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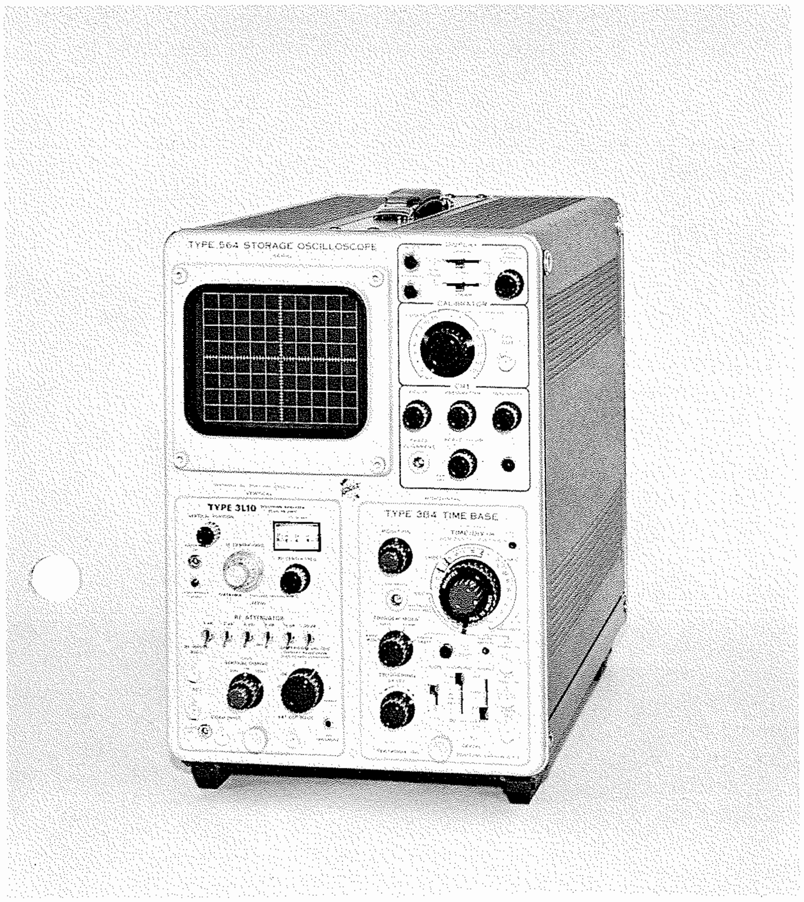
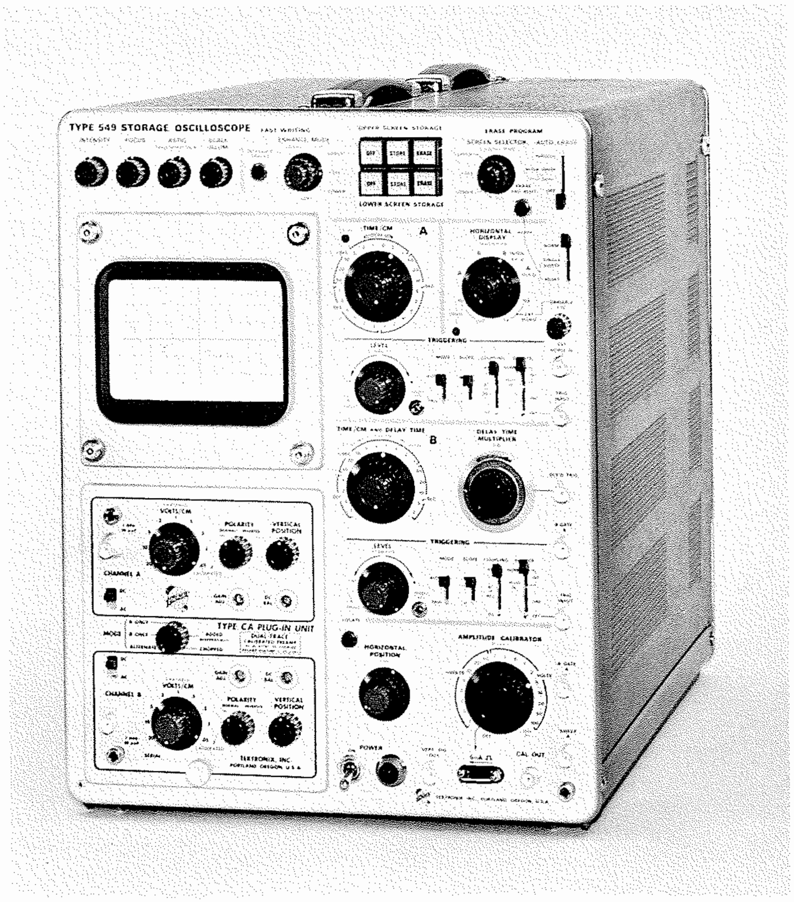




THE STORAGE OSCILLOSCOPE; WHY AND WHERE

by Geoffrey A. Gass
Tektronix, Inc.

