OSCILLOSCOPE APPLICATIONS GUIDEBOOK

Oscilloscopes are often described as the most versatile piece of test equipment that a Technician or Engineer can use.
The instrument provides an actual graph of voltage versus time on the screen. This type of graph is one of the most versatile "tools" for testing, analyzing, and troubleshooting electrical and electronic equipment because it allows you to actually measure instantaneous voltage levels and time periods of electrical signals. Additionally, oscilloscopes allow observation of amplitude changes (glitches), waveform distortion, and phase changes.
Transducers can also be used adapt the oscilloscope to measure such things as mechanical stress, heat, gas pressure, fluid pressure, light, weight, or just about anything else that a transducer can convert to an electrical signal.
Although applications for oscilloscopes are virtually unlimited, here are just a few of the more common uses:

- FIELD ENGINEERING.
- RESEARCH AND DEVELOPMENT.
- SECONDARY AND POST SECONDARY EDUCATIONAL INSTITUTIONS.
- ELECTRONIC AND ELECTRICAL EQUIPMENT REPAIRS SHOPS.
- CONSUMER PRODUCTS REPAIR SHOPS.
- GOVERNMENT REPAIR FACILITIES.

In order to use an oscilloscope to its best advantage, the Technician and Engineer should have a basic understanding of how an oscilloscope works as well as a good understanding of the oscilloscope's controls, features, and operating modes. This guidebook is useful to those with little knowledge of oscilloscopes as well as the experienced technician or engineer who wishes to refresh their memory or explore new uses for oscilloscopes.

1031 Segovia Circle,
Placentia, CA 92870-7137

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COMMON OSCILLOSCOPE TERMS

ACCELERATING VOLTAGE — The internal voltage that accelerates the electron beam and causes trace illumination on the oscilloscope display. A higher voltage causes a brighter trace. Oscilloscopes with higher bandwidth need a higher accelerating voltage to make the trace visible when viewing high frequency signals. Usually measured in kilovolts (kV).

ALIASING — A phenomenon which occurs in real-time sampling on a DSO when the sampling rate is too low for reliable sampling. Aliasing produces a display which looks valid but is in fact totally erroneous in terms of time measurement.

ALTERNATE SWEEP — A method of generating dual trace display at higher sweep speeds. In this method, one entire trace is drawn, then the other, in an alternating fashion. See "Chop".

ALTERNATE TRIGGER — A dual-trace triggering scheme in which the channel 1 signal triggers the channel 1 trace, and the channel 2 signal triggers the channel 2 trace in an alternate pattern. Thus, each signal becomes its own trigger source, and a synchronized display can be obtained even if the two signals have no time relationship.

ATTENUATION — A decrease in signal amplitude. Usually measured in decibels (dB).

BANDWIDTH — The frequency range of signals that can be observed on the oscilloscope with minimum degradation. Typically, bandwidth is specified in megahertz (MHz) and is the maximum frequency at which signals are within 3 dB in amplitude. A 20 MHz oscilloscope has a bandwidth of dc to 20 MHz. This means that a 20 MHz oscilloscope can be used to measure amplitude of a 20 MHz signal and will provide a measurement with a maximum of 3 dB (decibels) of attenuation compared to a reference frequency of 1 kHz. Since oscilloscopes are usually conservatively rated, less then 3 dB of attenuation will typically be experienced at the maximum rated bandwidth.

BLANKING — Turning off the CRT electron beam. An oscilloscope CRT is "unblanked" during the trace and "blanked" during the re-trace and while waiting for a trigger.

CHANNEL — The complete input circuitry, including the vertical attenuator, vertical amplifier. and input coupling network, for a single signal. Typically, modern oscilloscopes have two or more channels and therefore have two or more vertical attenuators, vertical amplifiers, and input coupling networks.

CHOP SWEEP — A method of generating dual-trace display at lower sweep speeds. In this method, the electron beam jumps from one trace to the other, drawing a small bit of each, as it makes its way across the screen.

COMPONENT TEST — A feature on some advanced analog oscilloscopes which allows testing of components in-circuit or out-of-circuit. When the component test mode is selected, normal sweep is disabled and the oscilloscope displays a pattern representing the dynamic impedance of the component when a 60 Hz sine wave is applied.

CROSSTALK — Sometimes referred to as channel isolation or channel separation. The undesired effect that a signal present on one channel has on another channel. Less crosstalk means that the channels are better isolated from one another. Usually expressed in dB.

CRT — Abbreviation for Cathode Ray Tube. The cathode ray tube is similar to a television picture tube and acts as the oscilloscope display.

DECIBEL (dB) — A unit of measurement usually used to show a ratio of input signal power or voltage to output signal power or voltage. Decibels are calculated by taking the log of the output power divided by the input power and multiplying that by 10. This can be expressed by the equation dB = 10 log (Output Power / Input Power).

DELAYED TIME BASE — A delayed time base oscilloscope allows a single signal to he viewed at two different time bases with the second time base expanding a portion of the waveform and starting at some point after the main time base begins. This type of display is more useful than merely magnifying the display because it allows simultaneous viewing of the main sweep signal and the expanded signal, and allows any desired degree of magnification.

DIGITAL STORAGE OSCILLOSCOPE — An oscilloscope that uses computer technology to digitize and store waveforms. This type of specialized scope is very useful for capturing and viewing extremely slow events, one-time events, and pre-trigger events. It can also provide disk storage and hard copy of a waveform through a computer/plotter interface.

DIGITIZE — To convert an analog quantity to digital. A DSO digitizes an analog voltage applied to its input and converts it to a series of digital numbers which are stored in memory.

DSO — Abbreviation for "Digital Storage Oscilloscope".

DUAL TRACE — An oscilloscope having two traces to display channel 1 and channel 2 signals simultaneously.

EQUIVALENT TIME SAMPLING — Method of sampling used on a DSO, wherein sampling is synchronized with the trigger signal, usually one sample per cycle of the input. Samples are taken at slightly increasing intervals after each trigger, so that one complete cycle is stored after many cycles of the input. Equivalent time sampling allows a waveform to be digitized using a much lower sampling rate, but the waveform must he repetitive. See "Real Time Sampling".

FALLTIME — The time required for a signal to fall from 90% to 10% of its maximum amplitude. Faster fall times cause steeper trailing edges of pulses, usually a desirable trait. The rise time specification for an oscilloscope can also be used as the fall time specification. See "Rise Time" for further explanation.

GRATICULE — The graph, usually etched on the inside of the CRT, that allows time and voltage measurements to be taken.

INTENSITY MODULATION — See "Z-Axis".

LINEARITY — A perfectly linear sweep would be produced by a perfectly linear sweep ramp. This means that any variance in the sweep ramp would cause the time represented by one horizontal division on the display (e.g. the leftmost division) to be unequal to the time

Common Oscilloscope Terms

represented by another horizontal division on the display (e.g. the rightmost division).

PHOSPHOR — A coating on the inside of the CRT that emits visible light when struck with an electron beam. Oscilloscope CRTs usually use a P31-type phosphor, which is a short-persistence type; that is, the emitted light quenches soon after the electron beam ceases or moves.

POST-TRIGGER DATA — Data which occurred after the event that caused a DSO to trigger.

PRE-TRIGGER DATA — