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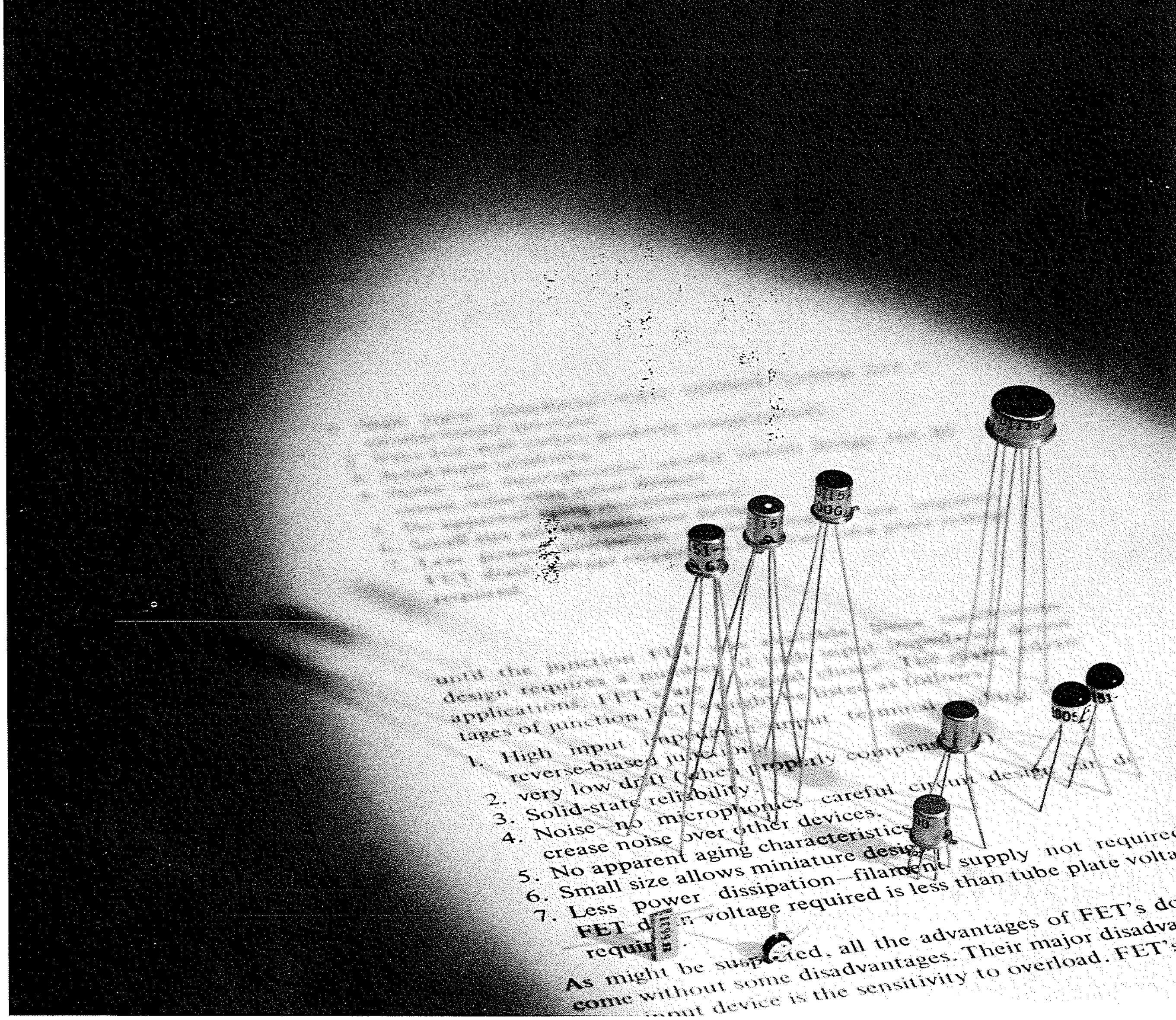
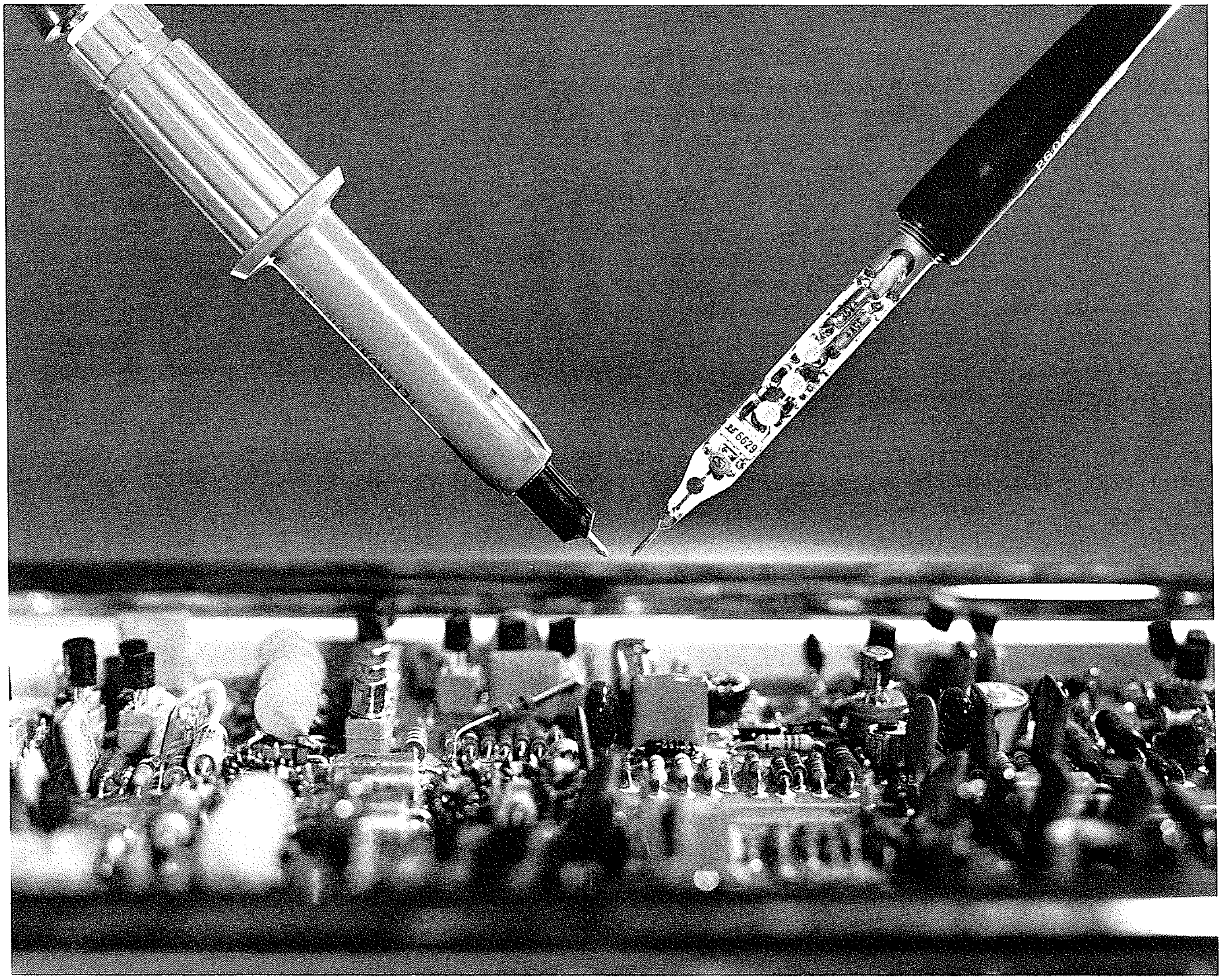


The FET takes its place



The P6045 X1 FET Probe is shown here with the P6006 X10 Probe. Note that the 1.5 ns P6045 with its active components and protective circuitry is smaller than the conventional passive probe.

COVER
Tektronix photographer Larry Jackson spotlights some of the FET's used in current Tektronix instruments.

The field-effect transistor is appearing in Tektronix instrument input stages with increasing frequency. Its high input impedance combined with the solid-state characteristics provide superior performance that has not previously been available. This article discusses some of the reasons for the widespread use of FET's in current Tektronix instruments.

Two years ago Tektronix introduced its first product using Field-Effect Transistors (FET's). Although Tektronix engineers had been evaluating and testing FET's since 1962, this was the first design that had proven completely feasible. The protective circuits required for an input design had been developed and refined in addition to the normal FET circuit operating considerations. The product was the Type 282 Probe Adapter which was designed to allow the use of conventional probes with Tektronix 50-Ω Sampling Instruments. A junction field-effect transistor was the logical choice for this useage since high input impedance was required and the probe power available at the sampling unit was limited. In addition, size was important as the 282 was designed to mount on the input connector.

Since that time, FET's have appeared in 26 other products at Tektronix. Many of these were designed with FET's initially; others that were designed before FET's were feasible have been converted to FET design.

What characteristics does the FET possess that cause it to be popular in instrument design at Tektronix? Its major use is as a solid-state high input impedance device. Tektronix circuitry has been predominantly solid state for some time now, but there has not been a suitable solid-state input device until the junction FET was available. Since oscilloscope design requires a number of high input impedance device applications, FET's are a logical choice. The major advantages of junction FET's might be listed as follows:

1. High input impedance—input terminal looking into a reverse-biased junction.
2. Very low drift (when properly compensated).
3. Solid-state reliability.
4. Noise—no microphonics—careful circuit design can decrease noise over other devices.
5. No apparent aging characteristics.
6. Small size allows miniature design.
7. Less power dissipation—filament supply not required. FET drain voltage required is less than tube plate voltage required.

As might be suspected, all the advantages of FET's do not come without some disadvantages. Their major disadvantage as an input device is the sensitivity to overload. FET's typically cannot withstand the abuse that vacuum tubes can handle. Because the FET has temperature-sensitive parameters, matching is used in critical applications. Tightly matched dual-FET's are now available from manufacturers to help solve this problem.

Once the design problems are solved (temperature compensation, bias tracking and protective circuitry to mention a few), performance may be obtained that is not available with any other device. FET's are especially useful in high-gain low-noise DC-coupled amplifiers with high common-mode considerations. The chart below compares some of the relative characteristics of tubes, junction FET's and insulated-gate FET's.

(continued on page 6)

Characteristics	Tube	Junction FET	Insulated Gate FET
Input Impedance	High	High	Very High
Noise	Low	Low	Unpredictable
Warm-up Time	Long	Short	Short
Size	Large	Small	Small
Power Consumption	Large	Small	Small
Aging	Noticeable	Not Noticeable	Noticeable
Bias Voltage Temp Coefficient	Low, Not Predictable	Low, Predictable	High, Not Predictable
Typical Gate/Grid Current	≈1 nA	≈.1 nA	≈10 pA
Gate/Grid Current Change With Temp	High, Unpredictable	Medium, Predictable	Low, Unpredictable
Reliability	Low	High	High
Sensitivity to Overload	Very Good	Good	Poor

FET Review

The FET may be referred to as a unipolar device compared to the "common" bipolar transistor. FET's use only one carrier type, majority carriers, while bipolar transistor operation requires both minority and majority carriers.

Fig 1 shows the basic lead configuration of the junction FET and illustrates the basic polarities for an n-channel device. The arrow points in the direction of conventional current flow across the p-n junction and normal voltage bias for the junction is always a reverse bias. Fig 2 compares the similar elements of vacuum tubes, transistors and FET's.

The field-effect transistor is a single junction device made-up with a source-to-drain material (the majority-carrier path) doped in either the "n" or the opposite direction. By applying voltage so as to oppose the majority carriers in the channel, the device is back biased. A negative voltage applied to the gate opposes electron flow in n-channel material and a positive voltage opposes hole flow in p-channel material. Under these conditions, the n-channel or p-channel material becomes a constrictive layer of dielectric material past which majority carriers must flow and can thus be controlled. Fig 3 indicates the polarities required for normal operation of both n-channel and p-channel FET's.

The junction FET is a "depletion" type device. Drain-to-source conduction is controlled by "depleting" the channel with reverse junction bias. Forward gate bias results in p-n junction forward current, and is not the desired mode of operation for the device. Fig 4 illustrates the effect on drain-to-source conduction as back bias is varied.

If the gate remains reverse biased, very little gate current flows so the control power is very small. The drain-source path may conduct current heavily however. The result is a basic device which is capable of very large current gain, substantial voltage gain, and thus a very large power gain.

Fig 5 illustrates the drain characteristics of a typical n-channel FET. To obtain these, the grounded emitter (source) mode of a Type 575 is used with NPN polarity. The base step generator is used in —POLARITY and a 1 kΩ, 1% resistor is connected between the base-and-emitter connections in order to convert base current in mA to gate voltage in volts. (See page 14)

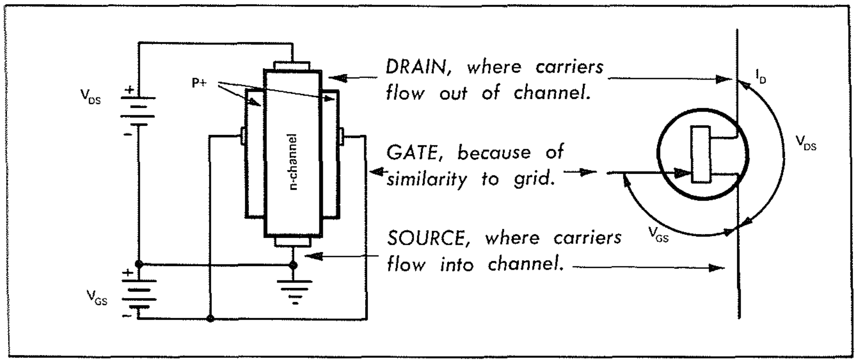


Fig 1 N-channel device and definitions.

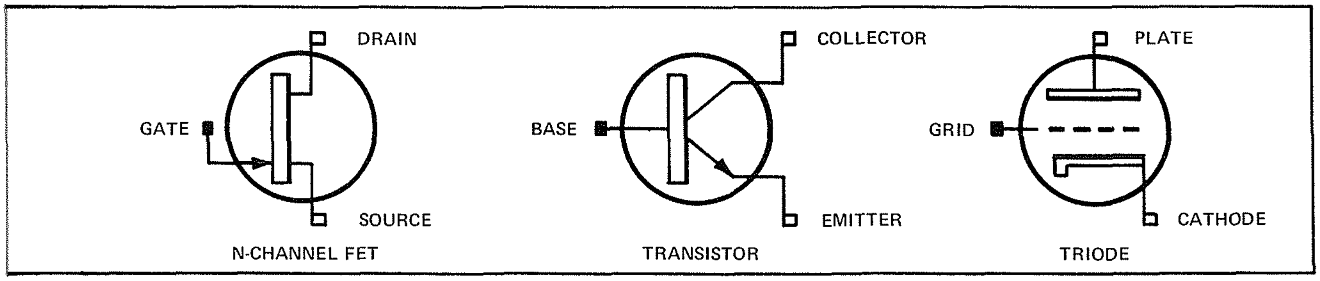


Fig 2 Comparison of basic lead terminology of FET's, transistors, and vacuum tubes.

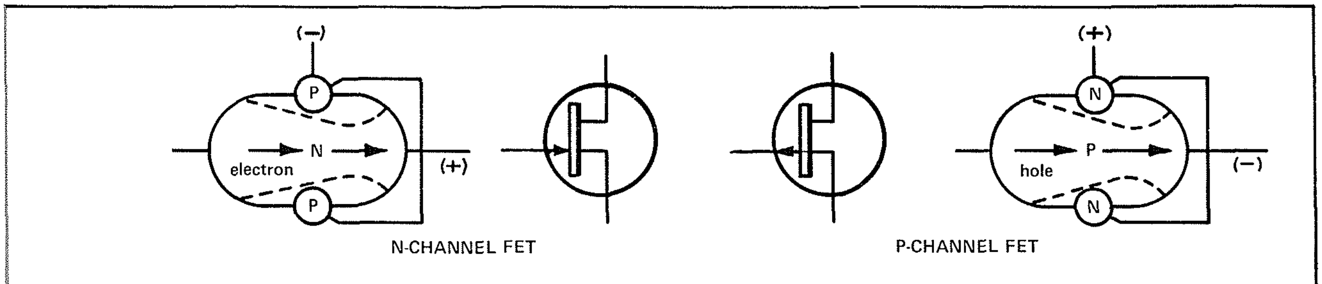


Fig 3 Comparison of an n-channel FET and a p-channel FET.

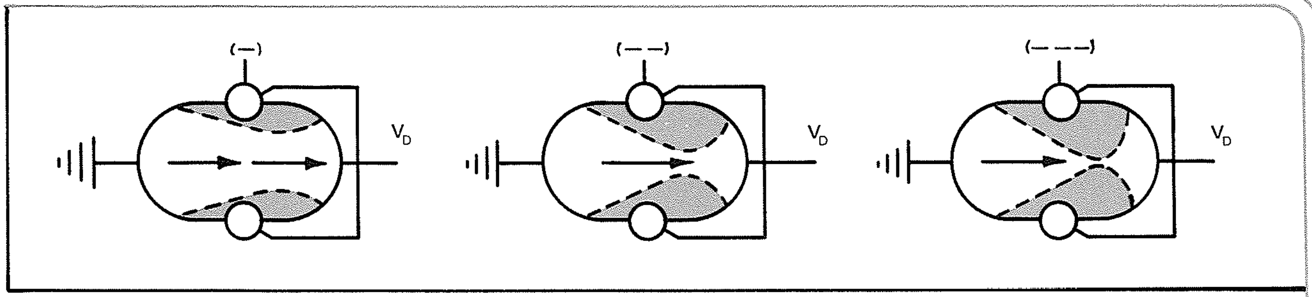


Fig 4 Back bias controlling current flow in an n-channel FET.

The result is a plot of drain current vs drain-to-source voltage for various gate voltages.

Note that the zero-biased curve is the highest current and succeeding curves result in turning the device off. The zero-biased characteristic in the A to B region can be understood by considering the conduction channel as the drain voltage is increased (see fig 5). For point A, where there is no bias on the device, there are only narrow depletion regions caused by the "contact" or "barrier" potential of the p-n junction.

The slope of the I vs V curve at point A is simply the conductance of the bulk n channel. As the drain-voltage increases, the gate-to-channel junction becomes increasingly reverse-biased at the drain end of the channel and the depletion region extends into the channel at this end. The depletion region is void of free carriers and is a space-charge region consisting of positive, immobile, impurity ions. Because the conduction channel becomes narrower as drain voltage is increased, the incremental conductance decreases until at point B the depletion regions nearly meet. At this point the gate-drain channel is said to be "pinched off" and further increase of drain voltage results in little additional drain current.

FET's are usually used in the regions to the right of B (fig 1) in the "drain pinch off" or "drain current saturation" region. Here the output resistance is very high since the current remains almost constant for large changes in V_{DS}. Note that in this region of its characteristic curve, the FET has an effective Rp approaching infinity.

The area to the left (where an increase in V results in an increase in I—close to the graph axis) is termed the "ohmic region." In this region the output resistance is relatively low but is controlled by the gate voltage.

The IGFET's (insulated-gate), sometimes called MOSFET's (metal-oxide-insulated), separate the gate and channel with a layer of intrinsic material. As temperature increases on this device, the channel apparently increases also as it starts to include some of the insulating layer into the main channel. The IGFET reacts more to changes in temperature than the regular FET's even though they do away with leakage currents in the gate circuit. Fig 6 indicates the symbol used by Tektronix for an n-channel device.

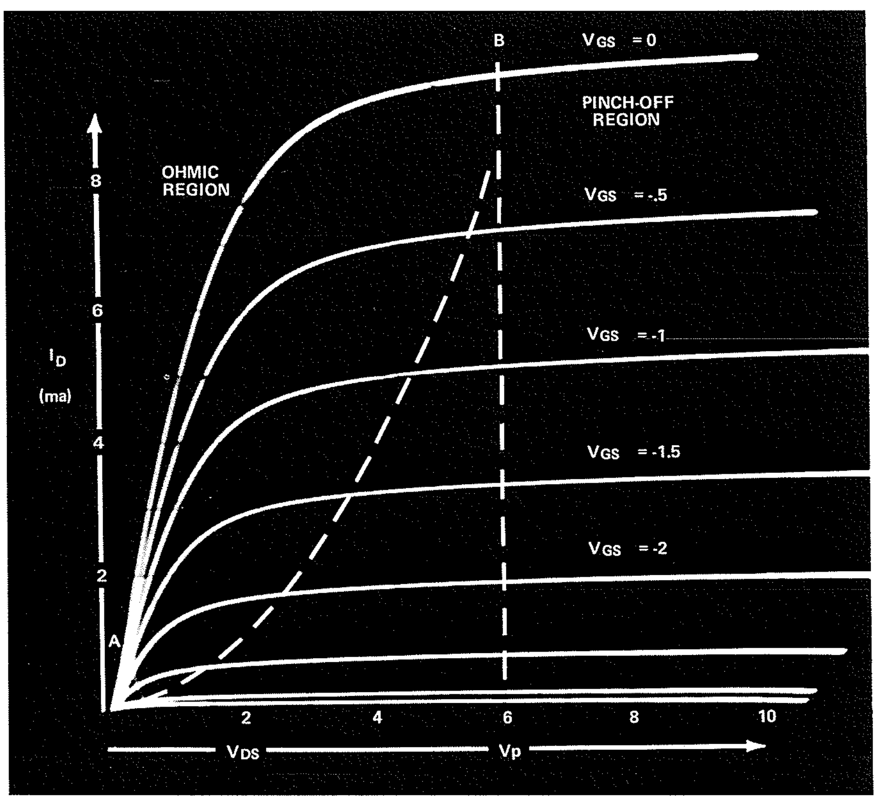


Fig 5 Drain characteristics of FET.

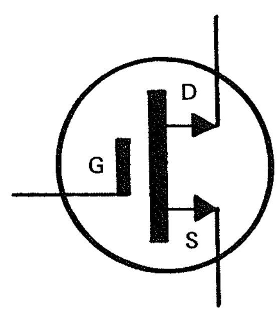


Fig 6 Tektronix symbol for n-channel IGFET.

In the case of the P6045 FET Probe which was introduced at WESCON '66, the FET was a necessity. The field-effect transistor, along with its protection circuitry, was designed into a package that was compatible with Tektronix miniature probes. This miniature probe, shown on the inside of the front cover, had size, power and input Z requirements that only a FET could meet.

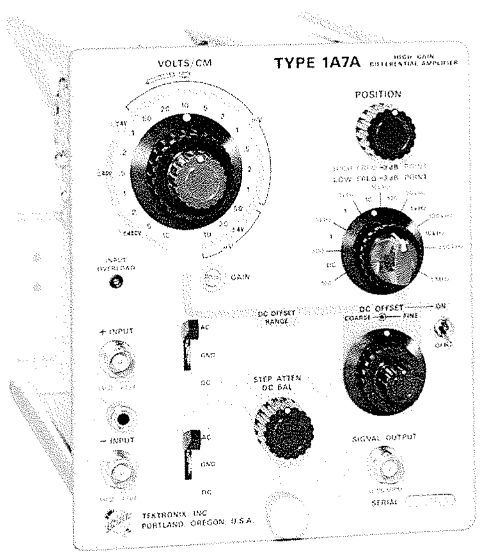
Tektronix sampling and digital circuitry makes extensive use of field-effect transistors. Memory slash (memory vertical drift when sampling gate is closed) used to be a limitation with low repetition rate signals. Because of the low leakage characteristics of FET's this is no longer a problem. The use of FET's in sampling preamplifier circuits provides better noise performance. Since FET's have become practical, the sampling preamplifier is no longer a significant source of noise.

In the case of the Type 611 Storage Display Unit, the FET was used for yet another reason. The Type 611 uses the FET as a square-law device. The dynamic correction circuitry necessary for the high resolution this instrument provides, requires an I^2 output from an E input. The FET is a square-law device that provides this characteristic in a single stage. The alternative was two transistor stages with the additional circuit complexity and cost.

FET's are used in the Type 410 Physiological Monitor for a number of reasons. One design consideration of the Type 410 concerned its rechargeable power pack. Field-effect transistors allowed the input circuit to operate effectively at 17 volts (10 standard 1.7-volt rechargeable cells). A vacuum-tube input in this circuit would have required a minimum of 25 volts, thus increasing the expense and weight of the power supply. At the same time the FET's contributed to a better common-mode design and assisted in a unique patient protection circuit.

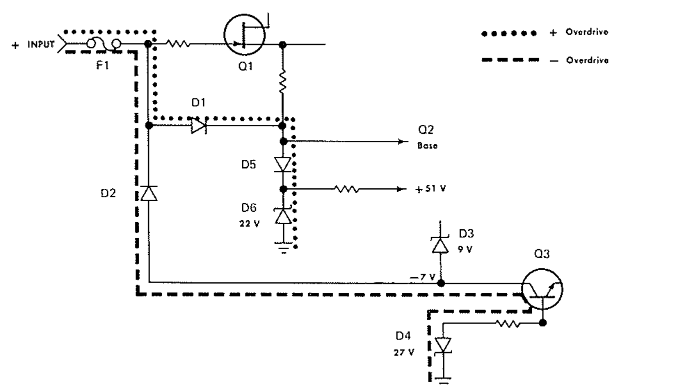
In the case of the Type 453, FET's improved overall circuit operation. Vertical drift was much reduced, reliability increased (elimination of microphonics, aging and shock), and the power requirement reduced by removing the vacuum-tube front end. Since the Type 453 is widely used in field service the reduced warm-up time is also desirable.

The use of FET's in plug-in vertical preamplifiers can increase overall performance and reliability. Performance of the Type 1A7A shown below represents a significant improvement from previous high-gain differential DC-coupled amplifiers. Maximum short-term drift is specified at 5 μV/minute and tangential noise is 15 μV at 10 μV/cm sensitivity and 1-MHz bandpass. FET design also allowed the elimination of a highly regulated 6.3-V filament supply that further simplified design and increased reliability. The input circuit of the 1A7A is fused against accidental severe overload as the simplified diagram below shows.



Above
Type 1A7A High-Gain Differential Unit

Right
Simplified Protection circuit for Type 1A7A.



Assume a steadily increasing positive voltage at the input. The floating power supply voltages continue to rise with the input. When the gate voltage of Q1 approaches approximately 23V, D1 turns on and clamps the gate, drawing current through F1. When the current through F1 exceeds 1/16A the fuse opens, removing the overdrive from the circuit.

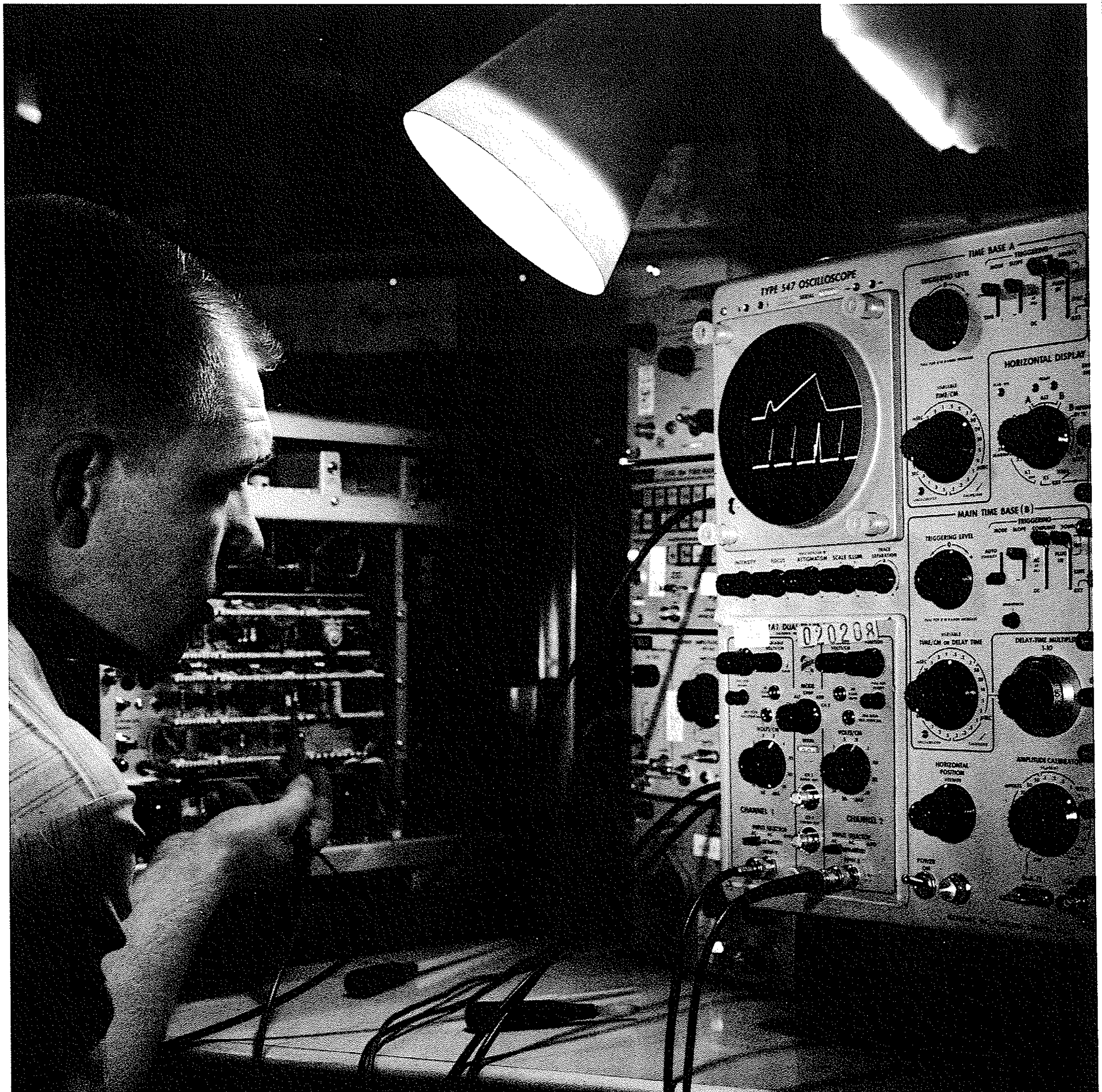
With a negative voltage whose magnitude is steadily increasing at the input, D2 turns on when the signal approaches approximately–7.6V and draws current through the –7V supply. The –7V supply becomes more negative (follows the input), causing the remaining supply voltages to go in the negative direction and Q2 cuts off. When the overdrive voltage becomes approximately–27V, the collector to base junction of Q3 becomes forward biased and conducts the overdrive current through D3. F1 opens when the current exceeds 1/16A.

GROUP	TYPE	CHARACTERISTICS	High Z In	Low Power Consumption	Small Size	Low Drift	Noise Characteristics	Short Warm-Up Time	Solid-State Reliability
			MAJOR FET CONTRIBUTION						
PROBES	282	50 Ω to 1 MΩ PROBE ADAPTER	●	●	●	●			●
	P6045	DC-230 MHz FET PROBE	●	●	●	●			●
	P6046	DC-100 MHz FET DIFFERENTIAL PROBE	●	●	●	●			●
GENERAL PURPOSE PLUG-IN UNITS	1A1	DC-50 MHz DUAL TRACE	●			●			●
	1A4	DC-50 MHz FOUR TRACE	●			●			●
	1A5	DC-50 MHz DIFFERENTIAL COMPARATOR	●			●			●
	1A7A	10 μV/cm DIFFERENTIAL	●			●			●
	3A3	100 μV/div DUAL DIFFERENTIAL	●			●			●
	81A	PLUG-IN ADAPTER	●						●
SPECTRUM ANALYZER PLUG-IN UNITS	1L5	50 Hz-1 MHz SPECTRUM ANALYZER	●				●		●
	3L5	50 Hz-1 MHz SPECTRUM ANALYZER	●				●		●
SAMPLING AND DIGITAL READOUT INSTRUMENTS	1S2	90-ps TDR	●		●	●	●		●
	3S1	DUAL-TRACE SAMPLING	●		●	●	●		●
	3S2	DUAL-TRACE SAMPLING	●		●	●	●		●
	S1	350-ps SAMPLING HEAD	●		●		●		●
	S2	50-ps SAMPLING HEAD	●		●		●		●
	3S3	DUAL-TRACE SAMPLING PROBE	●		●	●	●		●
	3T2	RANDOM SAMPLING SWEEP	●		●	●	●		●
	230	DIGITAL READOUT	●						●
	568	READOUT OSCILLOSCOPE	●						●
PORTABLE INSTRUMENTS	323	DC-4 MHz	●	●	●	●		●	●
	453	DUAL-TRACE 50 MHz-SWEEP DELAY	●	●	●	●		●	●
MONITORS	410	PHYSIOLOGICAL MONITOR	●	●	●			●	●
TV INSTRUMENTS	520	VECTORSCOPE	●		●	●			●
DISPLAY UNITS	601	STORAGE DISPLAY UNIT	●						●
	602	DISPLAY UNIT	●						●
	611	STORAGE DISPLAY UNIT	●						●

All of the preceeding designs discussed in this article have used junction FET's. Although the junction FET is the device best-suited for most oscilloscope designs, Insulated-Gate Field-Effect Transistors (IGFET's) are used in one Tektronix instrument.

The memory performance of Tektronix digital readout instruments has been improved with the use of an insulated-gate FET in the memory circuits. The extremely low leakage of these devices has contributed substantially to the improved performance and more accurate readout of the Type 230. The chart above shows those Tektronix instruments that incorporate FET's.

The Field-Effect Transistor is a welcome addition for the design engineer. Its high input impedance characteristic in addition to its solid-state properties of low power dissipation, small size, reliability, noise characteristics, etc. allow performance improvements in many circuits. The FET is replacing input vacuum tubes in much the same manner that bipolar transistors replaced vacuum tubes. Further evolution of the FET will surely result in even more FET circuits in oscilloscope applications.



UNDERSTANDING DELAYING SWEEP

Roger Loop, Tektronix technician, monitors a delaying-sweep display on a Type 547.

The accuracy of time measurements taken from an oscilloscope is primarily limited to the accuracy of the oscilloscope time base. Although measurements may be made directly from the graticule of the CRT more accuracy is possible using delaying sweep. This article discusses time interval measurements using the precision delayed sweep.

Introduction

Delaying-sweep measurements are based on the use of 2 linear calibrated sweeps. The first sweep, commonly called the delaying sweep, allows the operator to select a specific delay time. When this time is reached, the delayed sweep starts. The delayed sweep typically is a decade or two faster than the delaying sweep and offers additional resolution. The combinations of these two sweeps offers extra resolution and increases accuracy of time-interval measurement.

To understand delaying sweep operation, it is necessary to understand the time relationship between the delaying sweep and the delayed sweep. To illustrate, an event occurs that starts the delaying sweep at t_0. The delaying-sweep voltage ramp is applied to a voltage comparator that produces a trigger pulse at a later point in time, t_1. This trigger pulse occurring at t_1 starts the delayed sweep. Delay time, then, may be defined as the difference in time between the start of the delaying sweep and the start of the delayed sweep and can be expressed as $t_1 - t_0$.

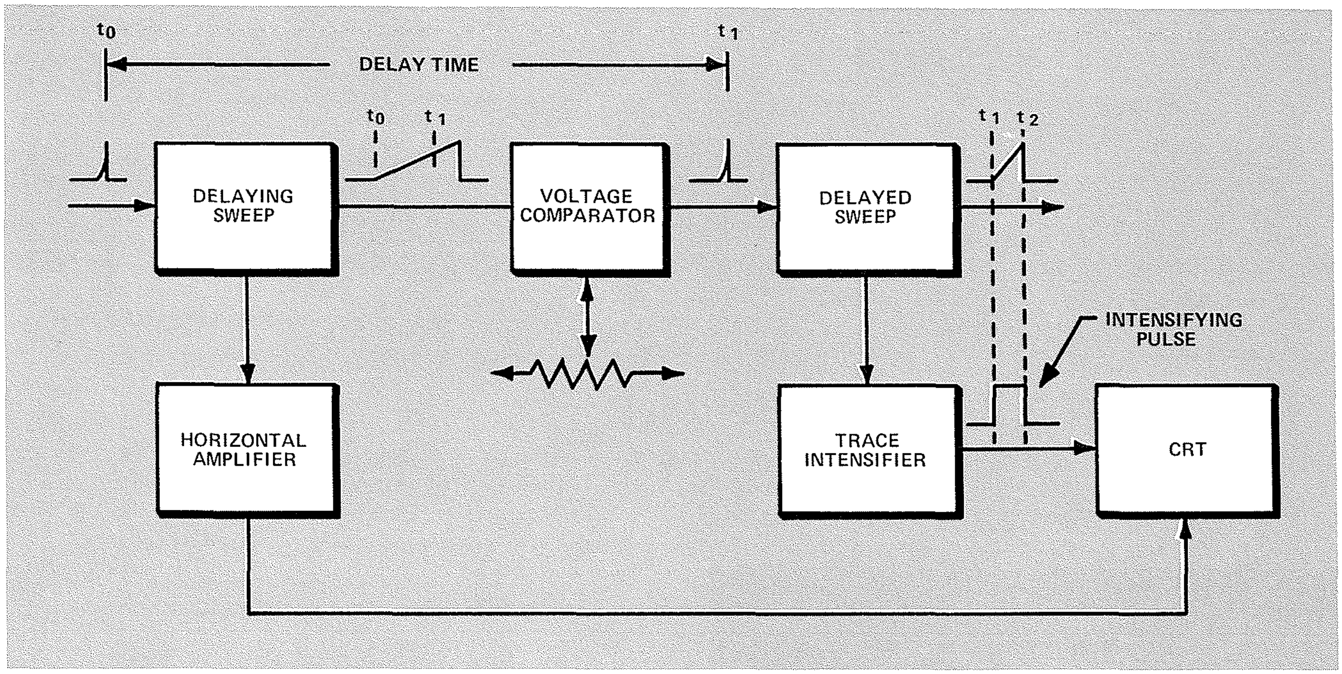


Fig 1 Block diagram of delaying sweep oscilloscope.

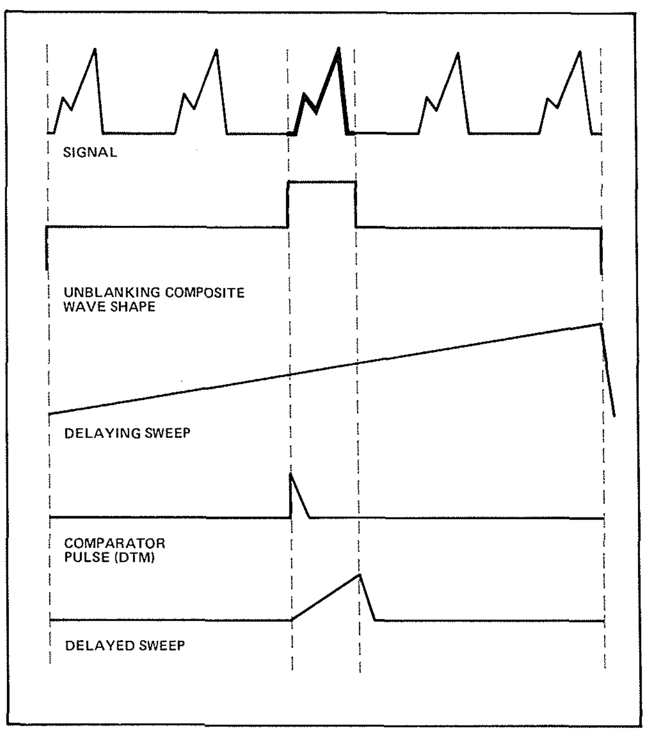


Fig 2 Delaying sweep oscilloscope circuit relationships.

The accuracy of delay time is basically determined by the delaying sweep and the potentiometer which sets the threshold level of the comparator. The horizontal amplifier and CRT **do not** affect the accuracy of delay time. An intensifying pulse indicates where the delayed sweep starts with respect to the delaying sweep, and so delay time can be determined independently of horizontal amplifier and CRT considerations. The portion of the delaying sweep that is intensified is a direct function of the duration of the delayed sweep as shown in fig 2.

Oscilloscope time-interval measurements usually involve finding the period of time between two events. By adjusting the delay-time multiplier (DTM), which controls a potentiometer in the comparator circuitry, the delay time from the start of the delaying sweep to both events is determined. The time between these events is the difference between their corresponding delay times.

The resolution of these delay times can be improved, thus improving the time-interval measurement accuracy, by driving the horizontal amplifier with the delayed sweep. The

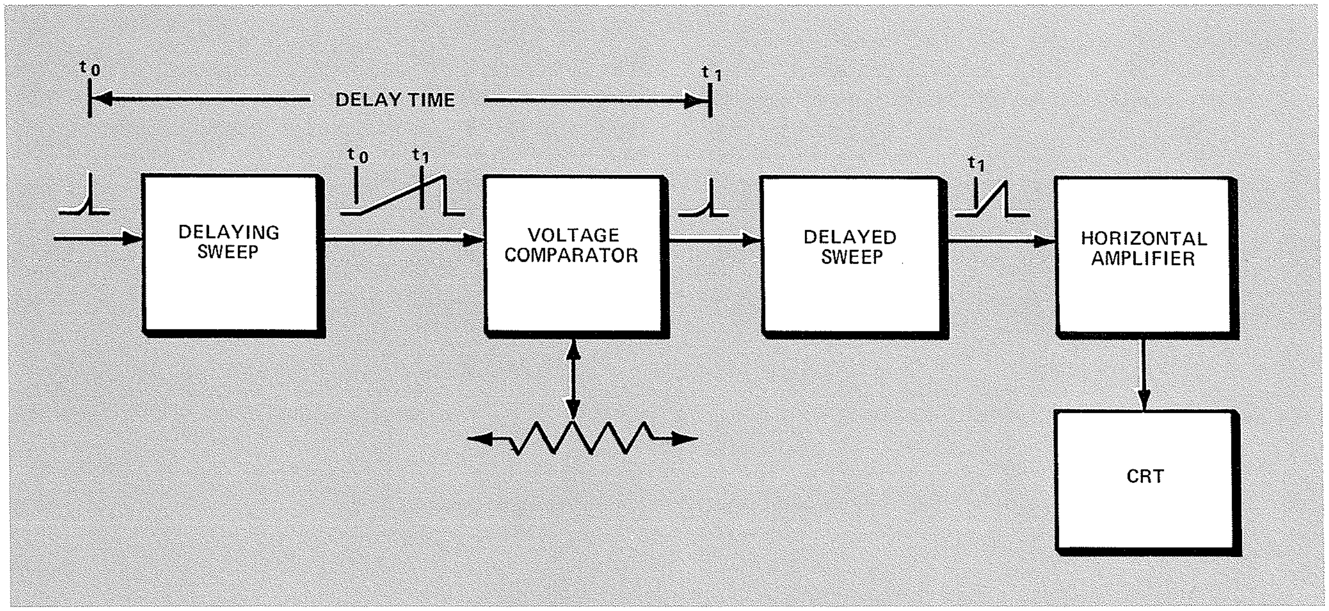


Fig 3 Delayed sweep mode.

intensified portion of the delaying-sweep presentation is now displayed over the full CRT display. In the case of fig 2, this appears as a 10X magnified display since 1/10 of the original waveshape time is now displayed over the same graticule area. A delaying-sweep oscilloscope, then, acts as a magnifier whose magnification power is the ratio of the delaying-sweep rate to the delayed-sweep rate.

$$\text{Magnification} = \frac{\text{delaying sweep rate}}{\text{delayed sweep rate}} = \frac{1\ \text{ms/cm}}{1\ \mu\text{s/cm}} = \frac{10^{-3}}{10^{-6}} = 1000{:}1$$

Fig 4 illustrates the use of delaying sweep to magnify a signal 1000X to allow closer examination of leading edge detail. Oscilloscopes such as the Tektronix Type 547 can provide a dual display of these two sweep rates. This is accomplished by using an internal multivibrator to switch between sweep rates and is referred to as automatic display switching.

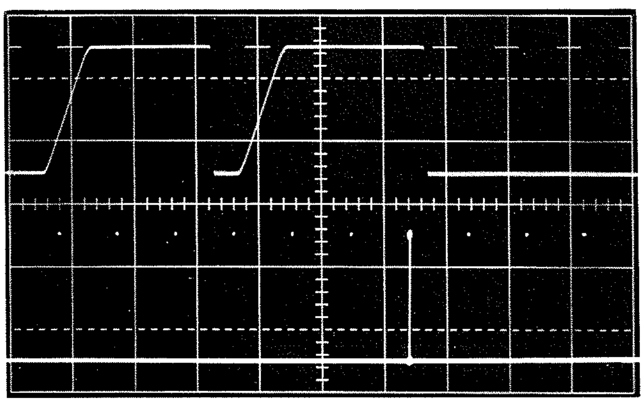


Fig 4 Display magnified 1000X resolves two pulses from apparent single pulse.

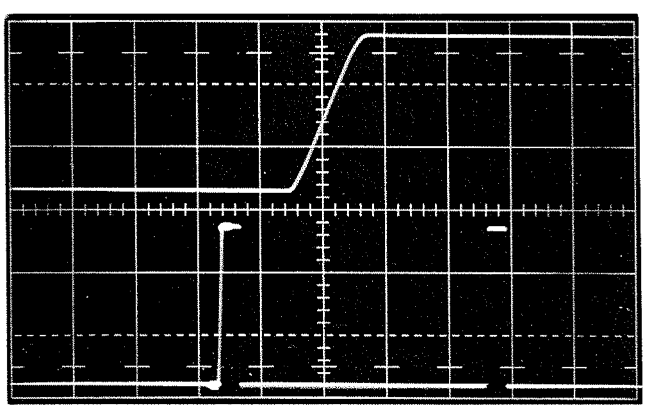


Fig 5 Determining delay time—pulse 1.

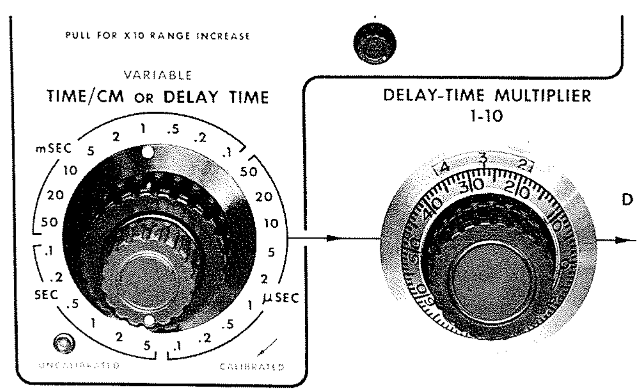


Fig 6 Delay time reading. 1 ms x 3.27 = 3.27 ms.

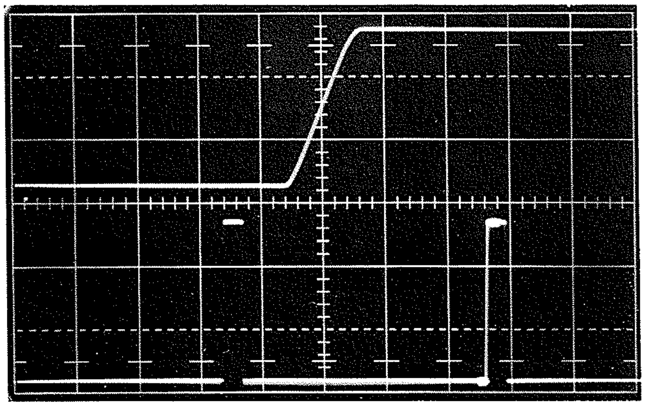


Fig 7 Determining delay time—pulse 2.

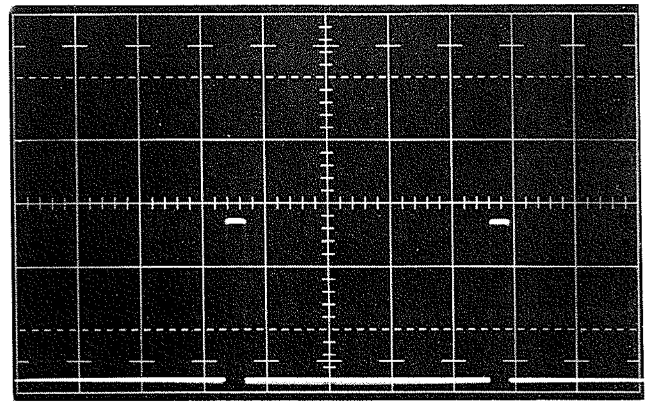


Fig 8 Determining time between events by graticule measurement.

Time-Interval Measurements

The example in fig 5 illustrates a typical time-interval measurement. Note the intensified portion of the lower waveform which is displayed in magnified form above it. The delay time associated with this event is determined by multiplying the delay time of 1 ms by the DTM reading of 3.27, as shown in fig 6. By turning the DTM until the next event is intensified and the upper waveform is in the same relative graticule position as before, a display like fig 7 is seen. If the delay time of this event is 7.47 ms, then the time interval may be computed.

It is not necessary to determine the actual delay time of the start of the event as indicated by the start of the intensified portion of the lower waveform. However, in both cases the DTM is adjusted until the magnified portion of both events is in the same relative graticule position. In the examples shown, the center (or 5-cm point) of the graticule is used. Any point on the graticule may be used as long as it is the same point for both events.

The difference between these two delay times is 4.20 ms and corresponds to the period of time between the two intensified events. Each minor division on the DTM represents 0.01 ms, which also represents the resolution of the delay time. Measuring with the graticule, the resolution is approximately 0.1 ms or reduced by a factor of ten. Fig 8 shows the same two events with a sweep rate of 1 ms/cm.

In fig 8, each minor horizontal graticule division corresponds to 0.2 ms. The time between the two events as read from the graticule is 4.2 ms. Making a graticule measurement, only one number past the decimal is significant because of the limitations in resolution due to trace width and display size. Thus the delaying-sweep method offers the additional resolution of an extra significant number.

Percentage of Error

In addition to improving resolution, the delaying-sweep method reduces percentage of error. The graticule method depends upon the oscilloscope's ability to line-up precision

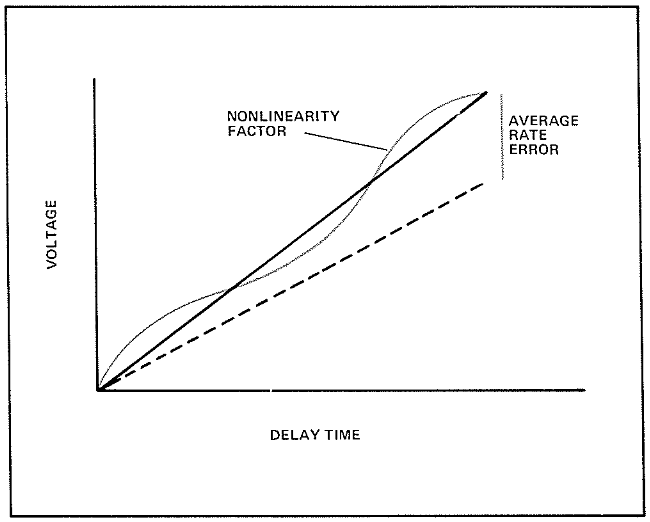


Fig 9 Basic error sources.

time-markers with major graticule divisions, and is subject to errors contributed by nonlinearity in the horizontal amplifier and CRT. The delaying-sweep method uses the CRT as a nulling device that does not affect the measurement accuracy.

The accuracy of the graticule method is determined by the accuracy of the sweep as observed on the graticule. With an accuracy of ±3%, the 4.2 ms in the previous example has a maximum possible error of ±0.126 ms. This type of error is easy to calculate because the ±3% specification normally includes both a timing or rate error and a nonlinearity factor. The delaying-sweep method also has these same basic factors which contribute to possible errors, although they are more complex in nature. Since the voltage ramp of the delaying sweep is the basic time base used in the delaying-sweep method, the basic sources of error in time-interval measurements can be illustrated as shown in fig 9.

The dotted line represents a no-error condition, while the linear solid line represents the average rate error due to differences of the timing networks in the delaying sweep.

The nonlinearity factor varies about the solid line and represents the actual delay time read on the DTM. This nonlinearity factor is a combination of both sweep and potentiometer nonlinearity, and is usually expressed in terms of dial divisions on the DTM. Delaying-sweep percentage error is then calculated by using this figure and the percentage figure for rate error.

Percentages of rate error are typically expressed in terms of actual delay time and are usually better than the sweep-rate accuracy as read on the CRT, because they do not depend on the horizontal amplifier and CRT. Delay-time accuracy is typically within ±1%. Also, because the average rate error lies totally on one side or the other of the no-error dotted line, the difference between any two delay times is accurate within ±1%, plus or minus the nonlinearity factor in dial divisions.

Another factor normally of lesser importance in making time-interval measurements is that of fixed delay. Fixed delay is a result of inherent circuit delays because the comparator requires time to generate a trigger pulse, and the delayed sweep and trace intensifier require time to generate an intensifying pulse. At faster sweep rates, this fixed delay is an appreciable percentage of the delay time. At these faster sweep rates, the delay time can be expressed as accurate within ±1% plus some fixed delay such as 100 ns. Because the fixed delay is included in both delay times it does not affect the accuracy of a time-interval measurement. Fig 10 represents fixed delay as a displacement of the error curve.

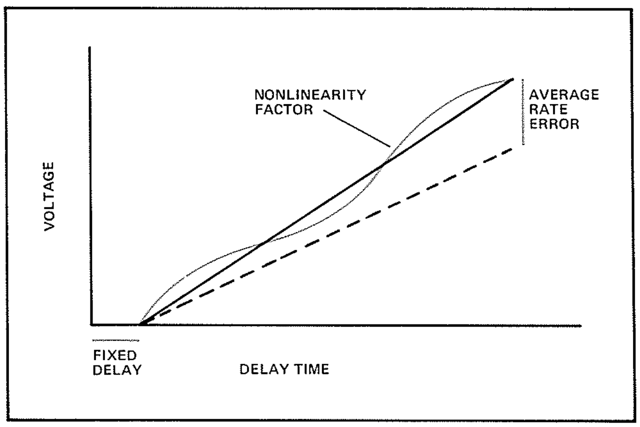


Fig 10 Basic error sources—fixed delay.

To calculate the error on the previous delaying-sweep method of time-interval measurement, a nonlinearity factor of ±2 dial divisions is assumed. Because the delaying-sweep rate is 1 ms/cm, the 100 minor dial divisions on the delay-time multiplier dial corresponds to 1 ms of time. Therefore, ±2 minor dial divisions is equal to ±0.02 ms.

If the delaying sweep rate is not changed, this nonlinearity factor remains ±0.02 ms regardless of the time increment measured. The total percentage of error is now ±1% of 4.20 ms ±0.02 ms or ±0.062 ms. Note that this error is about half as large as that using the graticule method (0.1 ms).

When using the delaying-sweep method, it is best to use the delaying sweep at the fastest possible sweep rate. The above ±2 dial divisions of nonlinearity factor then represents the smallest possible error. If the delaying sweep rate is 0.5 ms/cm, then ±2 minor dial division is equal to ±0.01 ms. This nonlinearity factor is only half as large as the previous one of ±0.02 ms.

When measuring short time intervals, it is not always possible to use the delaying sweep at a fast enough rate and still maintain a proper delaying sweep to delayed sweep ratio for the desired magnification. When this occurs, the graticule method may prove more accurate. For this reason, after using the delaying-sweep method, simply multiply the measured time interval by the delaying-sweep rate accuracy (as in the graticule method) and use the most accurate figure. In most cases, the delaying-sweep method will be the more accurate way of making time-interval measurements.

Improving Accuracy

Accuracy can be further improved by using a time-mark generator such as the Tektronix Type 184 to calibrate the DTM. By selecting time-marks so that accurate time-marks can be intensified and magnified for each ten major dial divisions, a calibration chart can be constructed for any delaying sweep rate that is needed. A calibration chart for a sweep rate of 1 ms/cm might look as follows:

TIME MARKS	DTM READING	ERROR
1.0 ms	1.000	.000
1.1 ms	1.100	.000
1.2 ms	1.200	.000
.	.	.
.	.	.
3.2 ms	3.205	+.005
3.3 ms	3.305	
.	.	.
.	.	.
7.4 ms	7.395	—.005
7.5 ms	7.495	
.	.	.
.	.	.
8.8 ms	8.800	.000
8.9 ms	8.900	.000
9.0 ms	9.000	.000

Fig 11 Calibration chart for optimizing accuracy.

Since 0.1 ms represents only 1/100 of the total sweep, the actual error of the delay-time multiplier dial reading of 3.27 ms can be considered +½ dial division high or +0.005

ms because both 3.20 ms and 3.30 ms contain this same error. For the same reason, the 7.47 ms reading can be considered low by the same amount or —0.005 ms. Therefore, a more accurate interval of time elapsed between the two previous events is time = (7.47 ms + 0.005 ms) — (3.27 ms — 0.005 ms) = 7.475 ms — 3.265 ms = 4.210 ms.

The accuracy of this final time interval is limited only by the accuracy of the time-markers and the nonlinearity that occurred in 10 dial divisions of the delay-time multiplier dial. This accuracy can be held to ±0.1% quite easily.

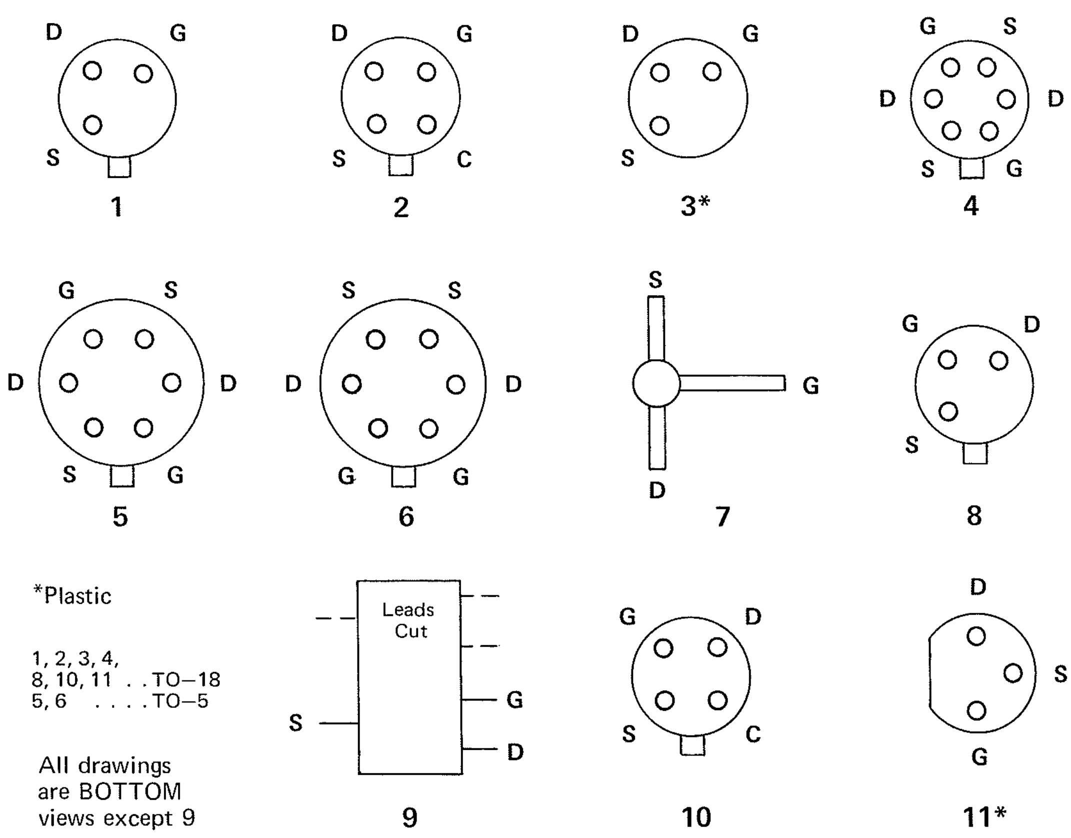
Summary

The delaying-sweep method of time-interval measurements offer additional resolution and accuracy for most measurements. Understanding the limitations of delaying sweep, as well as the advantages, allows the user to determine if this capability is required.

Service Notes

FET BASING DIAGRAM

Some confusion exists as to the different FET basing arrangements. The information below shows the basing for all of the FET's currently being used in Tektronix instruments.



Tektronix PN	Basing No	Tektronix PN	Basing No	Tektronix PN	Basing No	Tektronix PN	Basing No
151-1001-00	9	151-1007-00	4	151-1013-00	4	151-1022-00	1
151-1002-00	8	151-1008-00	6	151-1015-00	2	151-1024-00	10
151-1003-00	4	151-1009-00	4	151-1017-00	7	151-1025-00	11
151-1004-00	3	151-1010-00	4	151-1018-00	10	151-1026-00	3
151-1005-00	3	151-1011-00	4	151-1019-00	4		
151-1006-00	3	151-1012-00	2	151-1020-00	4		

Measuring FET's with a Type 575

FET's are becoming common in current Tektronix instruments and the need arises for a method of checking them. The following method will quickly determine whether a suspected FET is faulty.

The Type 575 can easily be used to show the typical operating curves of field-effect transistors FET's by connecting a 1 kΩ, 1 W, 1% resistor from the base to the emitter binding post on the Type 575. This converts the mA/step of the base step generator to V/step, providing the voltage swing required for the gate. The 575's constant current source is now a constant voltage source which is developed across the 1 kΩ resistor. See fig 1.

When testing an FET, the drain lead goes to the collector connection; the gate lead to the base connection; and the source lead to the emitter connection.

For testing n-channel FET's set the controls as shown:

Collector Sweep

POLARITY	+(NPN)
PEAK VOLTS RANGE	200
PEAK VOLTS	0 (to start)
DISSIPATION LIMITING RESISTOR	1-2 kΩ (to start)

Base Step

STEPS/FAMILY	12
POLARITY	−(PNP)
mA/STEP	.2 (+.2 V/step)

Display Calibration

VERTICAL	.5 mA/div
HORIZONTAL	2 V/div

CAUTION: Adjust the STEP 0 carefully before testing the FET. N-channel field-effect transistors may be destroyed by application of over ½ volt of positive bias. A set of FET curves, resembling those of a pentode, will appear as the collector voltage approaches the FET ratings. If there is any doubt concerning the FET, compare it with a known good device or consult a specification sheet. Note that the zero bias curve is the top curve in fig 2.

If you wish to look at the breakdown characteristics, it is only necessary to change the horizontal calibration and increase PEAK VOLTS until breakdown occurs. See fig 3.

For testing p-channel FET's, set the collector sweep POLARITY to −(PNP)and the base step POLARITY to plus. An easy method of remembering this testing procedure is to correlate an n-channel FET with a PNP transistor test, as far as the collector to emitter and drain to source voltage polarity are concerned. However, when testing field-effect transistors, the base step polarity must always be opposite the collector polarity.

A drain current vs gate source voltage curve may be easily obtained by changing the horizontal display to .5 base volts and repositioning the display. See fig 4.

The Type 575 base step amplifier has the ability to supply gate voltage to 12 volts maximum. This is sufficient to observe the majority of FET's as used in Tektronix instruments. A complete redesign of the base step amplifier and power supply is required to accommodate a greater voltage swing.

If the positive gate bias characteristics are desired, this can be done to a limited extent if adequate protection is employed to assure that the gate drain and source currents do not exceed the maximum rating of the device under test.

CAUTION: Gate input voltages in excess of +.6 V typically run the FET beyond its current rating.

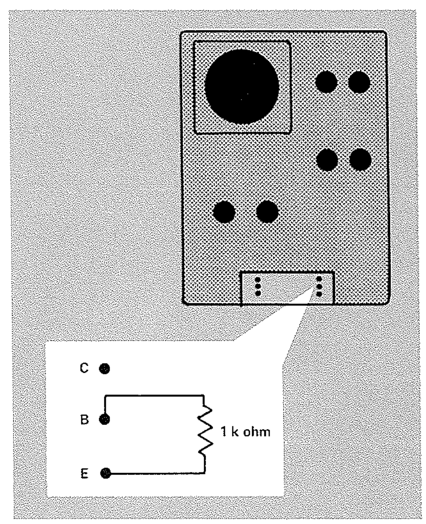


Fig 1 Type 575 modified for FET testing.