A perhaps over simplified definition of a Storage Oscilloscope is: "A versatile instrument combining the advantages of a high speed storage system and a conventional laboratory oscilloscope."

Here are six specific applications in three general application areas where the storage oscilloscope out-performs the conventional oscilloscope.

One of the desirable and potentially more useful features of a general purpose conventional oscilloscope is its ability to display, however momentarily, erratic events. Unfortunately, the conventional oscilloscope cannot always present these events in a conveniently-observed manner. To conveniently display information for visual observation, measurement, and analysis, the conventional oscilloscope requires events that recur in identical form many times per second. Given these conditions, the display will be a bright and steady trace. Erratic events are not always so accommodating so as to repeat themselves indefinitely and allow the observer to revise or complete his estimates.

So in a conventional oscilloscope, the ability to display erratic events and the ability to present them in a conveniently observed manner are not always compatible.

A principal purpose for a high-speed storage system in a general-purpose oscilloscope, then, is to bring display convenience into greater agreement with display capabilities, preserving the unexpected waveform for as long as may be required to note down its significant characteristics and dimensions—or long enough to find a camera, requisition some film, and make a permanent photographic record.

For the most part, the purposes of a storage oscilloscope can be served by a conventional oscilloscope, a camera, and film—lots of film. The usefulness of a storage oscilloscope, then, is primarily one of degree rather than one of kind; one of convenience rather than one of unique capability. Even so, anyone who has attempted to photo-record carefully-prepared multiple-exposure of an elaborate series of waveforms, only to find that he'd already used the last exposure on his roll of film, needs no reminder that even a small improvement in the degree of assurance that critical data to be recorded *has* been recorded can be of considerable value.

In the notes below, we have outlined some of the ways in which the storage feature can be put to work in obtaining more useful and convenient oscilloscope displays for viewing or for simplified waveform photography.

GENERAL APPLICATION AREAS

The three primary uses for storage in a general-purpose oscilloscope are:

(1) To retain waveforms of single events which cannot be repeated—or which, if repeated, may change significantly with each repetition.

(2) To allow direct comparison by simultaneous display of events happening at different times, or of related repetitive events observed at various different points in a system or by means of different transducers.

(3) To retain information from very slow-moving traces—such as those from low repetition-rate sampling systems or high-resolution spectrum analyzers—until the entire display may be observed.

SPECIFIC APPLICATION AREAS

Nonrepetitive Events

Recording of random transients is the most familiar application in this area, since the storage oscilloscope may be left unattended for extended periods waiting to be triggered from an intermittent or random event. Within this category of applications are also destructive testing or testing to near yield-limits where repeated testing may change the characteristics of the device under test, and measurements of phenomena where a number of "mis-fires" may be expected before a satisfactory (e.g., worst-case) waveform may be obtained. Much testing in the mechanical and electromechanical fields falls into the non-repetitive area.

1. *Transistor Beta Characteristic Above Power Rating*

Using an operational amplifier to differentiate the collector output waveform of a grounded-emitter transistor driven by a linear ramp of current provides an output voltage proportional to the low-frequency AC beta of the transistor for a given collector load resistor. Plotting dV_c/dt against V_c gives a continuous plot of beta variation along the given load-line from cutoff to saturation if a sufficiently large base-current ramp is available[1]. Plotting dV_c/dt against I_b gives a direct indication of large-signal output linearity over the range encompassed by the current ramp.

Combining this measurement technique with the capability of completing and preserving a useful display in less than a millisecond on a storage oscilloscope permits convenient determination of characteristics at many times the nominal maximum steady-state collector-dissipation rating of the transistor, and without significant shifts in beta due to large changes in junction temperature.

A simple circuit configuration providing a linear base-current ramp of up to 5 mA peak for NPN transistors is shown in Fig. 1. For low-beta or high-power transistors, a power amplifier or external ramp source is required to obtain the necessary linearity; for PNP types, an inverting amplifier with output voltage swing capabilities V_{cb} must be used to provide the base-drive current ramp.

