRT is fixed and related to the plug-in from which it comes. Each channel will display one word having up to ten characters. The characters are normally written without redundant spaces, but spaces can be called for in the code if desired. Only those channels in use have their readout displayed.

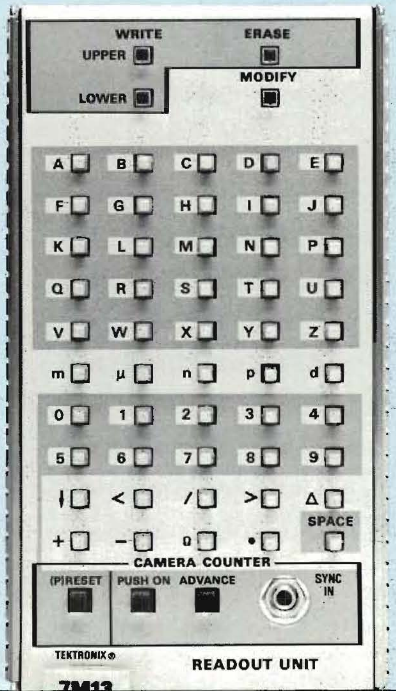
Some Benefits of Readout

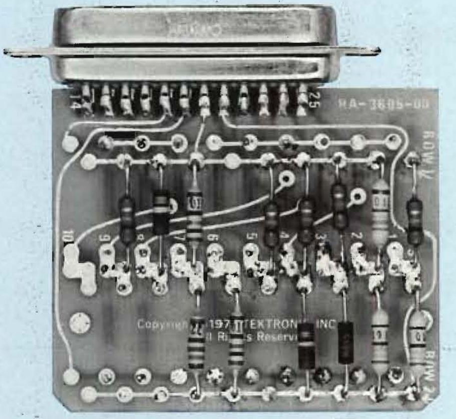
Now, what are some of the benefits afforded by CRT READOUT? To those whose work entailed photographing the waveform a major benefit was immediately apparent. The vertical deflection factors and sweep rates could be recorded right on the film with the



The 5403 Oscilloscope features 60-MHz bandwidth, plug-ins and CRT READOUT.







Optional readout programming board for the 5403.

7M13 Readout Unit for the 7000-Series.

displayed waveform. This would be a real convenience and time saver.

Another major benefit was the reduction of operator error in making measurements. More than one piece of research has had to be redone because of faulty data due to probe attenuation or uncalibrated knob settings going unnoticed. With CRT READOUT, the scale factor at the probe tip is automatically indicated when the proper probe is used. An uncalibrated knob setting is denoted by displaying < or > before the reading, e.g., <500 mV.

And then came a major breakthrough in oscilloscope capability. With the introduction of the 7D14 plug-in the oscilloscope became a 500 MHz digital counter[1]; the CRT READOUT serving as the display for the counter. And the oscilloscope/counter combination opened the door to previously difficult or impossible measurements. For example, selectively-gated counter measurements could now be made easily and accurately.

Another digital plug-in added digital voltmeter and temperature measuring capabilities. A digital delay plug-in provided a digital delaying time base and the ability to delay by a selected number of events. Spectrum analysis was included with reference level, dB/div, frequency span, resolution and other calibrated parameters all displayed by CRT READOUT.

Another significant measurement capability was introduced with the Digital Processing Oscilloscope. This instrument marries the oscilloscope to a computer or desk-top calculator. Here, again, CRT READOUT plays a vital role in displaying the parameters of the signal displayed on the screen, which may be considerably different from the signal fed to the oscilloscope input.

Getting a Word In

It didn't take long for customers to voice a need for putting their own words in the readout—information like the date, test number or the engineer's name. To accommodate these needs a "typewriter" plug-in was developed. The 7M13 Readout Unit provides a front-panel keyboard to write alphanumerics and a selection of symbols. Two ten-character words can be written on the CRT screen, one at the top and one at the bottom, in the position associated with the selected plug-in slot.

CRT READOUT In a Low Cost Scope

Because of its proven value, CRT READOUT is also included in the new 5400 Series, a line of low-cost, 60 MHz, plug-in oscilloscopes. Here again provision is made to insert two ten-character words of your own choice in the readout via a 25-pin connector on the rear panel of the scope. An optional plug-in program board makes it easy to build your own words.

Summary

CRT READOUT has proven to be much more than just a convenience, it is the key that opens the door to new measurements for the oscilloscope user. Just what the total benefits will be remains to be determined. We're still discovering new ones right along.

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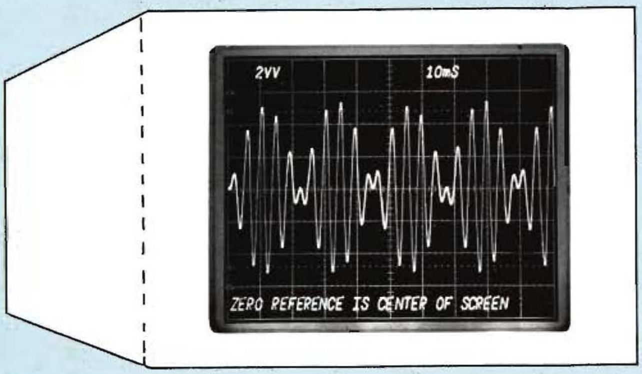
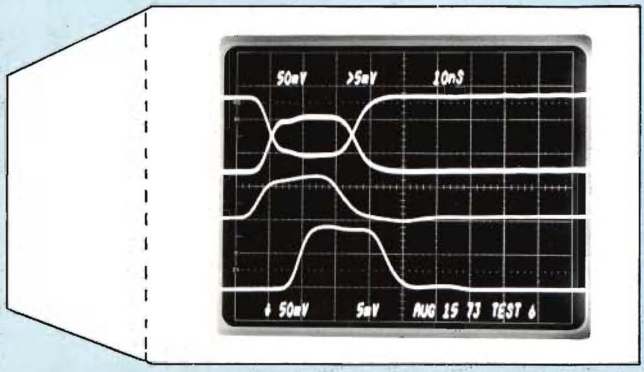
[1] Tekscope, January 1973, "A new world of measurements for the oscilloscope."

TEST 10



The readout in this photo was programmed by the computer in a Digital Processing Oscilloscope system. The double V indicates the waveform is the resultant of two voltage signals multiplied together.



This photo was dated and identified as Test 6 using the optional readout programming board in the 5403.

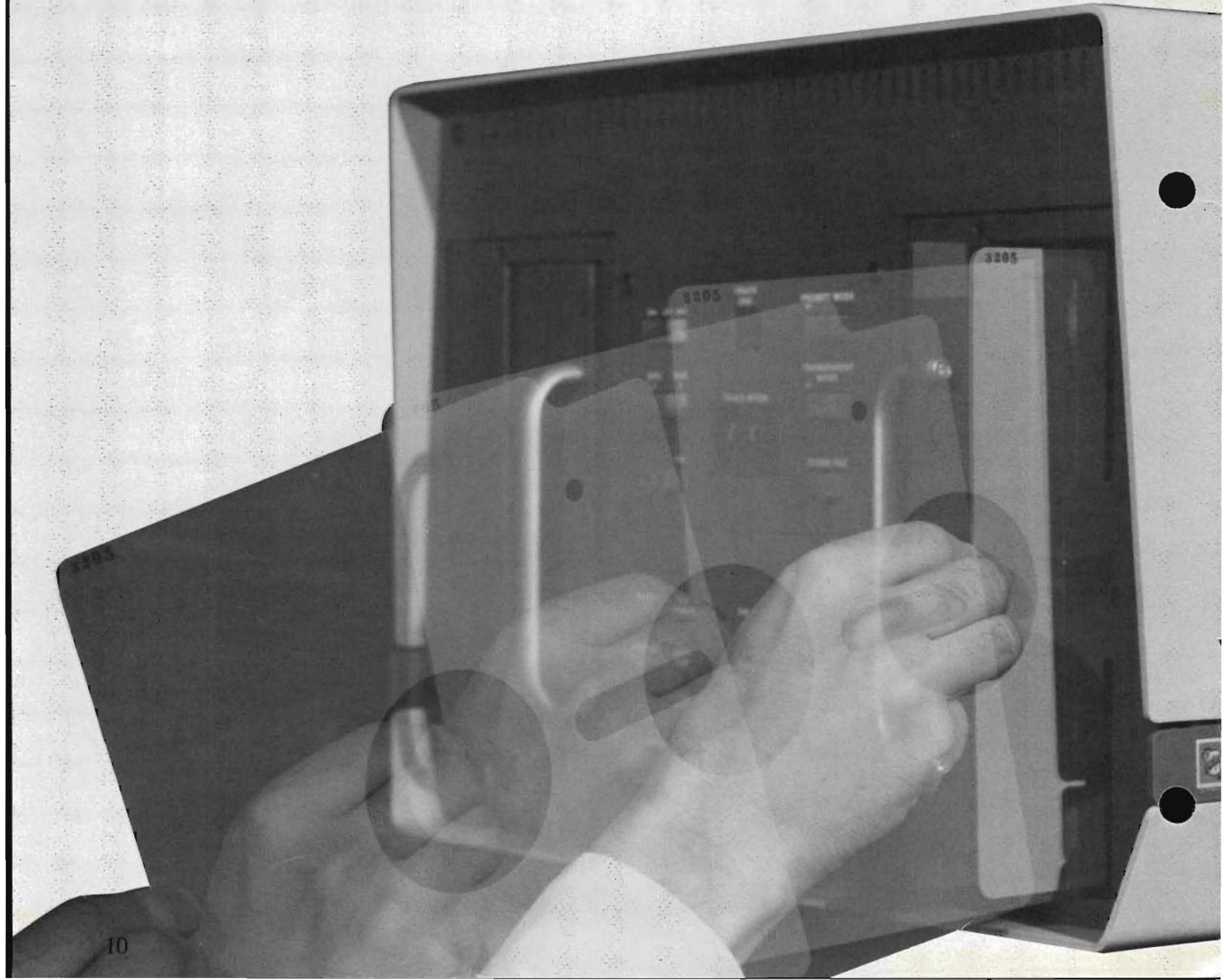
B ☐ 20mV

Teknique

Flexible disc measurements simplified by digital delay

Signals from a flexible disc and its associated circuitry can be measured using a conventional delaying sweep. However, jitter caused by small speed variations in the rotating disc can make the display difficult to interpret. And when you consider that there may be 100,000 data bits on a single track you can appreciate the difficulty of locating a particular bit. The 7D11 Digital Delay Plug-in eases the task considerably.

The 7D11 can be used in any 7000-Series Oscilloscope having CRT READOUT. The plug-in has two basic modes of operation. The first is a Delay-by-Time mode, where a highly accurate internal clock is the time base from which delays are derived. Digital delays from 100 nanoseconds to 1 second,



in 100-ns increments, are available in this mode. A helidial-controlled analog delay provides an additional 0 to 100 ns of delay providing time delay resolution up to 1 ns.

The second mode of operation, Delay-by-Events, is the mode we're most interested in for this application. In this mode the 7D11 counts arbitrary trigger events, and delivers an output (notifies the delayed sweep) when the preselected number of events is reached. The unit can count events from 1 to 10,000,000 occurring at rates up to 50 MHz, and the events can be periodic, aperiodic, and contain instability such as jitter and drift.

To determine when to start counting the selected number of events, we need to provide a related synchronization pulse to the Events Start Trigger input of the 7D11. This could be the origin pulse, or, perhaps, a sector pulse from the flexible disc, depending on the measurement to be made.

Now let's take a look at some measurements on the flexible disc system. We will be working with the Memorex 651 Flexible Disc Drive. This system uses a disc speed of ≈ 375 RPM. Depending on user requirements, the data may be organized on the disc in multiple records per track (sector) or single record per track (index) format. There are 32 sectors and 64 tracks on the disc. Fig. 1 shows the format for each mode of operation.

The clock frequency used is 250 kHz. The clock is recorded on the track along with the data to permit accurate readout of data with variations in disc speed. Fig. 2 shows the relationship between the index and sector pulses, and the clock and data pulses. The READ head reads the combined clock and data pulses recorded on the disc. The READ logic amplifies and separates them into two outputs: separated clock signals and separated data signals.

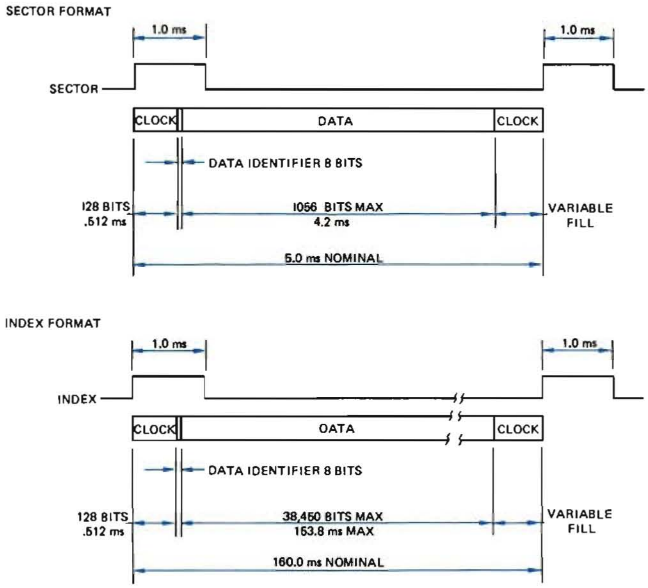


Fig. 1. Formats for data organized for multiple record per track (sector) and single record per track (index).

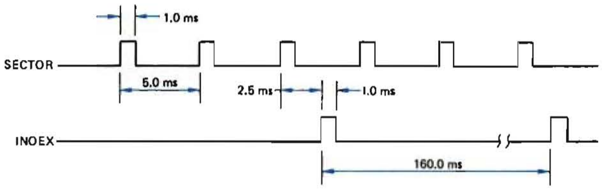


Fig. 2 (a) Timing relationship between the index and sector pulses.

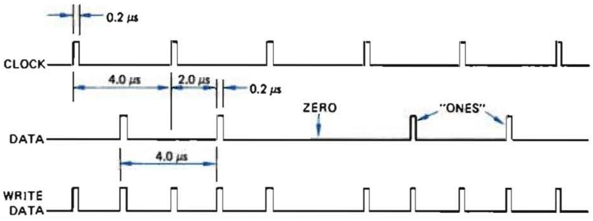


Fig. 2 (b) WRITE data timing and signal waveforms.

Signal Variations from Track to Track

One of the problems encountered in using a disc is the change in amplitude of the signal on the disc as you move from an outer track to an inner track. Fig. 3 (a) is the signal from Track 00 and 3 (b) the signal from Track 63. The bottom waveform in each photo is the analog signal from the READ head; the top waveform is the signal converted to a negative-going TTL-compatible pulse. You will note the events count is 1247. This indicates we have triggered the EVENTS START from one sector pulse and delayed out to permit us to view the start of data in the next sector. The shift of the data to the left in Fig. 3 (b) is due to the fixed spacing between the WRITE and READ heads causing us to miss more of the 136 bits between the start of the sector pulse and the start of data as we move toward the center

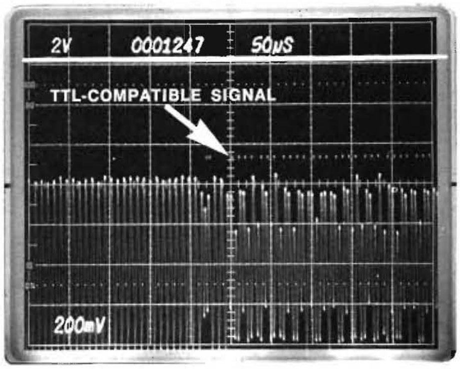


Fig. 3 (a) The lower trace is raw data from the READ head while reading Track 00. Upper trace is signal reconstituted in TTL-compatible format.

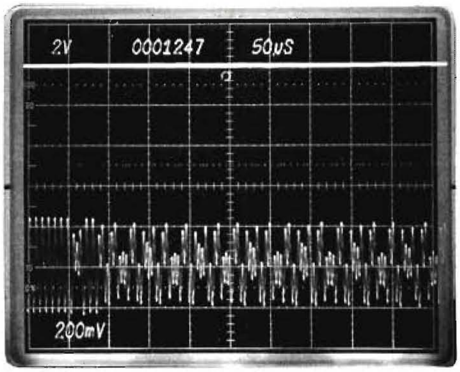


Fig. 3 (b) Same signal source as in Fig. 3(a) read from Track 63.

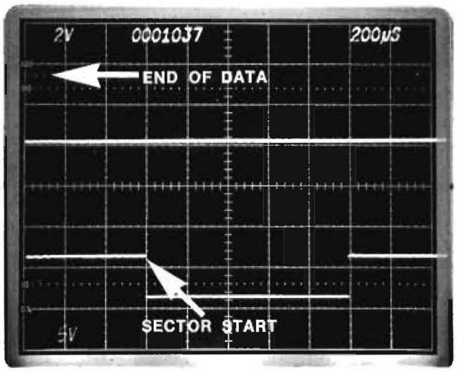


Fig. 5. Time interval from end of data in one sector to start of next sector pulse is easily viewed with the 7D11.

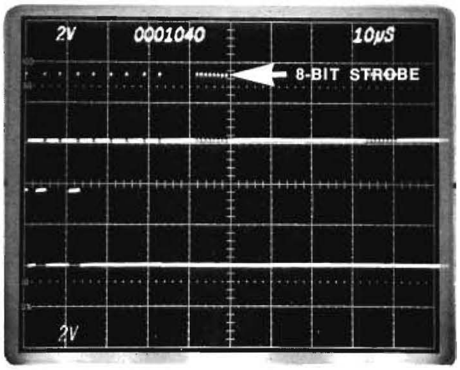


Fig. 7. An events count of 1040 takes us near the end of a sector to view the 8-bit strobe pulse moving data from the shift register to the computer terminal.

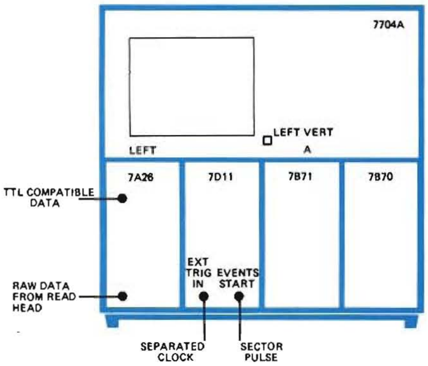


Fig. 4. Setup for making measurements displayed in Figs. 3(a) and 3(b).

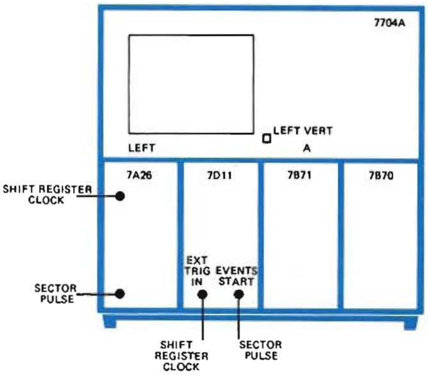


Fig. 6. Setup for making measurement displayed in Fig. 5.

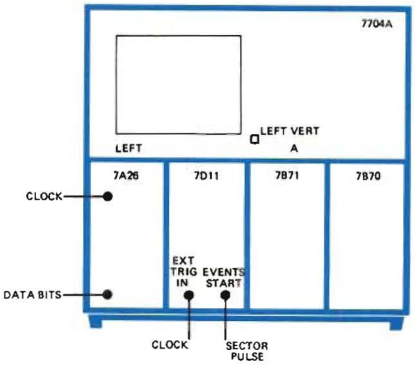


Fig. 8. Setup for making measurement displayed in Fig. 7.

of the disc. The setup to make this measurement is shown in Fig. 4.

Another point of interest in the system is the interval from end of data to the start of the next sector. This is shown in Fig. 5. The upper trace shows the data ending 100 µs from the start of the sweep. The lower trace shows the next sector pulse starting approximately 500 µs later. The events count of 1037 was selected to place the leading edge of the sector pulse conveniently on the vertical graticule line. Fig. 6 shows the 7704A setup for this measurement.

The photo in Fig. 7 shows some interesting sets of signals in the system. There are 1048 data bits recorded per sector. An events count of 1040 was selected so we could view the last data in the sector and check for the 8-bit strobing pulse that would transfer the data from the shift register to the computer terminal. The following 8-bit strobe pulse transfers the shift register to the next character. Fig. 8 shows the setup for this display.

Summary

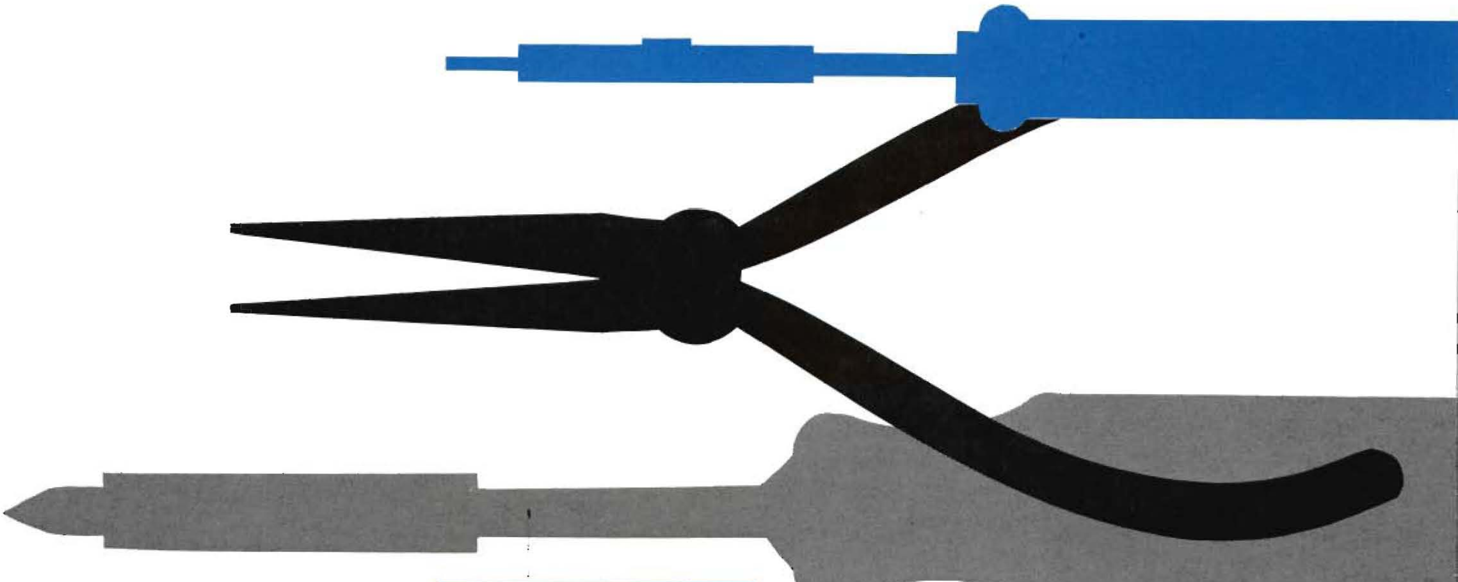
These are just a few examples of the use of the 7D11 Digital Delay unit in making measurements in a flexible disc system. It provides a convenient means of locating and viewing any of the thousands, or in some cases, millions of bits of data present in the disc system.

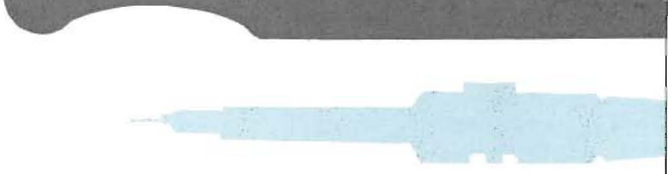
Other digital plug-ins such as the 7D12 A/D Converter and the 7D15 Universal Counter/Timer are also valuable aids in making accurate voltage and timing measurements in a disc system.

Servicing the 465 portable oscilloscope

The first thing you need to know in servicing a product is how to get the cabinet off. This is less than obvious in much of the packaging used today. You will find it takes a little longer to remove the 465 cabinet than you're accustomed to with the 453. But there's a good reason. The 465 is six pounds lighter than the 453A. And part of the weight reduction is achieved by using the cabinet to mechanically strengthen the package. This is accomplished by extending the cabinet slightly beyond the rear panel of the instrument. When the rear ring assembly, with the feet attached, is installed and tightened down it compresses the cabinet and pulls on the main chassis member, stressing both of them. This stress adds strength to the package.

The best procedure for removing the cabinet is to put the front cover in place, set the instrument on the front cover and remove the six screws holding the rear ring assembly. Four of these serve as mounting screws for the rear feet. The cabinet is then slid off vertically. When replacing the cabinet on





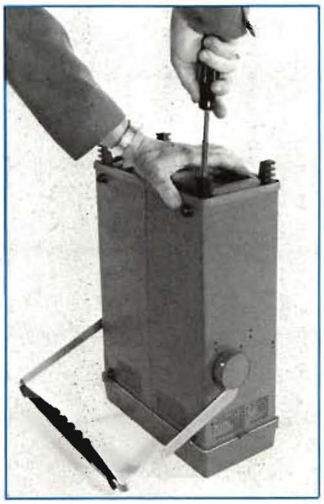


Fig. 1. The 465 cabinet is removed by loosening six screws on the rear panel.

earlier instruments, take care that the cabinet clears the components on the trigger-view board. In later instruments this circuitry is laid out on the trigger board.

It would be well at this point to make sure the instruction manual you are using matches the instrument you are servicing. Tektronix has always followed the policy of modifying the circuitry to improve performance and reliability as the occasion arises. Modification information is added in the back of the manual to keep it current with the instruments being shipped.

The Power Supplies

When a problem area is not readily apparent from front panel indications, a good place to start troubleshooting is the power supply. Temporarily-high line voltage sometimes causes the line fuse to blow. In instruments below SN B080000, circuits powered from the +120 V supply are protected from high line voltage by Q54 (Q1514 in some instruments). Should the line voltage exceed a given level, Q54 conducts placing a short across the transformer secondary and blowing the line fuse. When replacing the fuse you should use the specified value to prevent damage to the circuits protected by Q54. If the line voltage in your facility tends to fluctuate in the upward direction you may set the line Range Selector Switch Bar to the high position. The front-panel low-line light will come on should the line voltage fall below the lower limit of the regulating range selected.

Another problem you may encounter in the low-voltage supply is CR1512 shorting and taking out C1542. The cure for this is to remove CR1512. Do not discard this diode as it can be used in a modification to improve the high-voltage supply reliability.

The high-voltage supply is often difficult for many of us to troubleshoot. Here are some hints on servicing these circuits in the 465. The first step is to isolate the problem area. There are three major areas of concern: the high-voltage oscillator and DC-error amplifier, the over-voltage protection circuit, and the secondary load including the CRT and the high-voltage multiplier. By disconnecting the appropriate circuit the high voltage should come up. Try the following sequence:

1. Remove the CRT socket — this eliminates the CRT.
2. Disconnect CR1412—this eliminates the over-voltage protection circuit.
3. Remove Q1416 and place an 820 Ω to 1 kΩ resistor between the collector and emitter pins. This allows ≈ 8 ma of turn-on bias current to start the oscillator. If this does nothing, replace C1416 and C1419. (C1419 should be replaced anytime the high-voltage oscillator Q1418 is shorted.)

If at this point the high-voltage reading at TP1423 is ≈−400 volts, the high-voltage multiplier is most likely defective. In newer instruments this can be quickly checked by lifting the dummy resistor that connects the multiplier ground. Arcing from this point to adjacent circuitry sometimes occurs when this ground strap is lifted. For earlier instruments you will have to remove the vertical preamp board and the multiplier cover to get to the high-voltage transformer and multiplier connection. Lift the transformer lead and CR1421 from the mounting post on the multiplier, connect them together and dress them away from the mounting post to prevent arcing across. If the negative high-voltage supply comes up now, the multiplier is defective. A defective multiplier will also sometimes cause high-voltage fuse F1419 to blow.

Another condition that can effect the high voltage is leakage in diodes CR1482, CR1483, CR1487 or CR1488. These are in the CRT grid bias supply and can turn the beam on hard or turn it off so you have no intensity. Another point to check is pin 12 on the CRT; this should be +150 V. Leakage in C1427 may pull this point down in some instruments between SN B080000 and B130000.

Check to see whether R1427, which parallels C1427, has a zener diode in parallel with it. If not, your instrument doesn't have the high-voltage reliability modification and it should be installed. It consists of adding or changing just four components:

1. CR1476 located near Q1474 should be replaced by CR1512 which you removed from the low-voltage supply.
2. A 0.1 μF, 200 V capacitor should be added from the cathode of CR1476 to ground.
3. A 180 V zener, Tektronix part number 152-0289-00, should be paralleled with R1427 with the cathode to ground.
4. Lift the cathode end of CR1427 and add a 1.8 kΩ, ¼ W, 5% resistor between the cathode and the point to which it was soldered on the circuit board. This completes the modification.

The Sweep Circuit

The sweep circuit contains several feedback circuits and is difficult to troubleshoot unless you break the feedback loop. A convenient means of doing this is to pull the Disconnect Amplifier, Q1024. This causes one sweep to be generated and often provides a rapid clue as to what portion of the circuitry is in trouble.

The horizontal amplifier circuitry is push-pull and can be checked by the usual method of shorting the two sides by means of a jumper. Another useful technique is to swap transistors in each stage and see if the problem changes sides accordingly.

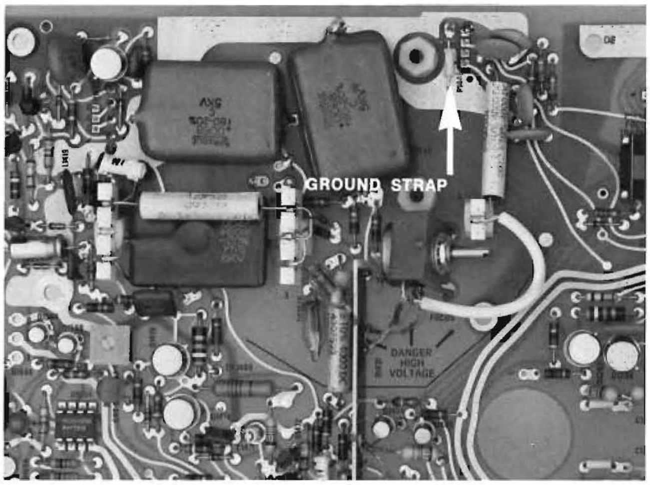


Fig. 2. A portion of the interface board showing location of the high voltage multiplier ground strap and other components.

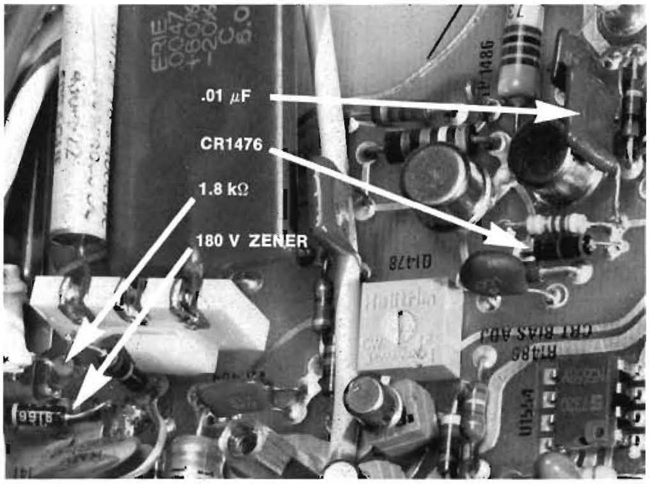


Fig. 3. A portion of the interface board showing the high-voltage reliability modification installed.

The Vertical Amplifier

If you have occasion to service several 465's you may note that some units have an integrated circuit output amplifier while others use discrete components. The front panel BEAM FINDER control provides a rapid means of detecting trouble in this circuitry. Pressing the BEAM FINDER button should bring the trace on-screen vertically. If it doesn't, look for the problem in the output amplifier circuitry.

Moving to the preamp, one of the more elusive problems you may encounter is an intermittent contact between transistors and their sockets. What usually happens, is the transistor is pulled from the socket, tested and found to be O.K. When the transistor is put back into the socket, the problem disappears. The basic cause seems to be a tendency for the contacts to "wick up" rosin and solder during the automatic flow soldering process. A change has been made in manufacturing procedures to overcome this tendency. If you suspect that you have this problem, you can clean the socket with isopropyl alcohol, using a wire to loosen the rosin inside. A camel hair brush works best in applying the isopropyl and a syringe is handy for blowing out dirt particles.

Another question often asked is how to get the transistor pairs used in the preamp, properly mounted in their heat sinks. The easiest way is to first insert the transistors in their sockets and then slip the heat sink loosely over them. Next, extract the transistors and heat sink together by gripping the heat sink firmly with a pair of pliers, and pulling. Continue to hold firmly with the pliers while tightening the screw in the heat sink. Then reinsert the transistors in their sockets.

While we're in the preamp area, another condition sometimes occurs that appears to be drift in the vertical attenuator compensation. In most cases this results from the technique used in making the adjustment. The compensation capacitors have a spring that provides tension. When making the adjustment it will help to "rock it in" to remove the torque portion of the spring tension. Just overshoot the desired setting a little and then back off to the proper point.

Mechanical Considerations

One of the unique components used in the 465 is the cam switch developed by Tektronix. These are relatively trouble-free but occasionally require cleaning of the contacts. Isopropyl can be used for this purpose. Here again you will find a camel hair brush handy. Do not use cotton swabs as they are prone to snag on contacts, damaging them.

Special care is needed when working on the vertical attenuator cam switches. The polyphenylene oxide boards are brittle and easily damaged by using too much force when tightening the screws holding the cam switch. Two fingers on the screwdriver will provide enough torque. These boards also are easily damaged by heat so when soldering on them, use a small iron and get on and off quickly.

Cleaning the Instrument

The same procedures and materials used to clean other Tektronix instruments can be used for the 465. For washing the entire instrument a solution of one part Kelite to twenty parts water can be used. For spot cleaning, especially in the area of the vertical attenuator boards, you should use isopropyl alcohol. Carbon-based solvents will damage the polyphenylene oxide boards used for the attenuators. This is also important to keep in mind when using spray coolants in this area.

INSTRUMENTS FOR SALE

360 Indicator, 126 Power Supply with cabinet, $145. Robert Kaplan, Ebasco Services Inc., 2 Rector St., New York, NY 10006. (212) 344-4400.

317, (2) 321A's. Lindsay Acuff, Cleveland Electric Co., 557 Marietta St. 1 N.W., Atlanta, GA. 30313. (404) 524-8422.

434 w/cart and accessories, unused. Roy Madison, 1606 18th Ave., PO Box 1088, Tuscaloosa, AL 35401. (205) 345-2990.

453A MOD127C in mint condition. $1750. Charles Boster, Box 2376, Apt. H-203, 635 Baker St., Costa Mesa, CA 92626. (714) 557-0792.

453, three years old, $1250. Fred Lindsey, Vallejo, CA. After 5:00 PM. (707) 644-7037. 503, good condition. $200. Ray Lefebrve, Electrical Eng., Louisiana State Univ., Baton Rouge, LA 70803. (504) 388-5241.

514D (7), 514AD, 511AD, 531 fair condition. Best offer. W. A. McConnell, Dutchess Community College, Poughkeepsie, NY 12601. (914) 471-4500, Ext. 268.

517, less power supply. Will trade for 530/540 Series vertical plug-in. Dr. Shuster, Box U125, University of Conn., Storrs, Conn. 06268.

517A w/power supply, no cables. As is $135. Type B plug-in, 122 preamp, 280 trigger. E.C. Fether, 8713 Marble Dr., El Paso, TX 79904. (915) 755-0226.

527 Waveform Monitor, MOD132. Thomas O'Brien, 2194 Coker Ave., Charleston, SC 29412. (803) 556-8824 (home), (803) 792-3030 (business).

531A, $400; 533, $450; B, $50; CA, $165. Exc. condition. Kurt Dinsmore, Box 67, Richardson, TX 75080. (214) 271-2431 or (214) 238-0591, evenings.

543B, 1A2 plug-in, good cond. $800 or best offer. Pat Young, (415) 654-6855.

545A w/cart, 2 ea. Best offer. Neria Yomtoubian, Master Specialties, 1640 Monrovia, Costa Mesa, CA 92627. (714) 642-2427, Ext. 218.

545A, RM 35A, 1A1, CA and two ea. 541's. Howard Baugh, Wyle Computer Products, Inc., 128 Maryland St., El Segundo, CA. (213) 678-4251.

547, 1A1, 1A5, like new, best offer. Paul Fincik, Automation Sys., Inc., 7031 Marcelle St., Paramount, CA 90723. (213) 634-5810.

INSTRUMENTS FOR SALE

549, 1A1. Maurice Bruneau, Nashua Corp., 44 Franklin St., Nashua, NH 03060. (603) 883-7711, Ext. 506.

549, $1000. Mike Surratt, OECO Corp., 712 S.E. Hawthorne, Portland, OR 97214. (503) 232-0161, Ext. 349.

561A/3A75/2B67, like new. Jack Gerylo, 5707 Santa Fe St., San Diego, CA 92109. (714) 453-4013.

661/5T4/4S1, clean, like new. Want Collins 30S1 linear or equiv. dollar value. Ed Valentine, Top-O-Hill Rd., Wappingers Falls, NY 12590. (914) 297-3461.

661/4S1/5T1, excellent cond. Sell or trade for real time scope around 10 MHz. George Capasso, 25 Quarry Dr., Wappingers Falls, NY 12590. (914) 297-7538.

3S7, 3T7 TDR plug-ins, never used. $950. Art Eberle, Columbia Gas Systems, 1600 Dublin Rd., Columbus, OH 43212. (614) 486-3681, Ext. 461.

2B67 and 3A74 to trade for 3B3 or 3B4 and 3A6. H. L. Beazell, 104 Key West Dr., Charlottesville, VA 22901.

202-2 Cart, $100; E Plug-in, $60. Neil Pering, 2803 Kipling, Palo Alto, CA (415) 321-2714 or Walt Sonnenstuhl, 41 Moraga Way, Orinda, CA 94563.

C-31 Camera, excellent condition. Reasonable. Mr. Sinclair, 160 E. 84th St., N.Y., NY 10028. (516) 234-0200 (days); (212) 861-9862 (evenings).

549 w/1A1. Bob Schmidhammer, Metric Data System, Rochester, NY. (716) 325-6550.

515, good condition, $300. Hal Greenlee, 430 Island Beach Blvd., Merritt Island, FL 32952. (305) 853-9991 (business), 636-0805, (home).

R5103N/D12, three 5A24N's. Almost new. Best offer. Maurice Asa, Box 2947, Rockridge Station, Oakland, CA 94618. (415) 654-2665.

2601, 26A1, 26A2, 26G3. John Foster, N/J Electronics, P.O. Box 577, Laramie, WY 82071.

211 (15). Richard Strickler, Storage Technology Corp., 2270 S. 88th St., Louisville, CO 80027. (303) 666-6581.

TELEQUIPMENT DM64, new. $1,000 or best offer. Alpha Labs, Inc., 2115 No. Piedras, El Paso, TX 79930. (915) 566-2927.

INSTRUMENTS FOR SALE

C-27R Camera, Polaroid roll film back and bezel. Good condition. $375. (203) 848-8614 after 7:00 P.M.

546 (2), like new, $1250 ea.; 543 w/CA, $750. Consider good cash offer. Ivan Sundstrom, 695 E. 43rd, Eugene, OR 97405. (503) 686-2380 evenings, weekends.

531A/CA/D. Wayne Siebern, St. Joseph Power & Light, 520 Francis, St. Joseph, MO. (816) 238-0025.

516, excellent condition. $500. Dave Friedman. (213) 837-3089.

564B w/2B67, 3A6, scope cart and C-27 Camera, new. Also 585A with 53/54G and scope cart. 661 w/4S1 and 5T1 and scope cart. Excellent condition. Chemistry Dept., Univ. of Bridgeport. (203) 384-0711, Ext. 382.

(3) 5103's. $450 ea. or best offer. Also (3) 5B10N's, (3) 5A18N's and (1) 5A21N. Jon Orloff, Elektros Inc., 10500 S.W. Cascade Dr., Tigard, OR 97223. (503) 620-2830.

INSTRUMENTS WANTED

160 Power Supply in working condition. Prof. Winthrop Smith, U46 University of Connecticut, Storrs, CT. (203) 486-4918. 321A. Marvin Loftness, 115 W. 20th, Olympia, WA 98501. (206) 357-8336.

422, 465 or any portable scope. H. O. Van Zandt, 18 Chandelle Dr., Hampshire, IL 60140. (312) 683-3690.

453 or 454. S. L. Shannon, G.T.W.R.R. Radio Shop, 105 Hampton, Battle Creek, MI 49016.

520 or 520A. Al Dodds, Applied Video Electronics, Inc., P.O. Box 25, Brunswick, OH 44212. (216) 225-4443.

555 with time bases, C-12 or C-27 Cameras. A. C. Smith, Jr., High Voltage Lab., Cornell Univ., 909 Mitchell St., Ithaca, NY 14850.

2-2A60's. Darwin Carner, General Electric, 3001 E. Lake Rd., Erie, PA 16501. (814) 455-5466, Ext. 2635.

2A63. Roy Schreffler, Box 531, Knox, PA 16232.

Plug-in vertical amplifiers for TELEQUIPMENT D43 scope. Wm. A. Richards, 46 Alderwood Lane, Rochester, NY 14615.

TELEQUIPMENT D67, D85. 453 or 422. Also 3B3 plug-in. Hal Greenlee, 430 Island Beach Blvd., Merritt Island, FL 32952. (305) 853-9991 (business), 636-0805 (home).

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Volume 6 Number 3

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TEKSCOPE

Customer Information from Tektronix, Inc.
P.O. Box 500, Beaverton, Oregon 97005
Editor: Gordon Allison,

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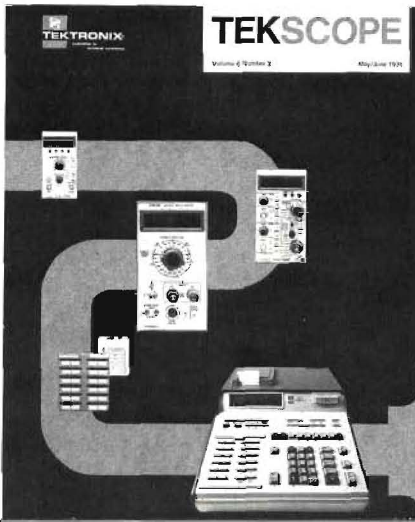
Cover: Measurement plug-ins and programmable calculator are symbolically coupled via an interface cable. The feature article in this issue describes the benefits of actually coupling these two elements to measure and process electrical data.



John Mulvey

The 31/53 calculator-based measurement instrumentation package

Couple a programmable calculator to a digital measurement instrument and what do you have? A quick, automatic, reliable way of doing nearly anything with measurement numbers that you wish. That can range anywhere from simply logging the numbers, to performing complex, sophisticated, mathematical calculations with them and issuing printed reports or command signals about what to do next.

The TEKTRONIX 31 Programmable Calculator serves as the central processing unit in a new instrumentation package that includes TEKTRONIX digital multimeters and digital counters. The package is small enough for bench-top use and low enough in cost for personal use by researchers and engineers. And if you unplug the calculator from the measurement instruments, both are immediately available for duty separately.

The compatible multimeters and counters are plug-ins that are among the TM 500 Series of test and measurement instruments. Essentially all it takes to make the calculator work with these plug-ins is a connecting cable and an interface unit. The interface is what is really new. We put most of the interface circuits in a special plug-in and the rest in a special frame that houses and supplies power to the plug-ins. We call the interface portion of the package a 153. When you connect a 31 to a 153 you have a 31/53 system.

The choice of multimeter or counter is yours. Two multimeters, two counters, or one of each, are acceptable combinations. Each 31/53 has at least two data acquisition channels. And you can add up to eighteen more channels by merely plugging together additional 153's. Every part of the package is plug-to-plug compatible. All you need to do when changing from one combination of measurement plug-ins to another is insert a different patch-plug at the rear panel and rearrange a few push-in jumper wires in the interface unit.

Who needs a programmable calculator coupled to a digital measurement instrument? Basically, anyone who may be (1) logging measurement data by hand, (2) performing calculations with measured data, (3) comparing measurement data with numbers in tables, (4) scaling strip-charts visually, or (5) spending too much money on computers or computer software processing measurement data.

Facing Interfacing

Making measurements with digital multimeters or counters is sometimes part of a process of acquiring data to be *analyzed*. Analysis is where the calculator comes in, of course. Hand-held calculators are very common nowadays, but the feasibility of putting calculators on-line with data inputs is not obvious to everyone. It didn't just happen that you can couple the TEKTRONIX 31 Calculator to a TEKTRONIX DM 501 Multimeter through an interface that also works with TM 500 Series counters. It was planned that way. The multi-pin connector on the rear of the calculator has been there from the beginning.

Most any digital readout device can be coupled to the 31 Calculator through an interface of your own design, if you have the time and know-how to build one. But there are too many diverse requirements to make an interface that will accommodate even a majority of digital readout instruments. On the other hand, the DM 501 Multimeter and DC 503 Universal Counter can provide nearly every kind of measurement presently done with numerous more-specialized instruments. The DM 501, for example, measures resistance and ac or dc volts and amperes over a very wide range, with 4½-digit resolution. In addition, the standard option DM 501 comes with a temperature measuring probe.

With a low-cost custom mod, you can trade the temperature measurement capability for ten times more sensitivity when measuring dc volts. That does such things as let you measure voltage and calculate temperature using the low-level dc signals from thermocouples. For example, if you are considering interfacing your digital thermometers to a minicomputer, you should think about using ordinary thermocouples and letting the 31/53 system do the whole job at a considerable cost savings.

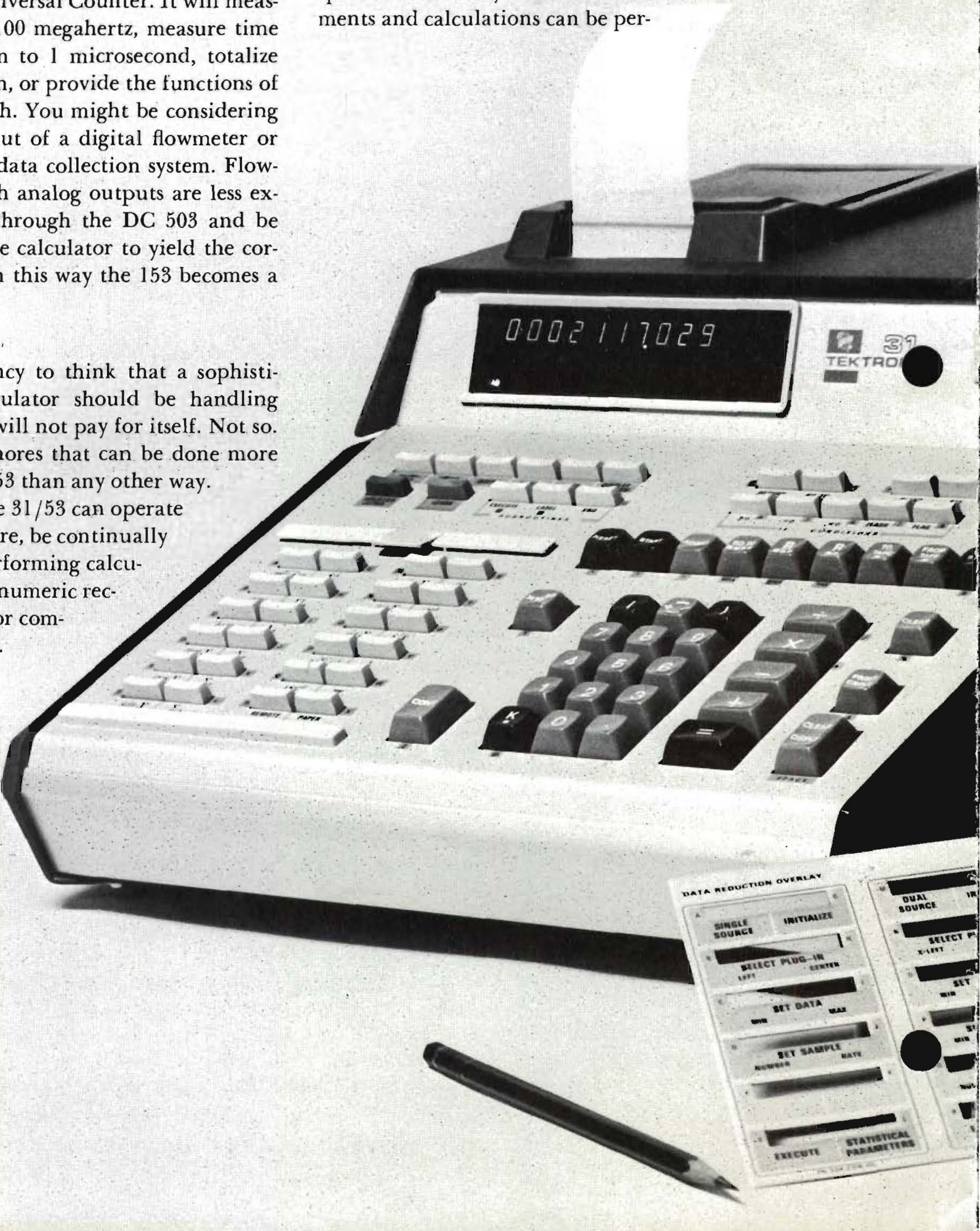
Consider the DC 503 Universal Counter. It will measure signal frequencies to 100 megahertz, measure time intervals with a resolution to 1 microsecond, totalize counts as high as 10 million, or provide the functions of a digital clock or stopwatch. You might be considering how to interface the output of a digital flowmeter or digital tachometer to the data collection system. Flowmeters or tachometers with analog outputs are less expensive. They can work through the DC 503 and be automatically scaled by the calculator to yield the correct numbers and units. In this way the 153 becomes a sort of universal interface.

The Economy Angle

There is a natural tendency to think that a sophisticated programmable calculator should be handling difficult calculations or it will not pay for itself. Not so. There are many simple chores that can be done more economically with the 31/53 than any other way. Under program control the 31/53 can operate unattended. It can, therefore, be continually monitoring input data, performing calculations, printing out alphanumeric records, and issuing warning or command signals when needed.

Consider the case where analog strip-charts are traditionally used. It is nice to know that you have logged all the available data. But sometimes the chore of reducing reams of data to the form essential to your purposes is too time consuming to get done when needed, or to be done economically. The 31/53 will monitor data continually, also, and not only discard unnecessary data but automatically produce summaries and statistics along the way. It can even be idling most of the time and pay for itself, when you compare the cost of equipment and man-hours needed to extract pertinent data from a strip-chart.

Another factor that adds up to economic benefits for even simple calculations is the speed and accuracy with which measurements and calculations can be per-



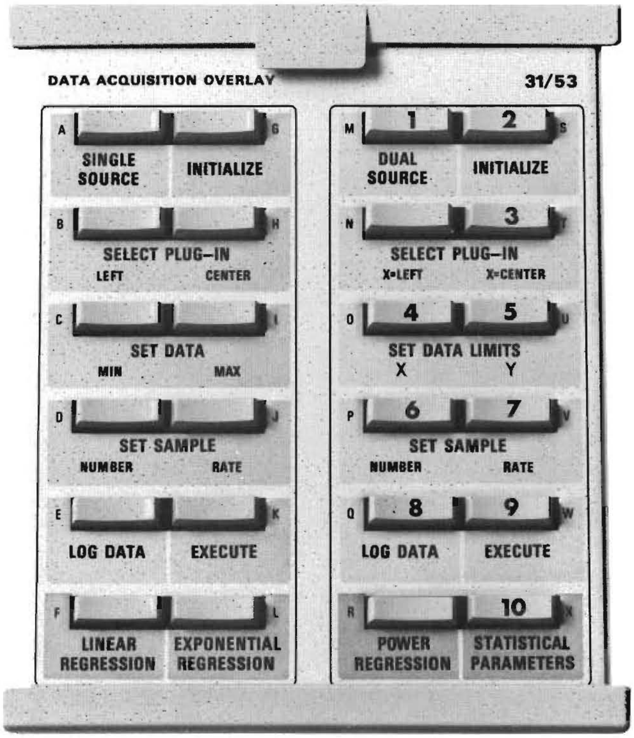
formed when you don't have to enter numbers or instructions manually through the keyboard. An unskilled calculator operator can easily be taught to push one or two specially-labeled keys to cause a set of measurement data to be entered and operated on. With a very simple program and your own labeled user-definable keyboard overlay, that sort of thing can be done. User-definable overlays are a very valuable standard feature of the TEKTRONIX 31.

In a low-volume, precision-component production situation at Tektronix, hours of oven-stabilization time were once required that proved to be unnecessary when the 31/53 was used. Using the old method we had to wait until the oven temperature had stabilized enough so that all the data, logged by hand, could be compared to numbers in one set of tables. Using the 31/53, the precise voltage-drop across each component could be measured almost simultaneously with the measured temperature of the oven. Calculations followed immediately. The operator needed only to select the component with a switch, and push one calculator key. Efficiency was improved to where production could be more than doubled without additional equipment.

Measure, Measure, Calculate

Single measurements on individual devices or circuits seldom provide adequate data, even if we are talking about only one characteristic of the device; and there may be several characteristics to be measured. Numerous measurements often need to be made and correlated before you have adequate information. For example, if you measure the frequency of an oscillator with a high-resolution digital counter, you will usually find that the last digit or two changes each time a new reading

Typical use of data acquisition overlay



Standard software includes two special overlays and two pre-programmed magnetic tapes to go with them. The DATA ACQUISITION overlay is shown. These pre-recorded programs and overlays allow many ordinary data acquisition and analysis problems to be solved without custom software. Here is how you would typically solve a problem using the DATA ACQUISITION overlay.

1. Push DUAL SOURCE. We wish to acquire data from both measurement plug-ins.

2. Push INITIALIZE. We are prepared to make the next selections.

3. Push X = CENTER. We have a multimeter in the left plug-in compartment and a counter in the center plug-in compartment, and we would like voltage to be on the vertical (Y) axis in case a graph is ever plotted of the data pairs.

4. Push DATA LIMITS for X-axis. Follow this by keying in the minimum and maximum numerical values the acquired X-axis data may have before the program is intentionally interrupted.

5. Push DATA LIMIT for Y-axis. Follow this in the same way as for Step 4.

6. Key in the number of data-pair samples you wish to take before the test finishes. Push SET SAMPLE NUMBER.

7. Key in the number of seconds you wish to wait between each successive act of transferring acquired data to the calculator. Push SET SAMPLE RATE.

8. Push LOG DATA. We wish each datum to be printed on the paper tape. The data is stored for later analysis whether logged or not so there may be no interest in logging the raw data.

9. Push EXECUTE. We are ready to take data and want to begin.

10. Push STATISTICAL PARAMETERS after all the data has been acquired. This will yield a print-out of the Mean, Standard Deviation, and Variance on both sets of data. If we wished to see how well the data-pairs correspond to a curve expressed by one of three common equations, we could press the Linear Regression, Exponential Regression, or Power Regression key.

```
TEKTRONIX 31/53
PROGRAM E

AVG. FREQ:
(KILCHERTZ)
     591.475

MAX:
      591.56

MIN:
      591.31

RANGE:
         .25

% DEVIATION:
        .042
```

Fig. 1. Tape readout from an actual test of oscillator performance. Average frequency and minimum and maximum frequencies are readily measured and recorded.

comes up. Then you wonder what the average frequency is and how much the frequency is varying. Your counter will tell you the average frequency over a selected period of time, but you won't know what the frequency variation has been.

The 31/53 can be programmed easily to tell you all of that. Figure 1 shows a paper tape readout of just that kind of test. It took less than one minute to measure frequency 50 times, keep track of the highest and lowest readings, calculate the average frequency from all the measurements, calculate what percentage of the average frequency the maximum deviation was—and print out the results.

Most systems that would do all this faster would not be as economical. If you were to determine the short-term frequency-drift characteristics of an oscillator, as in the above example, you might need to extend the time from 1 minute to 10 minutes. In that case the low-cost calculator and counter obviously would be more economical.

Another measurement often of interest is how the oscillator frequency varies as a function of ambient temperature. With two data acquisition channels available in the 31/53, one channel can provide temperature information for repeated correlation with frequency information supplied by the other channel.

Quick Calculations—Better Measurement

You wouldn't normally suppose that the ability to make rapid calculations would have anything to do with making better measurement, but it is true. The traditional ways to measure things are often based on yielding numerical results with little or no calculation required. Sometimes unconventional methods would be better if the calculations could be done quickly and accurately. We discovered a good example when thinking about how we might easily demonstrate the curve-fitting capabilities of the TEKTRONIX 31.

Most electrical engineers know that a charged capacitor will discharge through a resistor at an exponential rate and that the time to discharge from a given voltage level to 37% of that level will be equal to the product of R and C, resistance and capacitance. How many times have you determined the value of a capacitor by (1) knowing the value of resistance it discharges through, (2) measuring the rate at which it discharges, and (3) calculating the value from this data? The 31/53 does this very well for capacitors with many microfarads of capacitance. Our components test department was delighted. Measuring the value of such capacitors by conventional methods was yielding questionable results. A difference in measured capacitance of about 20% was suspected and confirmed when comparing reactance at 120 Hertz with storage of direct voltage.

Why Calculator-Based

Both the minicomputer and the calculator have great computational power. Both will do most of the same jobs. How do you decide between systems? It is not always easy and sometimes it is a toss-up, but here is a little perspective:

Learning to operate the TEKTRONIX 31 Calculator keyboard is easy for an engineer. Learning to program the calculator is easy for anyone with programming experience. Programming a minicomputer will also be easy to anyone with programming experience if it happens that the minicomputer uses a high-level language like BASIC. This is unlikely, however, because most minicomputers are programmed using a unique assembly language. Unless you or your programming people already have experience with that kind of minicomputer, programming can be a hidden cost and a bottleneck.

Another point to keep in mind is that the bare mini is probably not all you need if you want to keep programming costs reasonable, especially if you intend to have the computer do several different jobs in its lifetime. You should also look at the benefits of at least a tape punch and tape reader before firmly fixing a price tag. And for a readout device you may need at least a teletype machine.

What About Measurement Speed

Compared to the average computer, most calculators are slow. The TEKTRONIX 31 Calculator is no exception. But the 31 is not slow compared to the rate at

How the 31/53 works

Using the DM 501 Digital Multimeter and DC 503 Digital Counter

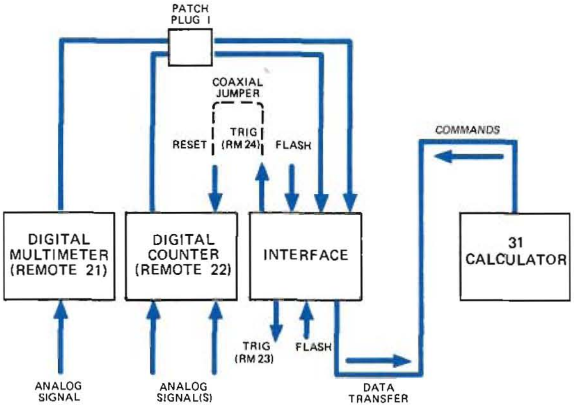
The digital multimeter repeatedly measures and converts analog signal amplitude information to digital numbers, five times per second. The counter performs a similar A-to-D conversion at a rate depending on the signal and the mode of operation of the counter, often less than five times per second.

The digital information in the readout window of the multimeter and counter is routed to the Interface via a patch plug that makes connections to the correct pins. The Interface alters the form of the digital information so that it may be transferred to the calculator in the form required by the calculator.

A REMOTE 21 command signal from the calculator initiates the transfer of data from the left plug-in, to the calculator, via the Interface. A REMOTE 22 signal does the same for the center plug-in. The command signals may be generated from the keyboard of the calculator or as part of a program in progress.

A REMOTE 24 command issued by the calculator results in a trigger signal being generated at the rear panel of the Interface. This signal is sometimes used for resetting the counter plug-in to zero. That trigger signal, or a similar one available on the front panel (addressed by REMOTE 23), can be used for other things such as stepping a relay, or scanner. Or one trigger could be used for stepping a scanner and the other for resetting a scanner. A coded burst of trigger pulses may be issued in more sophisticated applications, to distinguish between the kind of response solicited or to distinguish between devices from which a response is solicited.

The Flash connections on the front and rear panels of the Interface provide a means of signaling the calculator anytime an anticipated event takes place. This can be anything from an alarming situation, to a condition which merely tells the calculator data is ready to be taken from one of the plug-ins. The calculator is programmed to respond in some particular way as a consequence. Only a 2-microsecond pull-down pulse is required to activate the Flash condition. The calculator can be programmed to reset itself immediately so it can repeatedly recognize a new Flash condition.



which fresh measurement data arrives from a typical multimeter or counter. You don't need the speed of a computer to handle data that changes less than five times per second.

Operated in the data-capture mode the 31/53 can store ten-digit numbers at a maximum rate of about 16 per second. If it is given a pause periodically, it can process the captured data during those pauses. When logging data the alphanumeric printer will print about 2½ lines per second, 16 characters to the line. This is not very fast by some standards, but it is often much faster than needed. You should ask yourself how fast you really need information from your system.

Another consideration should be the extent to which your system must be doing the same thing day after day, or month after month. If you are wondering whether a dedicated measurement instrumentation system of any kind is feasible, think about how the equipment can be used to advantage if production demands are not as great as you expected. The TEKTRONIX 31 Calculator can be unplugged from a 31/53 and used in a different job immediately. The TM 500 Series of counters and multimeters can also be used alone, wherever electrical measurements are being made.

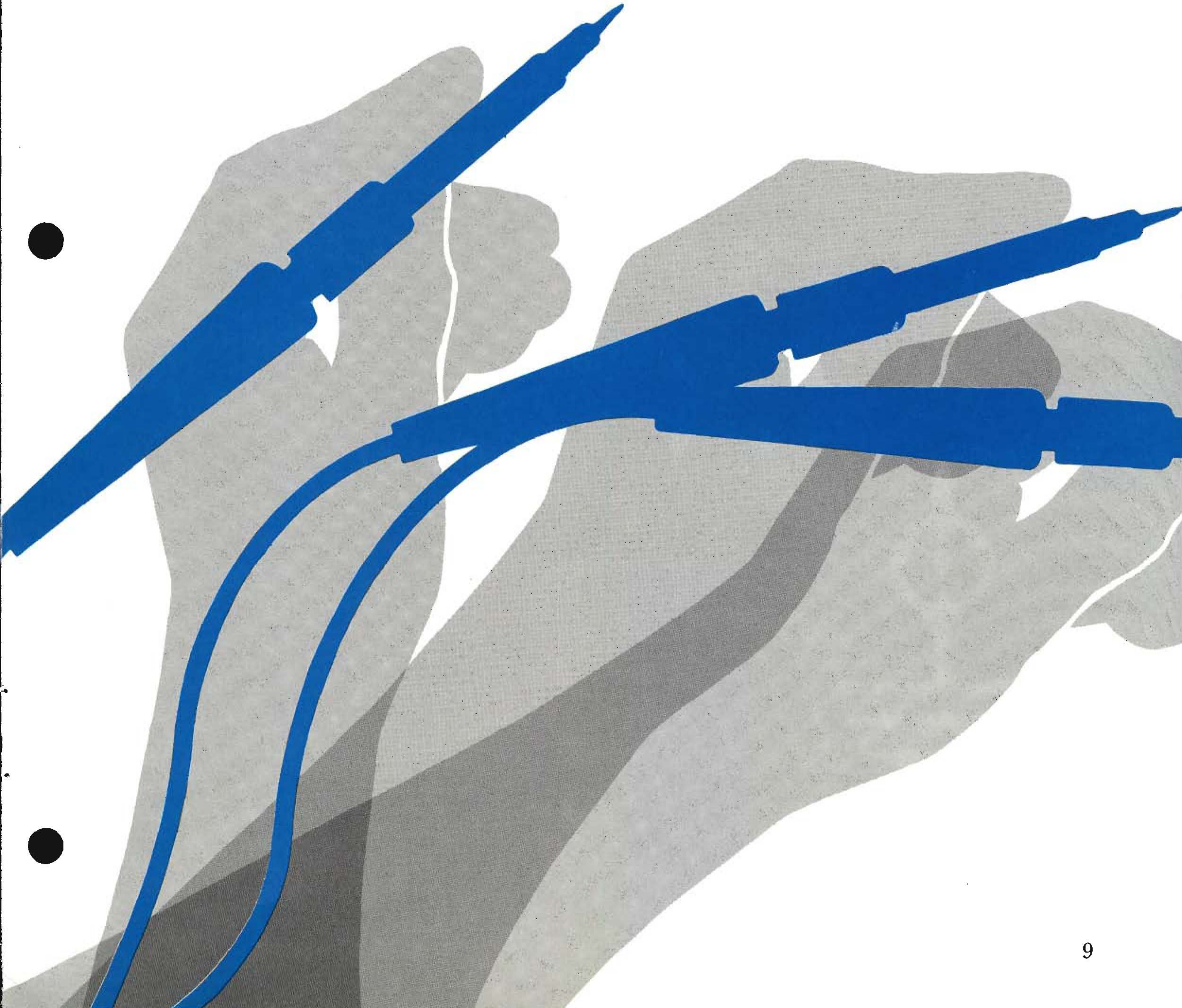
What You Get

The 31/53 is shipped with standard software consisting of two pre-recorded magnetic tape cartridges, two corresponding keyboard section overlays, and a 31/53 system manual. One of the two overlays, the data acquisition overlay, is shown on page 6 with a step-by-step example of how it may be used. After inserting the Data Acquisition tape cartridge you can put your 31/53 to work immediately by pushing the keys identified on the overlay that perform the desired functions. Custom software can be developed for you in the USA by a highly competent Tektronix system analyst near you.

Using your oscilloscope probe

Riley Stock

When a probe is needed to accomplish a measurement function, the typical concept which comes to mind is a passive voltage probe. These probes constitute, by far, the greatest number of probes in use today. Part I discussed passive probes and several of the considerations required in their use. In Part II the world of probes is broadened to include two less well known, but exceptionally useful classes of probes. First, the active, or FET, probe is discussed in the context in which Part I presented the passive probe. The second section presents some of the considerations which can lead to the selection of a current probe as the most appropriate and least circuit-disturbing signal acquisition method.



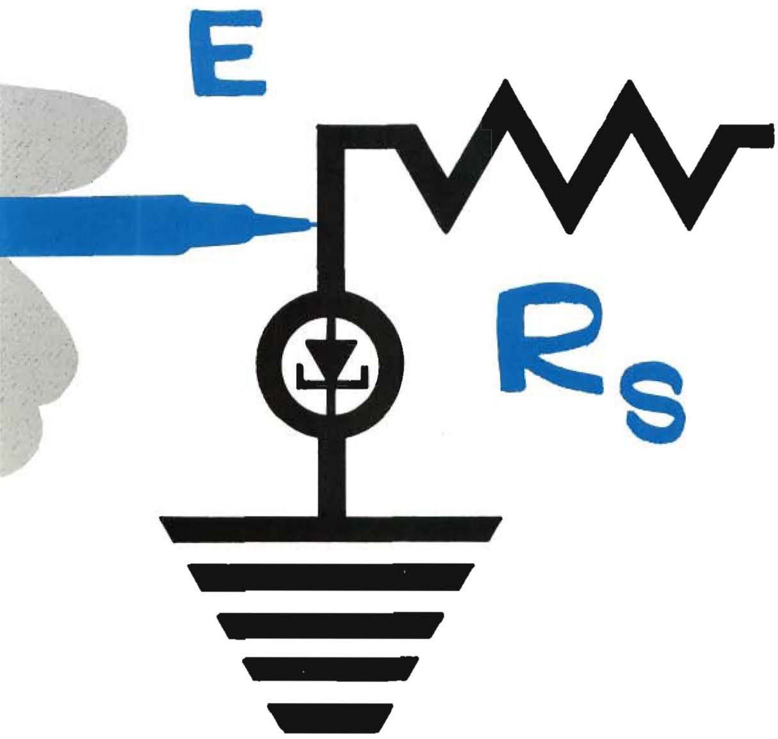
PART II Active and Current Probes

Active probes

Two prime advantages of active probes are: the isolation provided between the measurement point and the probe cable and scope, allowing high input resistance and low capacitance to be achieved; and full bandwidth without input signal attenuation.

Most active probes are compatible with either 1MΩ or 50Ω scope inputs without using external adapters. When working in the 50Ω mode, a 50Ω cable can be used to extend the probe length without increasing capacitive loading. However, longer cables will slow the risetime.

The typical active probe uses a FET input and contains both ac coupling capability and voltage offset for observing signals riding on top of a dc level. The active probe used in this discussion is the TEKTRONIX P6201 probe. It uses a FET input and has a probe only bandwidth of dc to 900 MHz with a risetime of 0.4 ns or less. Other active probes will provide similar advantages within their frequency capability. For example, the P6045 will handle signals up to 230 MHz.



Measuring pulse signals

To provide for a common basis of comparison with the passive probe, the same signal source used in Part I is used for this discussion of active probe performance. The source consists of an ideal step-function generator providing a voltage step of infinitely fast risetime. The source impedance is 200Ω shunted by 20 pF, resulting in a source risetime of 8.8ns (Figure 1(a)).

As we noted in Part I, the capacitive loading caused by applying a probe to the circuit under test can significantly alter the risetime of the signal we desire to measure. If the probe resistance approaches that of the signal source (within two orders of magnitude) risetime can also be affected.

In Figure 1(b) we see the effect of applying the P6201, with 10X attenuator head (1.5pF, 1MΩ), to our signal source. The capacitive loading of the P6201 has increased the pulse risetime from 8.8 ns to 9.5 ns. In Part I of this article we noted that the loading effect of the probe on the signal source could be stated as the percentage change in risetime. In this instance the loading effect is:

$$\frac{t_{r3}-t_{r1}}{t_{r1}} \times 100 = \frac{9.5-8.8}{8.8} = 8\%$$

This is a considerable improvement over the 48% increase in risetime caused by the typical high impedance 10X passive probe, and somewhat better than the 12% decrease in risetime caused by the low-resistance, low-capacitance P6048 passive probe.

We also noted that loading is directly related to probe capacitance, assuming the probe resistance (R_p) to be much larger than the source resistance (R_s). When the probe resistance approaches that of the source, the source impedance is effectively reduced, causing a decrease in the risetime and a considerable reduction in signal amplitude.

Measuring low-level signals

One of the prime advantages of an active probe is full bandwidth at 1X attenuation with minimum circuit loading. This is essential when viewing fast signals in the millivolt region. The P6201 (X1) probe has an input resistance of 100KΩ and a capacitance of 3pf. Let's see what happens to the risetime and amplitude when we apply it to our typical signal source.

Figure 1(c) shows the risetime increased from 8.8 ns to 10 ns for a change of 14%. Though somewhat greater than the 8% of the P6201 (X10) the error is comparable to the 12% error caused by the low-resistance, low-capacitance P6048 passive probe. And note that the P6201 (X1) has negligible effect on signal amplitude.

From the graph in Figure 2 we see that the active probe provides a more accurate risetime measurement than does the passive probe, over a wide range of source risetimes. However, at lower values of source impedance or slower risetimes the small differences in measurement error may not justify the difference in cost between the passive and active probes.

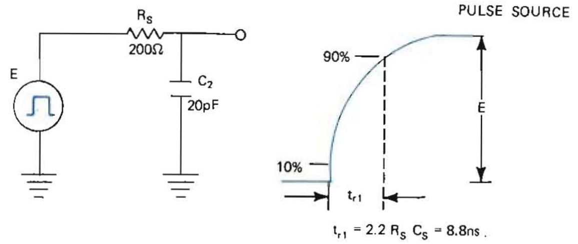


Fig. 1(a). Typical pulse signal source.

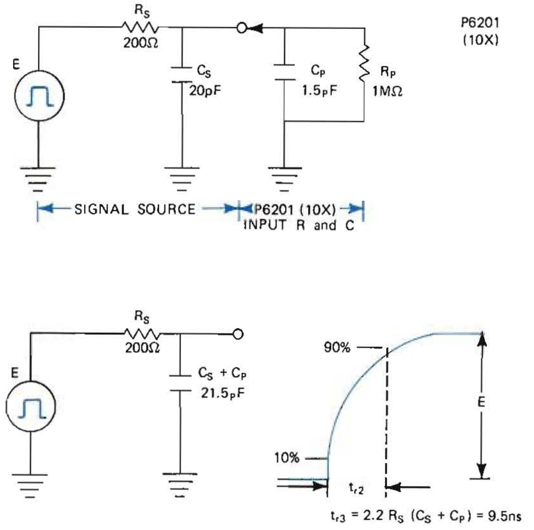


Fig. 1(b). P6201 (10X) probe added to typical pulse source.

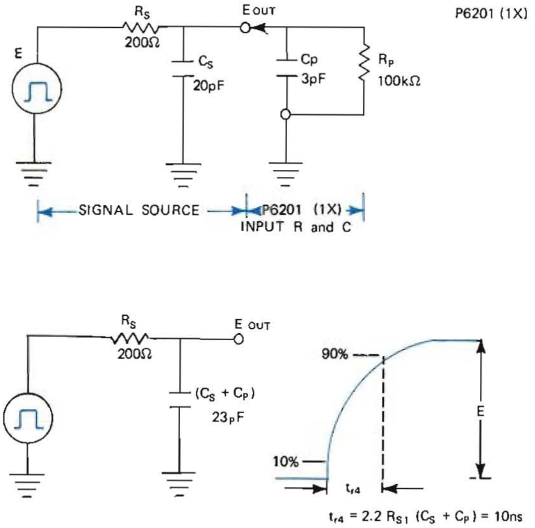


Fig. 1(c). P6201 (1X) probe added to typical pulse source.

Measurement of sine wave signals

Now let's see how the active probe performs when measuring sine wave signals. Figure 3(a) shows the same 10 MHz sine wave source used in Part I. Applying the P6201 (10X) probe we find the source is loaded by a probe resistance (R_{p3}) of 1 MΩ and a capacitive reactance (X_{p3}) of 11 kΩ. This compares with an R_p of 40 kΩ and X_p of 1.7 kΩ for the typical high impedance passive probes (See Figure 4).

Since $R_{p3} >> R_s$ it can be disregarded. However, the shunting effect of X_{p3} in parallel with X_s yields a total reactance, X_{ct}, of 790Ω. The resulting impedance is $Z = \sqrt{R_s^2 + X_{ct}^2} = 815\Omega$. E_{out} with the P6201 (10X) applied becomes $\frac{790}{815} \times 100 = 97\%$ (Figure 3(b)). We see that at the 10 MHz frequency the P6201 has negligible effect on the signal output amplitude.

The advantages the active probe offers for measuring sine wave signals are: a more gradual decrease of R_p with increasing frequency, and a lower input capaci-

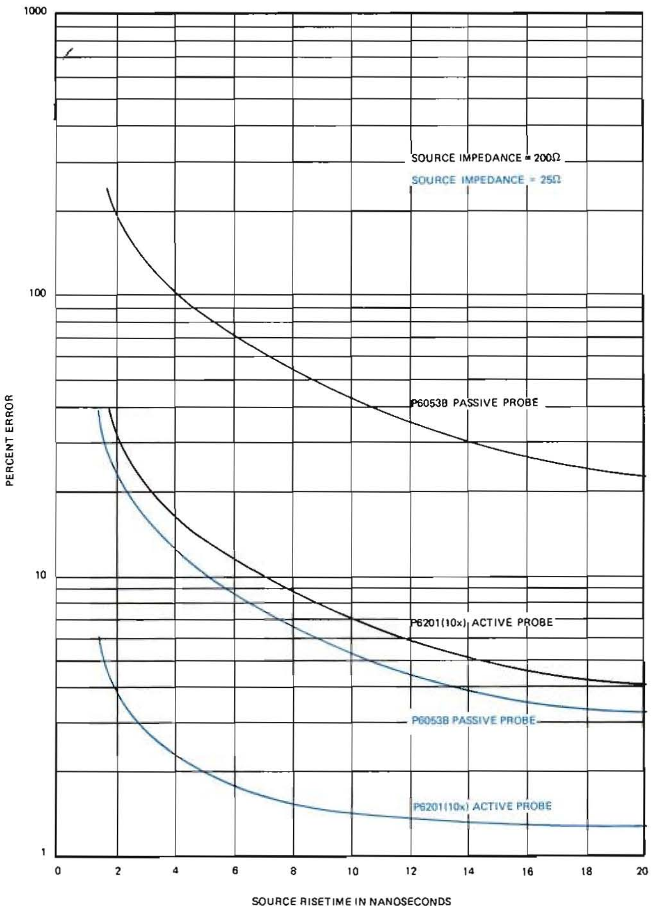


Fig. 2. Relative performance of the P6201 and P6053 when measuring various risetime signals from a 200Ω source and a 25Ω source.

tance providing higher X_p. These characteristics become even more important as the signal frequency increases. For example, if the frequency of our typical source is increased to 50 MHz, the P6201 (10X) causes a change in source output voltage of 3%, while the typical passive probe causes a change of 20%.

Summing it up for active probes

Active probes can provide definite advantages when viewing signals from high impedance and/or low capacitance sources. They provide the best obtainable combination of high input resistance and low capacitance, without signal attenuation; they therefore can be considered capable of providing the best general-purpose measurement capability.

Following is a summary of some general considerations for selecting an active probe:

1. Full bandwidth is provided with no signal attenuation using the 1X configuration.
2. The active nature of the probe provides the high input impedance characteristics of most passive probes and the low input capacitance of passive probes designed to work into 50Ω inputs. These features yield the best of two worlds—minimum risetime and minimum pulse-amplitude error.
3. Impedance selection to permit use with either 50Ω or 1 MΩ inputs is usually provided.
4. Probe length can be extended through the use of 50Ω cable without increasing probe loading.
5. Over-voltage capability is typically provided. However, to minimize the likelihood of over-voltage, the highest attenuation configuration should always be used when probing unknown voltages.
6. Dynamic signal range of the active probe is not as great as that of a passive probe. For example, the P6201 (1X) can handle signals up to ±600 mV. This can be extended to ±60V using the 100X attenuator. DC offset provides a measurement window of ±5.6V using the probe alone, with the range extended to ±200V using the 100X attenuator.

The current probe

Now let's turn our attention to a measurement tool often overlooked—the current probe. Current probe measurements are particularly applicable for high impedance measurement points where the voltage probe would significantly alter the circuit characteristics.

The current probe offers the lowest circuit-loading of any available probe. There is, however, an insertion impedance reflected into the circuit under test, which consists of a series resistance shunted by a small induc-

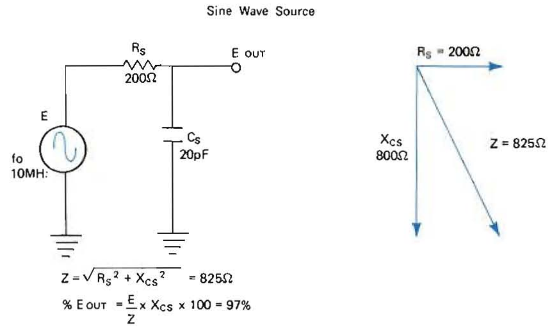


Fig. 3(a). Typical sine wave signal source.

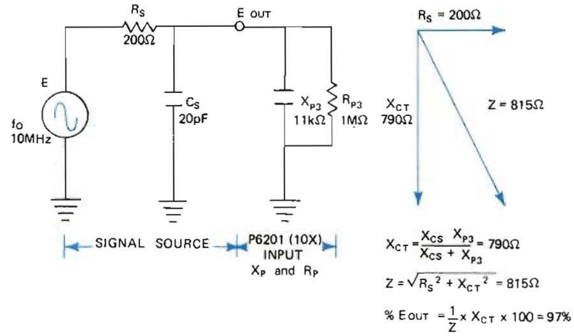


Fig. 3(b). The P6201 (10X) probe to typical sine wave source.

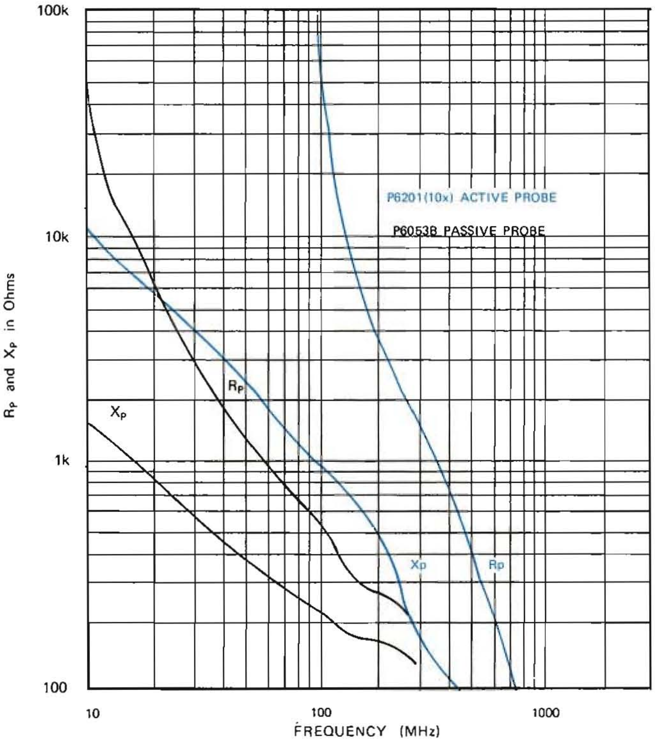


Fig. 4. Typical X_p, R_p vs. frequency curves for the P6053B and P6201 probes.

tance. The value of this inserted impedance is associated with the design of the current-sensing unit in the probe head. In the instance of the TEKTRONIX P6042 (dc to 50 MHz current probe) the insertion impedance is 0.1Ω at 5 MHz. Thus, to realize an amplitude measurement error of less than 2%, the signal source impedance should be 50 times the insertion impedance or, in this case, 5Ω.

A second consideration in the use of the current probe is the capacitive coupling from the probe to the circuit. This coupling is the only shunt loading placed on the circuit by the probe and will vary depending upon the size and type of material of the current conductors. For example, with No. 20 AWG wire the capacitance will be ≈0.6pF and with No. 14 AWG it will be ≈1.5pF. The majority of this capacitance is to a shielding can placed about the current-sensing unit, and its effect can be minimized by using the probe ground lead when working with large voltage swings of high-frequency signals. Another technique is to select a current-monitoring point to minimize voltage swing; for example, monitoring the current on the dc supply side of a load resistor.

Some typical applications

One of the measurements for which a current probe is ideal, is looking at the output required of a generator driving a capacitive or partly-capacitive load. An example would be the gain requirements of an output stage driving the beam-blanking structure of a cathode ray tube. If voltage were monitored, a square wave would be observed. However this is not at all indicative of the current spike that the transistor needs to provide. In this particular measurement, the current probe disturbs the functioning circuit very little, whereas, the capacitive loading of the voltage probe causes a severe disturbance.

A few of the many other areas of usage include transformer design, where the current distribution is the most important parameter; the design of electric motors and generators including looking at starting currents, generated transients, and checking commutation currents; numerous SCR-oriented applications including balancing SCR currents, as well as measuring rate-of-change and peak currents.

Think current measurement

After one becomes accustomed to thinking "current," there are many areas where better measurements can be made and the resultant data is in a more useful form. For example, in evaluating transistor performance, the current probe is ideal for measuring base drive, collector current and even emitter current if the impedance is not too low. You can determine many of the operating characteristics of the transistor through analysis of the collector current waveform.

Differential measurements simplified

If differential measurements are required, the current probe is inherently a high CMRR device. The addition or subtraction of currents by passing two or more wires through the probe sensing unit provides an unsurpassed differential probe. There are no amplifiers, only the opposing or reinforcing flux fields determine the probe output. Similarly, added sensitivity may be obtained by looping the current conductor through the probe more than once.

Another useful technique is to make simultaneous voltage probe and current probe measurements to determine incircuit capacitive or inductive characteristics. If the system is compensated, i.e., has no net reactive components, the voltage and current waveforms will be congruent.

Two styles of current probes

Two styles of current-sensing probes are available. The closed-core unit, such as the CT-1, requires the current-carrying wire to be threaded through the unit. These devices are designed to allow permanent mounting within the circuit to provide continuous monitoring within a controlled electrical environment, for example, a 50Ω strip line. The second style available is the split-core unit which provides for a portion of the core to slide back allowing the current-carrying lead to be inserted without breaking the circuit.

Operational characteristics

The typical current probe has its operational capabilities described by a different set of terms than is characteristic of voltage probes. The **Amp-Second Product** is directly related to the flux saturation of the transformer core. Effectively, the Coulomb charge under one pulse is integrated to determine whether it will place the current transformer into saturation or not.

The **RMS current** indicates the power handling capability of the probe. This power limit may be the wattage capability of the terminating resistance, the wire size of the secondary winding, or a similar power-sensitive component.

The **maximum peak pulse current** rating is indicative of the voltage breakdown characteristics of the weakest component in the system.

Summing up the current probe

Though the use of a current probe may require a slight change in how we customarily evaluate circuit performance, the advantage of using a current probe in certain aspects of circuit design and evaluation make the effort well worthwhile.

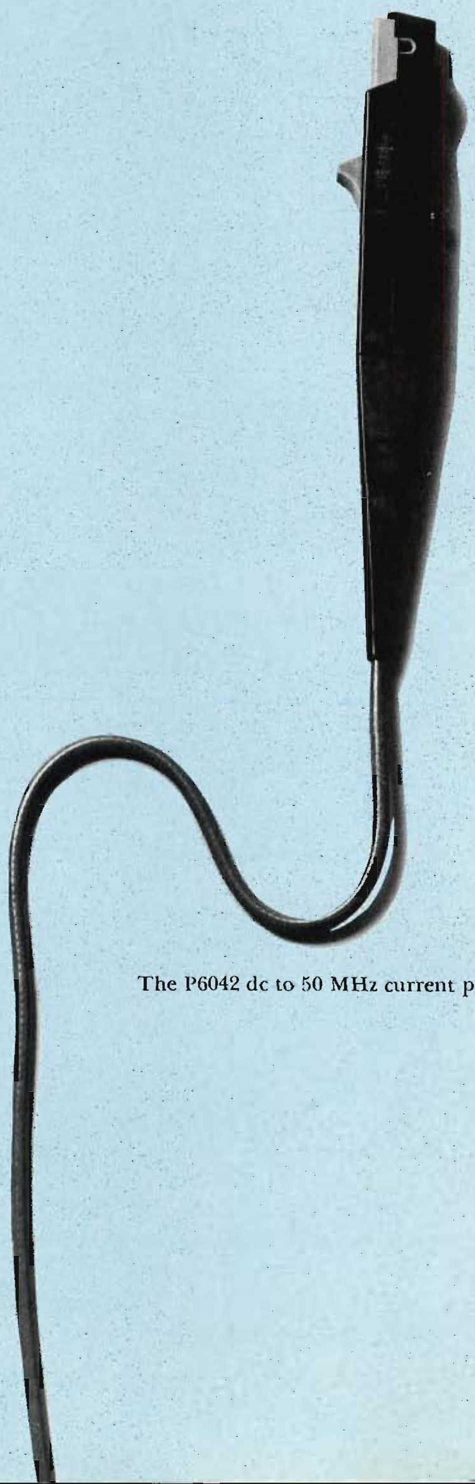
Here are some general considerations leading to current probe use.

1. The current probe can be considered complementary to the voltage probe in the respect that where the voltage probe desires low impedance points for accurate measurements, higher impedance points are desired for the current probe.
2. The current probe exhibits lower loading than any voltage probe. This generally implies minimum signal amplitude attenuation and minimum risetime inaccuracies.
3. Where information on current supply requirements is needed, primarily into capacitive elements, the current probe is almost a necessity.

The P6201 dc to 900 MHz active probe.

Conclusion

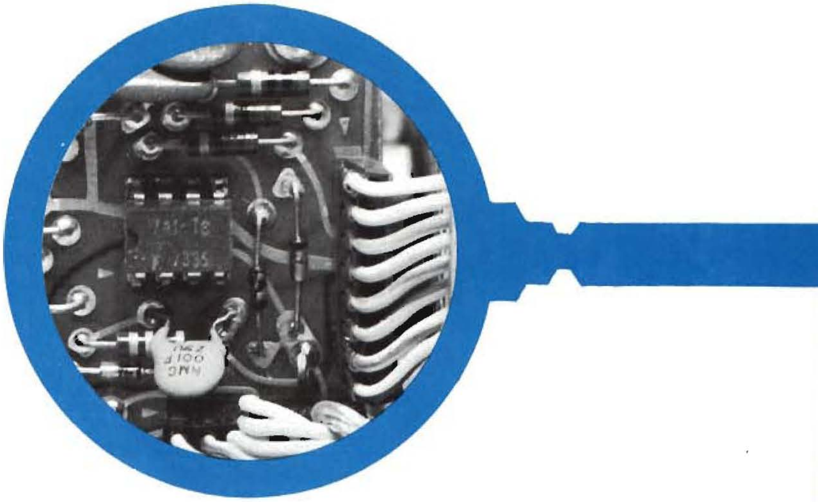
Both the active probe and current probe extend the measurement capability of your oscilloscope. They can yield more accurate measurements than passive voltage probes in many instances, and often provide the only means of making some measurements. They could prove to be ready-made solutions to some of your more difficult measurement problems.



The P6042 dc to 50 MHz current probe.

Servicescope

Servicing the 7904 high-efficiency power supply



The high-efficiency power supply, in some form, is used in many TEKTRONIX instruments. While this particular article deals with the 7904, some of the techniques discussed here will be helpful in servicing other instruments using this type of supply.

The high-efficiency supply, a relatively recent innovation in power supply design, provides a considerable savings in volume, weight, and power consumption. Figure 1 shows a simplified block diagram of the supply, which is essentially a dc-to-dc converter. The line voltage is rectified, filtered, and used to power an inverter which runs at approximately 25 kHz. Operating frequency is determined basically by the resonant frequency of a series-LC network placed in series with the primary of the power transformer. The inverter drives the primary of the power transformer, which supplies the desired secondary voltages. These are then rectified, filtered, and regulated for circuit use.

Pre-regulation of the voltage applied to the power transformer is accomplished by controlling the frequency at which the inverter runs. A sample of the secondary voltage is rectified and used to control the frequency of a monostable multivibrator. This multivibrator, in turn, controls the time that either half of the inverter can be triggered, thus controlling inverter frequency. Pre-regulation to about 1% is achieved by this means.

Now let's turn our attention to troubleshooting the instrument.

Look for the clues

Stop, look and listen. You can often save valuable time by noting symptoms that can serve as clues to the section in trouble. For example, the high-efficiency supply has two basic failure modes:

1) The inverter is working in the "burst" mode, as evidenced by a ticking sound occurring about four times a second.
2) The scope is dead, no inverter operation at all, possibly the sign of a blown fuse.

Let's examine these two problems separately.

Problem 1: The inverter is working in the burst mode. The plug-ins have been removed to eliminate them as the source of trouble and the problem still exists.

Procedure: Remove the line plug and set CONTROL ILLUM to OFF and GRAT ILLUM counterclockwise. Remove the instrument side panels and locate the Z-axis board located on the right side of the instrument at the rear.

Using a VOM, take resistance readings at the supply test points located on the Z-axis board. See Figure 2. Contact the +5V lamp supply at the rear wafer of the CONTROL ILLUM switch (red and black lead).

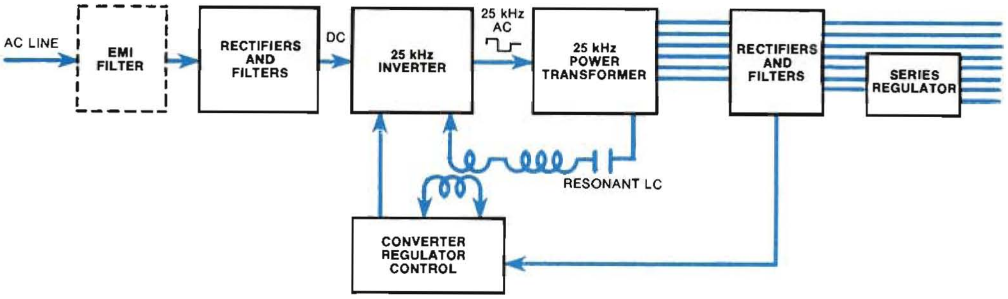


Fig. 1. Simplified block diagram of a typical high-efficiency power supply.

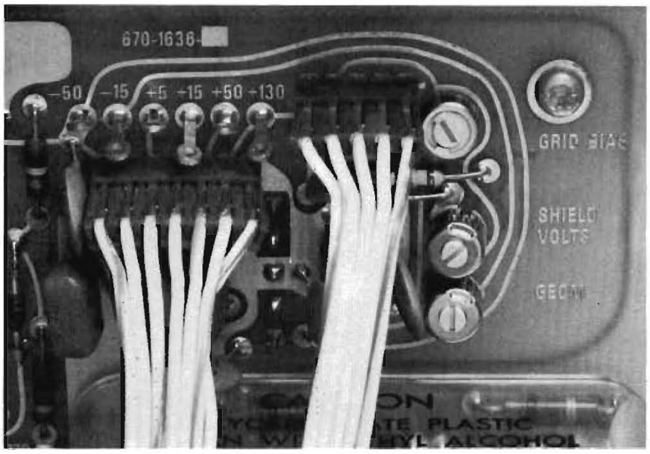


Fig. 2. Power-supply test points on the Z-axis board.

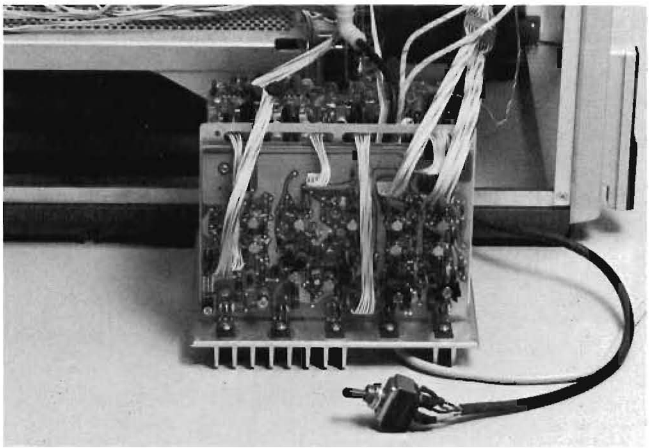


Fig. 3. The high-efficiency supply extended for servicing.

A. Check resistance of the supplies and mainframe.

Supply	Scale
+130V = 6 kΩ	X1k
+50V = 2 kΩ	X1k
+15V = 90 Ω	X100
−15V = 100 Ω	X100
−50V = 250 Ω	X100
+5V lamp = 800 Ω	X100

A low resistance reading usually indicates trouble in the mainframe. Since only troubles in the power supply will be considered in this procedure, continue on to the next step.

To perform the next step it is necessary to remove the power supply unit from the mainframe. This is easily done by removing the four screws holding the power unit to the rear frame of the instrument and then sliding the unit out the rear. Disconnect all connections between the mainframe and the power unit. (The POWER switch can remain mounted in the scope front panel.) When disconnecting the crt anode lead, ground it to the scope frame momentarily to dissipate any stored charge.

B. Check resistance of the mainframe only, taking readings at the same test points on the Z-axis board and CONTROL ILLUM switch.

Supply	Scale
+130V = 6.6 kΩ	X1k
+50V = 2 kΩ	X1k
+15V = 90 Ω	X100
+5V = 65 Ω	X100
−15V = 110 Ω	X100
−50V = 2 kΩ	X100
+5V lamp = infinite	X100

If the mainframe readings are as listed, the trouble is probably in the power unit.

To gain access to the components inside the power unit, remove the nut holding the POWER switch to the front panel and remove the switch and its interconnecting cable through the rear of the instrument. The unit is now completely free of the mainframe, making it easy to remove the power-unit covers.

A note of caution is in order at this point. The primary storage capacitors, C1216 and C1217, remain charged with high voltage dc for several minutes after the line power is disconnected. A neon bulb located on the power supply inverter board flashes when this stored voltage exceeds about 80 volts. Do not remove the power-unit covers while this light is flashing.

After removing the covers the power unit can be positioned as in Figure 3 and the leads connected so the unit can operate. A pair of multi-pin cable extensions (Tektronix Part Nos. 012-0577-00 and 012-0578-00) are available to extend the cables between the low-voltage regulator board and the main interface board on the mainframe 7904 and 7704A.

There are a number of faults that will cause the supply to operate in the burst mode. Let's examine the symptoms and the probable causes individually.

Symptom 1: Burst operation—resistances are normal.

Probable cause: One of the semi-regulated supplies is overloaded.

Procedure: Check the semi-regulated voltages at the points indicated on the capacitor-rectifier board (Figure 4). With your test scope set for a sweep of 10ms/div, vertical sensitivity for an on-screen display using a 10X probe and dc coupling, the voltage waveforms should resemble that of Figure 5.

If the burst voltage pulse is within ≈15% of the stated semi-regulated value the supply is probably all right. If abnormally low, remove the power, wait for the large filter capacitors to discharge and then check the tantalum filter capacitors associated with the supply for shorts or leakage.

To speed servicing, you can use a 1.5 kΩ, 2 watt insulated resistor to short the storage capacitors (C1216 and C1217). Do not place a dead short across the capacitors as this can damage them.

Symptom 2: Burst operation—semi-regulated voltage normal.

Probable cause: High-voltage circuit problems or inverter control circuit problems.

Procedure: With the line power off, disconnect the crt anode lead and short it momentarily to ground to bleed off any charge. Disconnect multi-lead cables P1675 (green), and P1704 (yellow), at the Z-axis board.

If the power unit now operates properly, a crt failure or problem in the mainframe high-voltage circuitry is indicated.

If burst operation persists with these cables disconnected, replace U1275 and check the components in the inverter control loop. A good place to start checking is pins 6, 7, 10 and 11 back to T1235 and then pins 8 and 9 back to T1230.

Another point to check is the over-voltage protection circuitry Q1248 and VR1246. If the zener voltage of VR1246 has shifted it can cause erratic operation.

If these circuits are normal, remove the low-voltage regulator chassis and check on the high voltage board for shorted or leaky components.

Problem 2: Now let's consider the conditions which cause either the 2 amp or 4 amp fuse to blow.

Symptom: The scope is inoperative and the 4 amp fuse is blown.

Probable cause: Trouble in the line input circuitry or in the inverter section.

Procedure: Remove the line plug from ac power and discharge storage capacitor, C1216 and C1217, using the 1.5 kΩ, 2 watt resistor. Check diode bridge, CR1215, and the associated line input circuit for a shorted component, then replace the four amp fuse.

If these circuits appear normal, connect the line plug to a variable line source and advance the line voltage from 0 to 20 V ac. Using your test scope check the waveform on each of the storage capacitors (C1216, C1217). The capacitor should have a 60 Hz waveform displaced by some amount of dc as in Figure 6. The dc voltages should be equal in amplitude and of opposite polarity. These waveforms permit you to check the condition of the bridge rectifiers and storage capacitors.

Symptom: The scope is inoperative and the 2 amp fuse is blown.

Probable cause: Malfunction in the inverter.

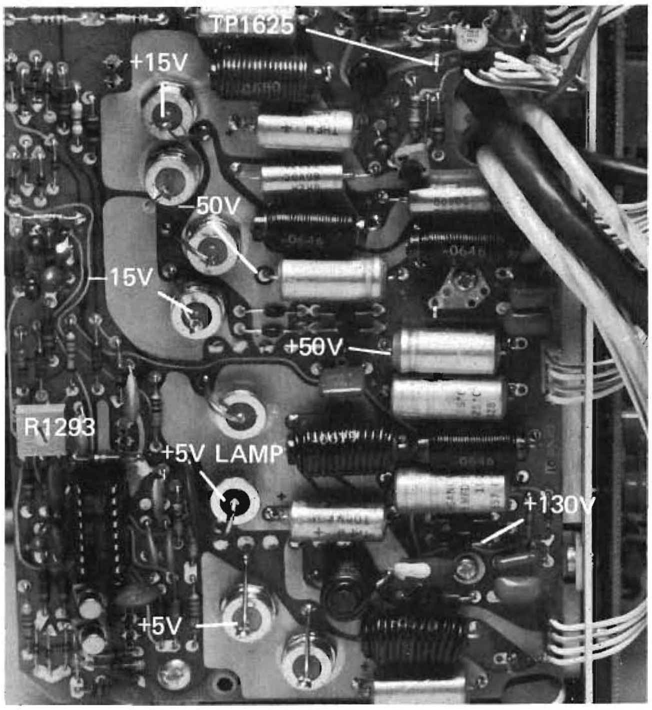


Fig. 4. Partial view of the capacitor-rectifier board showing voltage check points and key components.

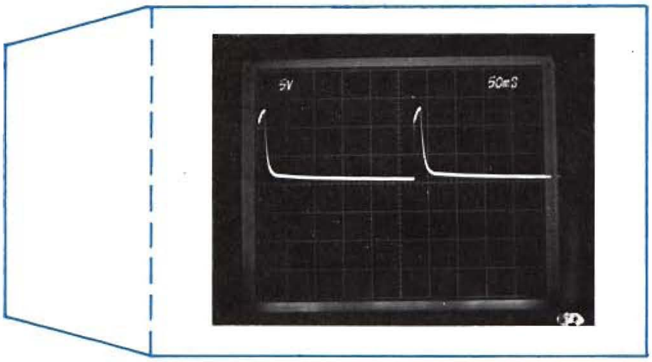


Fig. 5. Typical supply voltage waveform when operating in the "burst" mode.

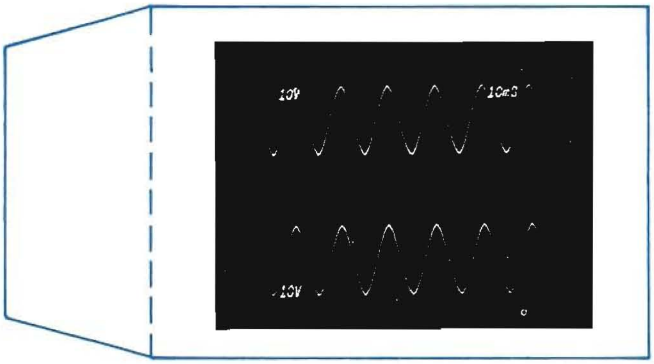


Fig. 6. Typical waveforms on C1216 and C1217 with line voltage set to about 20V.

Procedure: Remove the line plug from the variable line source and manually discharge the storage capacitors as before. Remove the gray cover from the inverter board. Remove Q1234, Q1241, CR1234 and CR1241 from the inverter board (Figure 7) and check their characteristics with a curve tracer or VOM.

Install the checked components in the inverter board and replace the 2 amp fuse. Locate T1230 on the inverter board and note a black wire loop that passes through small toroid T1235. Connect a current probe (TEKTRONIX P6021 with passive termination, or equivalent) to the black lead and set the test scope for an equivalent vertical sensitivity of 1A/div and set the time base for 2 ms/div.