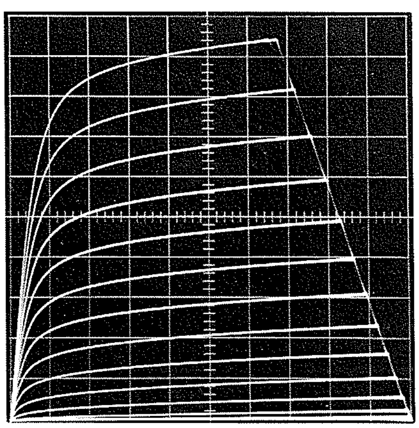


Fig 2 Drain family of characteristics V_{DS} vs I_D.

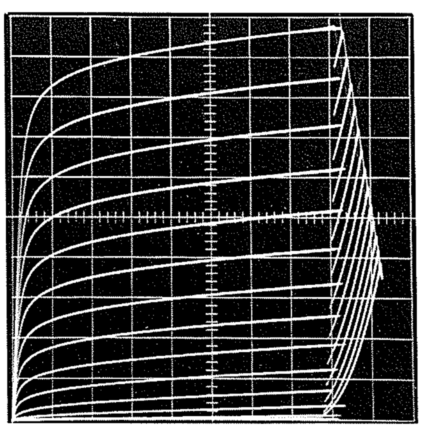


Fig 3 Drain family of characteristics showing avalanche V_{DS} = 10 V/div: I_D = .5 mA/div.

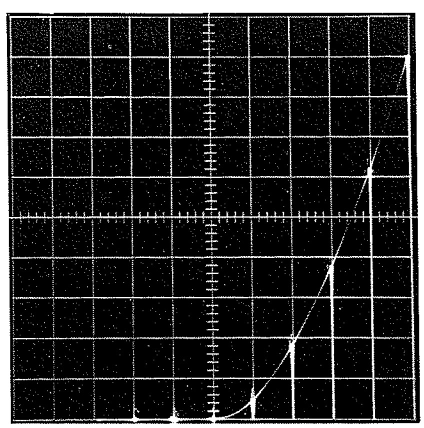


Fig 4 Drain current vs gate source voltage V_{GS} = .5 V/div: I_D = .5 mA/div.

USED INSTRUMENTS FOR SALE

1—Type 564 Storage Oscilloscope, SN 4897; 1—Type 201-1 Scope-Mobile® Cart; 1—Type 2A60 Single Trace 1-MHz Plug-In; 1—Type 2A61 Low Level Differential Plug-In; 1—Type 2B67 Time Base. Condition like new. Used very little. Price: $1,495.00. Contact: J. M. Edelman, M.D., 4550 North Boulevard, Baton Rouge, Louisiana 70806. Telephone: (504) 924-6266.

2—Type 3A72, SN 3116 and 2791. Contact: Dr. Zia Penefsky, New York Medical College, Fifth Avenue at 106th Street, New York, New York 10029. Telephone: (212) 876-5500 Ext. 539.

1—Type 511AD-121 Amp—Scopecart. Total price $225.00. Contact: Fred Chambers, 11 Locuswood Blvd., Elmont, New York. Telephone: (212) 775-6938.

1—Type 661 Sampling Oscilloscope with Type 5T3 Sampling Timing Unit and Type 4S2 Dual-Trace Sampling Unit. Price: $2,500.00. Contact: Grant Wales, G. T. Schjeldahl Company, Northfield, Minnesota. Telephone: (507) 645-5633.

1—Type 526, SN 1860. Used only 6 months. Contact: N. Friedman, Professional Closed Circuit TV, 342 Madison Avenue, New York 17, New York. Telephone: (212) 687-4422.

1—Type 517A. Excellent condition. Contact: Ed Knight, Industrial Communications, 8300 Fenkell, Detroit, Michigan 48238.

1—Type N Sampling Plug-In Unit. Like new. Price: $325. Contact: Dick Landis, Landis Associates, 5222 Venice Boulevard, Los Angeles, California. Telephone: (213) 933-8187.

1—Type 567, SN 2821; 1—Type 6R1A, SN 2191; 1—Type 3S76, SN 3961; 1—Type 3T77A, SN 4771; 2—Type P6032. Used only 4 hours. Price: $4900. Contact: Bill Burns, Digital Equipment Corporation, 146 Main Street, Maynard, Massachusetts 01754. Telephone: (617) 897-8821 Ext. 613.

1—Type 547/1A1/202-2. Contact: Meyer Bar, 5523 EauClaire Drive, Palos Verdes Peninsula, California. Telephone: 377-2121 (home); 772-8111 Ext. 6437 (office).

1—Type 517A, SN 1377. Sell or trade and cash for Type 535 or Type 545 and CA Plug-In. Contact: Duane Beyer, 1756 Elmhurst Lane, Concord, California. Telephone: (415) 682-6161, Ext. 372 (days); (415) 682-5273 (evenings).

1—Type 1A1 Dual-Trace Unit, SN 7420. Price: $425. Contact: L. Springer, Creative Electric, 18 Hulbert St., Auburn, New York 13021. Telephone: (315) 253-9759.

1—Type RM504, SN 001315. Less than 300 total hours on instrument. Price: $395 FOB Houston, Texas. Contact: D. D. Fitzgerald, Southwest Instrument Co., 7722 Westview Drive, Houston, Texas 77055. Telephone: (713) 682-7801.

1—Type 531, SN 493; Type 53A; Scope-Mobile. Price: $400. 1—Type 535, SN 692; Type 53/54C; Scope-Mobile Cart. Price: $550. Contact: Milt Groban, 9656 South Merrion, Chicago, Illinois 60617. Telephone: (312) 721-3442.

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1—Type 517 high speed with power supply. Condition of both good. Contact: D. Schendel, Electro Optical Industries, Inc., 92 Aero Camino, Goleta, California 93017. Telephone: (805) 968-2591.

1—Type 4S2, SN 000523. Price: $965. 1—Type 113, SN 001226. Price: $165. Contact: Robert Williams, University of Virginia, Physics Department, Charlottesville, Virginia. Telephone: (703) 295-2166 Ext 3345.

1—Type 503, SN 7345. Price: $500. Contact: Chuck Fredricks, Nortec, Richland, Washington 99352. Telephone: (509) 943-9141.

1—Type 4S2A; 1—Type 5T3 Plug-In Unit; 1—Type 661. Contact: Jerry Borchert, 3300 Hillview Avenue, Palo Alto, California. Telephone: (415) 326-9500.

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USED INSTRUMENTS WANTED

1—Type 564 Storage Oscilloscope, 3A75/2B67 Plug-In Units. Contact: Charles Stuart, 1 Finch Place, Huntington, New York 11743.

Type 575 Transistor Curve Tracers. Contact: Mr. Schaeffer, Dage Corporation, 757 Main Street, Stamford, Connecticut. Telephone: (203) 324-3123.

1—Type 511; 1—Type 512; 1—Type 513; 1—Type 514. Maximum—$200. Contact: R. Stayton, 4403 Vangold, Lakewood, California 90712. Telephone: 429-9429.

1—Type 502; 1—Type 502A. Contact: Don Modlin, Reflectone Division, Otis Elevator Company, 2051 West Main Street, Stamford, Connecticut 06902. Telephone: (203) 325-2251.

Will trade 1—Type 541, SN 6092 for 1—Type 531A, no plug-ins. Contact: John Bowen, Pressure Products Industries, Inc., 412 South Warminster Road, Hatboro, Pennsylvania 19040. Telephone: (215) 659-3300.

1—Type 515 or comparable scope. Will consider more sophisticated type with 10-MHz bandwidth. Contact: Tom Annes, P.O. Box 2232, Denver, Colorado 80201.

1—Type 515A, 541 or 545. Please state condition and price. For personal use. Contact: E. D. Haley, Jr., 909 Monticello Avenue, Charlottesville, Virginia 22901. Telephone: (703) 296-2037.

1—Type 575 Curve Tracer. Contact: Robert J. McNaul, Spar Electronics, 7969 Engineer Road, San Diego, California 92111. Telephone: 279-1641.

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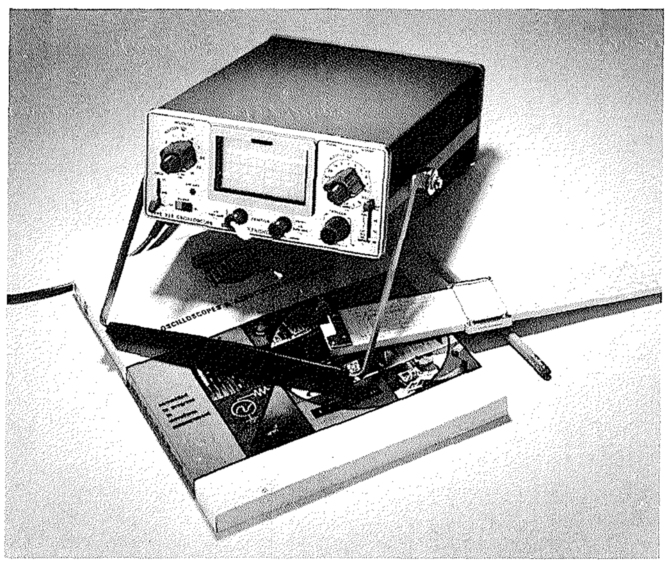

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