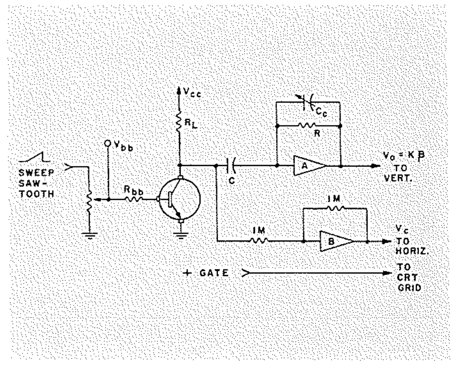


Fig. 1. Test circuit for plotting β vs I_c, V_c for NPN tronsistor. Differentiation V_c when I_b is a linear ramp produces a voltage proportional to β. Capacitor C_c (≈ 0.01 C) corrects for overshoot in differentiator.

Direct calibration of the oscilloscope vertical amplifier in terms of beta per centimeter is as follows:

$$\beta/\text{cm} = \frac{(\text{Volts/cm})\ (R_{bb})}{(R_L)\ (R_f C_i)\ (\text{Ramp } dV/dt)}$$

R_{bb} is the constant-current series resistor in the base drive circuit. Ramp dV/dt may be measured at the V_{bb} test point using the internal time-base display. R_L is the collector load resistance, and R_f and C_i are the differentiating components of the operational amplifier. A quick check of calibration may be obtained by removing the transistor and shorting together the base and collector terminals of the socket. A beta of −1 should be indicated in the display.

Figure 2 shows beta variation of a Type 2N1308 150 mW germanium transistor for a 50-Ω load line and a V_{cc} of 20 V. Peak dissipation is 2 W at I_c 200 mV, V_c 10 V.

Using this circuit, families of curves for a given transistor may be displayed on the storage oscilloscope for (a) various collector load values (changing V/cm or R_f with R_L to hold the β/cm value constant), (b) various V_{cc} values, or (c) various temperature values, using external heating and monitoring equipment and triggering a single display as the temperature passes through each desired point. This type of application properly belongs to the second category below, direct comparison of events happening at different times. A waveform photograph illustrating (b) is shown in application 4.

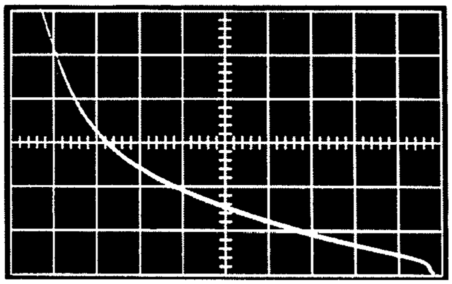


Fig. 2. Plot of β for 2N1308 transistor versus V_c, I_c for $V_{cc} = 20$ V, $R_L = 50\ \Omega$, V_{bb} 0 — 120 V, R_{bb} 24 k. Vertical calibration (β) 100/cm; horizontal, 2 V/cm, 40 mA/cm. Peak β of >600 is close to avalanche region for transistor. (Type 549 Oscilloscope, Type O Plug-In.)

2. *Transformer Inrush Current and Effects on Switches*

A major cause of AC power-switch failures in transformer-powered equipment is the so-called inrush current occurring during turn-on. A combination of four conditions establishes the magnitude of peak inrush current for a given turn-on: (a) the hysteresis of the transformer core material, (b) the phase angle of the AC power source at the instant of last turn-off, (c) the phase angle of the power source at the instant of turn-on and (d) the impedance of the input power loop, including the DC resistance of the transformer primary. In the worst case, inrush current amounts to essentially the peak power-line voltage divided by the DC resistance of the transformer primary circuit.

Where inrush currents alone are to be routinely measured, test-sets employing silicon controlled rectifiers and power diodes provide a means of providing a worst-case condition for each turn-on.

Where the frequency of usage does not justify specialized test equipment, or where the effects of inrush currents on the switch itself during the closure process are to be evaluated, the storage oscilloscope (with a suitable differential input amplifier and probe arrangement) permits observation of hundreds of turn-ons with minimum inconvenience or film waste, but with full assurance that permanent records may be kept of any turn-on waveform containing information of value.