Connect the line plug to the variable line control which should be set at 0V. Slowly increase the line voltage and note a burst waveform of ≈20 kHz occurs at ≈60 V ac (Figure 8). As you continue to increase the line voltage, stable operation should occur at about 85 V ac. Figure 9 shows the normal waveform at 115 V ac. Note that the test scope sweep speed has been increased to 50 μs/div. Analysis of these waveforms should give you a clue to the circuitry in trouble.

Symptom: The inverter does not run and the fuses are alright.

Probable cause: Inverter circuit malfunctions.

Procedure: Remove the line plug and discharge the storage capacitors as before. Remove Q1234, Q1241, CR1234 and CR1241 and check their characteristics with a curve tracer.

Install the checked components and check the circuit for operation as in the preceding procedure. If the power unit is still inoperable, connect your test scope, using a 10X probe, to TP1234 on the inverter board (see Figure 7). Set the variable line control at 20 V ac and check to see that the 60 Hz waveform is approximately dc centered (Figure 10). If not centered, check Q1246, CR1232, CR1240, CR1242, CR1249 and CR1244 for shorts or leakage.

Increase the line voltage to 60 V ac and check to see that the 60 Hz waveform has start triggers at each negative tip. If no start triggers occur, check CR1238 characteristics on the curve tracer.

Symptom: Unstable inverter operation.

Probable cause: One of the semi-regulated voltages is of improper value.

Procedure: With the current probe attached to the black wire loop associated with T1230, adjust the variable line voltage for the most stable waveform. (The 20 kHz waveform should be limited to 5 amps peak-to-peak.)

Referring to Figure 4, check the raw voltages on the capacitor-rectifier board with your VOM. They should be as follows:

Check +15V dc at CR1345 for ≈ +17V dc.
Check −15V dc at CR1347 for ≈ −17V dc.
Check −50V dc at CR1362 for ≈ −54V dc.
Check +50V dc at CR1358 for ≈ +54V dc.
Check + 5V dc at CR1313 for ≈ + 7V dc.
Check +5V dc lamp supply at CR1312 for ≈ +5V dc.
Check +130V dc at CR1323 for ≈ +130V dc.

For stable operation of the inverter control circuitry, +5V lamp, −17V dc and +130V dc must be present on the capacitor-rectifier board and −50V dc must be present on the low-voltage regulator board.

Symptom: Stable inverter operation when the multilead cables P1675 (green) and P1704 (yellow) are removed.

Probable cause: Crt circuit malfunction.

Procedure: Remove the line plug and disconnect P1675 and P1704 from the Z-axis board. Place the VOM on the cables to hold P1675 and P1704 down on the bench so that voltage readings can be taken. Apply power to the setup and set the VOM to the 60 V dc scale. With the positive meter lead on pin 2 and negative lead on pin 3 of P1675 (green) you should read ≈25 V. (Auto focus check.) With the positive lead on pin 4 and negative lead on pin 5 (P1675) you should read ≈35V. (Auto focus check.) Moving to P1704 (yellow), with the positive lead on pin 1 and negative lead on pin 2 you should read ≈35V. (Auto focus check.)

With the positive lead on pin 7 and negative lead on pin 6 of P1704 (yellow) check for ≈25V. (Exercise caution as pin 7 is elevated to 3 kV.) This is a crt grid bias check.

Change the VOM setting to the 60 V ac scale and apply the leads to pins 8 and 9. Check for ≈8V ac. This is a crt filament check.

If the auto focus or bias voltages were low or zero in any of the previous checks, there is the probability of shorted or leaky diodes on the high voltage board. These can be checked using the 100 kΩ scale on the VOM.

If the crt filament voltage was low or zero, remove the high-voltage assembly and check for open runs on the circuit board.

A quick operational and cal check.

After locating and repairing the malfunction, it would be good to make a quick operational and calibration check before installing the power unit back into the mainframe. Here are the points to check and adjust:

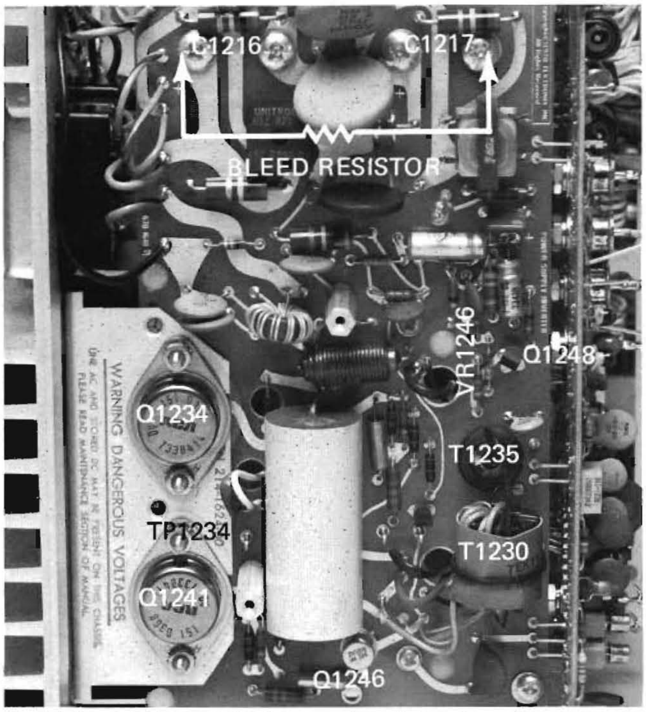


Fig. 7. Partial view of the inverter board showing where to apply bleeder resistor to discharge C1216 and C1217.

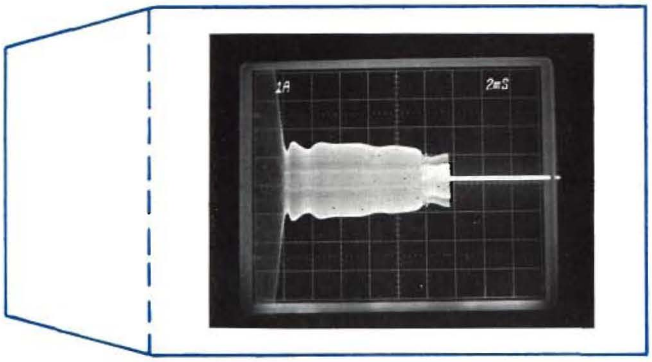


Fig. 8. Current waveform at T1230 showing burst operation at a line voltage of about 60V.

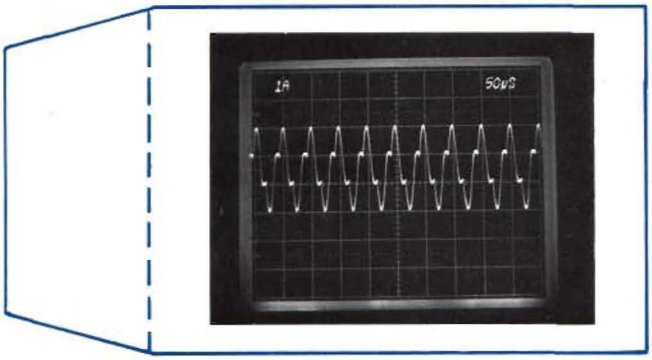


Fig. 9. Current waveform at T1230 for normal inverter operation at a line voltage of 115V.

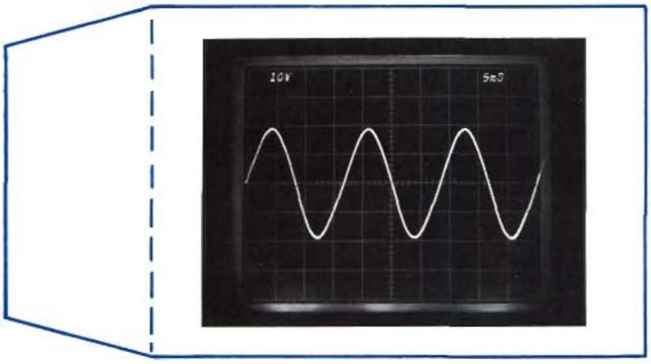
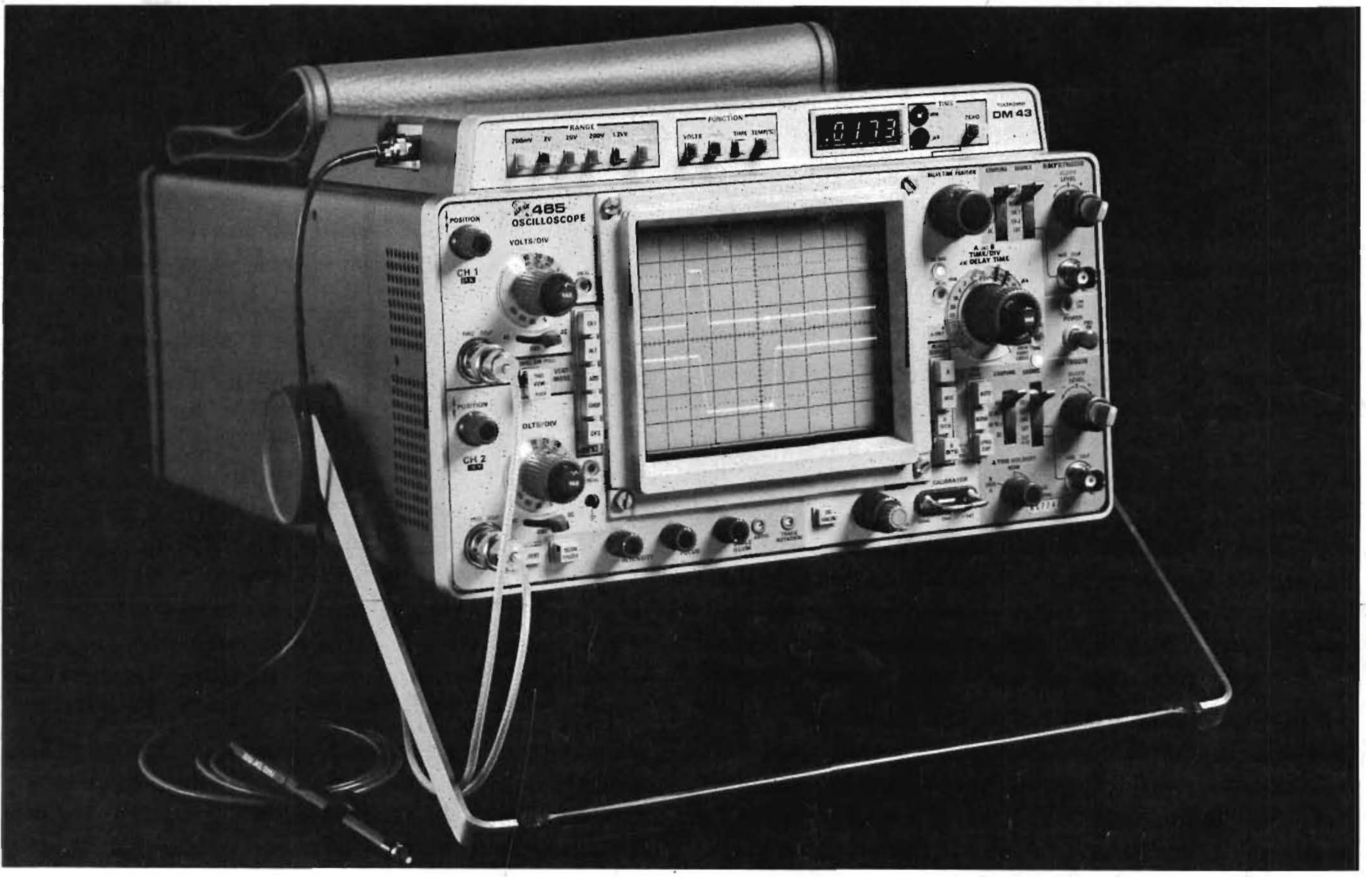


Fig. 10. Waveform at TP1234 on inverter board with line voltage set to about 20V. Waveform should be equally displayed from center-screen.

1) Connect a precision dc voltmeter (0.1% or better) to the −50V sense and ground sense points on the low-voltage regulator board near P1483 (orange). Adjust R1513 (−50V adjust) for −50V, ± 0.1V.
2) Check +50V supply for +50V, ± 0.25V.
3) Check +15V supply for +15V, ± 0.1V.
4) Check +5V supply for +5V, ± 0.05V.
5) Check −15V supply for −15V, ± 0.1V.
6) Check the above supplies for regulation while changing variable line voltage from 90V ac to 132V ac.
7) Connect the voltmeter between TP1625 and ground on the capacitor-rectifier board and turn inverter adjustment (R1293) full ccw to full cw and check for a voltage range of −49V to +132V. If unable to adjust to these voltages, try replacing U1635 and check Q1627, Q1631 and VR1635.
8) With the mainframe CONTROL ILLUM to OFF and GRAT ILLUM full ccw and all plug-ins removed, set the line voltage to 117V ac and set R1293 for +40V.
9) Connect a pair of 1X probes to a vertical amplifier in your test scope suitable for differential measurements. Check the ripple of the supplies on the sense points located on the low-voltage regulator board as follows:
   −50V, less than 2 mV.
   −15V, less than 1 mV.
   +5V, less than 1 mV.
   +15V, less than 1 mV.
   +50V, less than 3 mV.
   +130 V, less than 500 mV at +130V test point.
   +5V lamp, less than 25 mV at pin 4 of P1415 (green).

This completes the troubleshooting and recalibration procedure. Remove the extender cables and other connections, replace the power unit cover and reinstall the power unit in the mainframe.

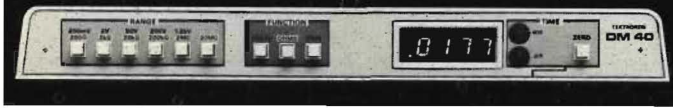
Digital Timing Measurement The Easy Way........



Digital timing measurement with improved resolution, 1% accuracy, increased freedom from error, faster operation, and greater operator convenience. The new TEKTRONIX DM43 with its unique direct numerical readout of time intervals adds all of these advantages to the field proven 465 and 475 oscilloscopes. What's more the DM43 includes precision digital meter capabilities as well. The DM43 is also available in the new 466 and 464 Fast Storage Portable Oscilloscopes.

The DM43 provides a direct numerical readout of the time between any two points on the oscilloscope screen selected by the delay time position control. 3½ digit resolution and the 1% accuracy of the DM43/oscilloscope combination provide convenient measurement of critical digital system timing in field servicing, in production, and in the design lab. Speed of measurement, freedom from error, and operator convenience are all improved since no dial readings or mental calculations are needed to arrive at a final reading.

Dc voltage measurement with an accuracy of 0.1% from 0 to 1200 V, resistance measurement within 0.75% over the range 0 to 20 MΩ, and the convenience of temperature measurement with a probe over the range −55°C to +125°C add still more to the versatility of the DM43. In field servicing, in production, and in design laboratory applications the DM43/Portable Oscilloscope combination provides the capability to meet almost any measurement need, and it's all in one compact package which can easily be carried wherever tests must



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