Figures 3 and 4 show the test circuit for measurement of inrush current, and a typical waveform obtained by these means. A current transformer used instead of probes and a resistive shunt would allow use of a single-ended oscilloscope input. But the low-frequency response requirements to reproduce accurately the current waveforms of a transformer in a typical capacitor-input semiconductor power supply—for example—having a very small conducting angle and virtually no load for a large part of the cycle, are sometimes difficult to achieve and verify in a current transformer that will also give adequate indication of momentary peak currents in the 50 to 100 ampere region.

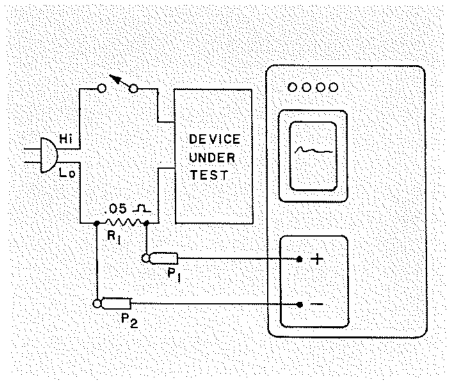


Fig. 3. Observation of inrush current using high-speed storage oscilloscope with differential input and differential probes. R_1, P_1, P_2 may be replaced with suitable wideband current transformer.

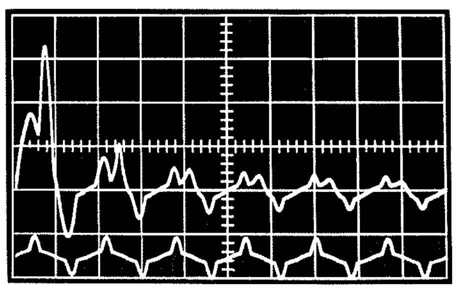


Fig. 4. Inrush current in nominal 120 V, 240 W system (upper trace) compared with current waveform after warmup. Vertical: 10 A/cm; Horizontal, 10 ms/cm. (Type 549 Oscilloscope, Type W Preamplifier.)

Figures 5 and 6 show the test circuit and typical results in measuring the potential drop across a switch in the process of closing a 60-Hz transformer primary circuit.

The display is obtained by triggering the oscilloscope from the inrush current signal. Good overload recovery characteristics in the input amplifier are essential for this measurement, as the full line voltage is impressed across the probes until the switch has closed.

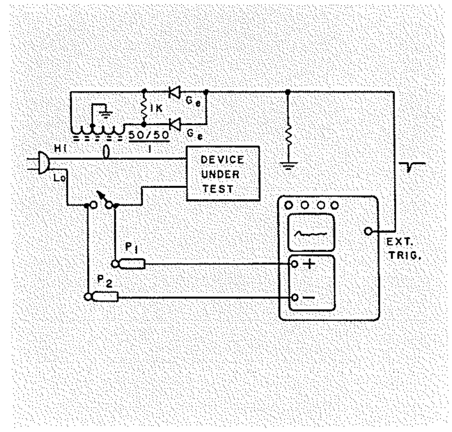


Fig. 5. Observation of switch closure characteristic during inrush. Current transformer 1:50:50 provides trigger for either polority inrush. Switching "low" side of line makes amplifier requirements less critical.

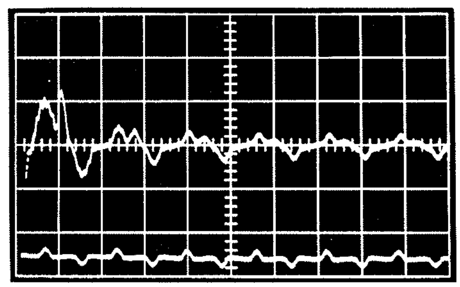


Fig. 6. Potential across switch contacts during inrush (upper trace) and after warmup. Vertical, 200 mV/cm; horizontal, 10 ms/cm. (Type 549 Oscilloscope, Type W Preamplifier.)

Direct Comparison of Events Happening at Different Times

Multiple-beam and multiple-trace oscilloscopes are designed to facilitate the direct comparison of events happening at the same, or very nearly the same time. The storage oscilloscope extends this capability to events happening at quite different times or at test points that are not conveniently close together.

3. *Speech Therapy for the Deaf*

A microphone, a storage oscilloscope, and suitable filters emphasizing the significant parts of word and syllable waveforms allow the student to practice vowels, syllables or words, with direct visual comparison of the subtle harmonic phase shifts which convey speech intelligence, against his instructor's standard waveform stored on the screen. The split storage target permits continuous trial-and-error operation on one half of the screen without losing the reference waveform on the other.

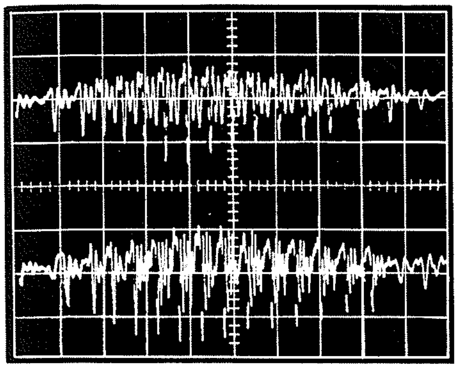


Fig. 7. Stored single-sweep waveforms of speech sounds aid in speech therapy. Upper trace: the word "reed". Lower trace: the word "red". Release of the "d" sound is offscreen to the right. Waveforms are somewhat distorted due to poor room acoustics. Sweep, 30 ms/cm. (Type 564 storage oscilloscope, Type 3A3 vertical amplifier set for 5 kHz bandwidth.)

In Figure 7, waveforms representing the pronunciation of the words "reed" and "red" are compared, using a 5-kHz bandpass filter. More elaborate normalizing systems may be employed in actual therapy work.

4. *Comparing the Effects of Circuit Adjustments*

A record of the effects of a series of adjustments or substitutions is often of value in circuit or component work. An illustration (Fig. 8) is the effect of changing collector supply voltage V_{cc} in application 1, showing the beta range for a given collector load resistance for four values of V_{cc}.

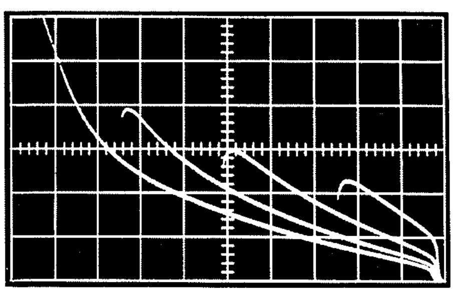


Fig. 8. Comparison of waveforms under variant operating conditions. Type 2N1308 transistor beta vs V_c, I_c as in Figs. 1 and 2, but V_{cc} of 20, 15, 10 and 5 V. Vertical calibration (β), 100/cm.

Preservation of Complete Slow Displays

The problem of retrieving data from oscilloscope displays of slow-rate information can result in loss of information either because the beginning of the slow trace is forgotten when the display is finished, or the display is deliberately completed at a faster than optimum rate, resulting in loss of information in the display itself.

5. *Sampling System at Low Signal Repetition Rates*

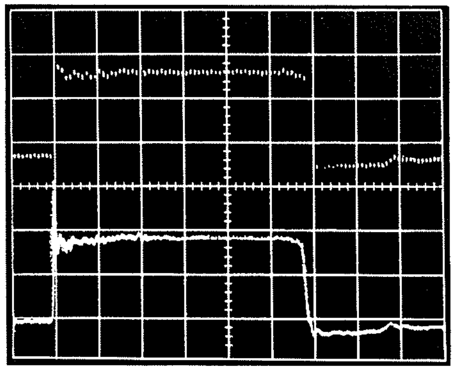


Fig. 9. Use of storage oscilloscope and manual scan feature of sampling system to obtain optimized dot density where needed. Upper trace, 10 dots/cm. Lower trace, manual scan. Fill-in required about 10 seconds with 100 Hz sampling rate, but provided same detail as >1000 dots/cm requiring >1.5 minute sweep. (Type 564 oscilloscope, Type 3T77 time base.)

The upper trace of Fig. 9 illustrates a case of possible information loss when a sampling oscilloscope dot density setting is insufficient to resolve all the significant data. In this particular case, the signal repetition rate was 100 Hz, completing the display shown (100 samples) in 1 second, but with a serious loss of information in the leading edge which occurred "between dots", so to speak. The alternative of increasing dot density to 1000 dots/cm to obtain the necessary resolution would have required over 1.5 minutes to complete the display.

The problem was solved in the lower trace by storing the low dot-density trace, and then using the manual scan of the sampling system to increase dot density only at the points where needed, completing the display in minimum time, and revealing the 70% overshoot which was hidden in the first trace. Whether with manual scan or internally-controlled high dot-density, the storage oscilloscope facilitates retrieval of high-resolution waveform information even from very slow-repetition-rate events from sampling systems.

6. *High Resolution Displays from Spectrum Analyzers*

The maximum sensitivity and resolution of a spectrum analyzer are achieved only when the dispersion (frequency sweep) df/dt is made to be very small. For normal viewing, in order to obtain a useful repetitive display, it's usually necessary either to confine the dispersion to a very narrow value, or keep the resolution low in order to maintain reasonable sensitivity and a usable display repetition rate.

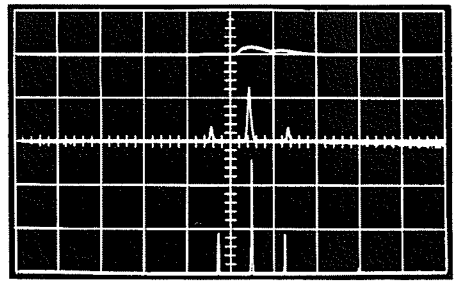


Fig. 10. Effects of df/dt on high-resolution spectrum analysis. Dispersion of 10 kHz, resolution 1 kHz. Sweep rates are: Upper trace, 20 ms/cm (50 kHz/s); middle trace, 200 ms/cm (5 kHz/s); lower trace, 2 s/cm (500 Hz/s). Signal is second harmonic of 5 MHz carrier modulated by 1 kHz squarewave (Type 549 Oscilloscope, Type L10A/1L10 Plug-In Spectrum Analyzer).

Figure 10 illustrates the effect of df/dt sweep rate on sensitivity and resolution in a representative spectrum analyzer application. Observing the second harmonic of a 5-MHz carrier modulated by a 1-kHz squarewave, a sweep of 10 kHz in 200 ms with a nominal 1-kHz resolution (top trace) produces only a hint of the signal and possible sidebands. Holding the same dispersion and resolution but reducing the sweep rate to 200 ms/cm (5 kHz/s) begins to reveal the true nature of the signal. In the bottom trace, reducing the sweep to 500 Hz/s provides sufficient resolution to identify the modulating signal as a squarewave. Time required to complete this 10 kHz sweep was 20 s. The advantage of the storage tube in preserving the entire display becomes evident.

SUMMARY

Applications making best use of the capabilities of a storage oscilloscope are those involving (a) non-recurrent waveforms, (b) comparison of waveforms of non-simultaneous events and (c) displays requiring several seconds for completion. Within the writing speed limitations of the instrument used, the storage feature may be used as a substitute for, or as an aid to, oscilloscope photography. Representative applications in these areas are: plotting transistor beta above nominal power rating; measurement of transformer inrush current and its effect on power switches; comparison of human speech waveforms; and improving resolution of sampling oscilloscope and spectrum analyzer displays.

Photographic Note: Waveform photographs reproduced here were taken with Polaroid® No. 47 film, using an exposure of 1/5 s at f/5.6, except Figs. 7 and 9, which were taken at 1/2 s, f/11.

[1]John V. McMillin, "Simple Curve-Tracer Displays Transistor Beta" *Electronics*, August 24, 1962.

TYPE 564 STORAGE OSCILLOSCOPES — REMOTE ERASE FEATURE

This modification provides an external Remote-Erase feature for the Type 564 Storage Oscilloscope.

It installs a circuit assembly which contains two monostable multivibrators—one for the Upper display area and one for the Lower display area. When activated from either the front panel Erase controls or the Remote-Source Erase controls these multis erase their respective display areas. The Remote-Source Erase control can be any switch contact that can short a wire from the Type 564 to ground or any equipment that can provide a negative-going 5-to-10 volt pulse for the multi of each display area.

The external connections are brought out to a four-contact connector on the rear of the Type 564 and a mating connector is included to permit attachment of the Remote-Erase control.

This modification applies to Type 564 Storage Oscilloscopes, all serial numbers. Order through your local Tektronix Field Engineer or Field Office. Specify Tektronix part number 040-0352-01.

P510 CATHODE-FOLLOWER PROBE —PROBE REPAIR KIT

This modification kit contains the parts necessary to repair several P510A Cathode-Follower Probes. The instructions are divided into sections, so that any individual portion of the probe can be repaired.

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0287-01.

TYPE 531, TYPE 535, TYPE 541 AND TYPE 545 OSCILLOSCOPES—CHOPPING-TRANSIENT BLANKING

Installation of this modification supplies a means of applying a blanking voltage, to the cathode of the oscilloscope CRT, to eliminate switching transients from the display. These transients will occur when a multiple-trace plug-in unit—installed in the oscilloscope—is operated in its chopped mode. The blanking voltage is applied by activating a switch installed on the rear panel of the oscilloscope.

The modification involves the changing of V78 tube socket to a 9-pin type and adding a CRT CATHODE SELECTOR switch to the rear panel. Also, V78, a 6AU6 vacuum tube, operating as a Multi-Trace Unit's Sync Amplifier in the oscilloscope, is changed to a 6DJ8. One half of the 6DJ8 is used as the Sync Amplifier and the other half is used to generate the blanking voltage.

This information applies to Type 531, Type 535, Type 541, and Type 545 Oscilloscopes, serial numbers 101 to 20,000 and to all Rack Mount instruments in these types with serial numbers 101 to 1000.

Order from your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0403-00.

TYPE 532 AND TYPE RM32 OSCILLOSCOPES—SWEEP LOCKOUT

Your Type 532 or Type RM32 Oscilloscope can be modified for the study of one-shot phenomena by installation of this kit.

The Sweep Lockout feature permits you to "arm" the sweep to fire on the next trigger to arrive. After firing once the sweep is locked out and cannot fire again until rearmed by pressing the RESET button. All original features of the instrument are retained.

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0147-00.

TYPE 453 OSCILLOSCOPE—PORTABLE-TO-RACKMOUNT CONVERSION

This modification supplies the necessary mechanical components and hardware to securely rackmount the Type 453 Portable Oscilloscope.

A special feature of this kit is the Rackmount Rear Support assembly. A Type 453 correctly installed as a rackmount and using the Rear Support assembly will successfully withstand an environmental shock of 30 G's or vibration of 4 G's. This can be an important consideration for Type 453's installed in mobile or shipboard units and in aircraft.

A frame, assembled from components and hardware in the modification kit, allows the oscilloscope to be mounted in a standard 19" open or closed relay rack, or slide out tracks.

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0420-00.

TYPE 526 VECTORSCOPE — QUIET FAN MOTOR

This modification installs a lower r/min fan motor assembly to reduce the audio noise-level of the fan motor assembly. The new fan motor assembly is a direct replacement except for the addition of a motor capacitor, which requires the drilling of two 5/36 inch holes in the rear panel of the Type 526.

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0412-00.

OSCILLOSCOPE CRADLE MOUNT

This modification enables the Tektronix Oscilloscopes listed below to be rack-mounted in a standard 19" relay rack. Required vertical front-panel space is 17½ inches.

The modification is applicable to the following oscilloscopes: Types 524AD, 531, 532, 541, 545, and 570, serial numbers 5001 and up; also, Types 531A, 533, 533A, 535A, 536, 541A, 543, 543A, 543B, 544, 545A, 545B, 546, 547, 575, 581, 581A, 585, 585A, and 661, all serial numbers.

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0287-00.

DC FAN MOTOR FOR LISTED OSCILLOSCOPES

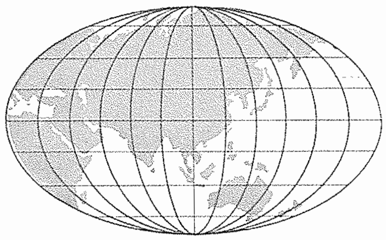
This modification enables the oscilloscopes listed below to operate on 50- to 400-cycle power lines. It installs a DC fan motor, a thermal time-delay relay, and a DC power supply relay.

The modification is applicable to the following instruments:

TYPE	SERIAL NUMBER
531A	20001-22073
535A	20001-24349
541A	20001-21454
545A	20001-27729
RM31A	1001-1579
RM35A	1001-1850
RM41A	1001-1189
RM45A	1001-1892

(Please note: If your instrument has the DC Relay Modification Kit 040-258 installed, use Field Modification Kit 040-0233-00.)

Order through your local Tektronix Field Office, Field Engineer, Field Representative or Distributor. Specify Tektronix part number 040-0231-00.



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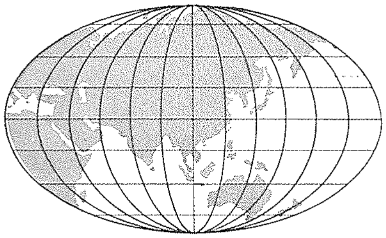

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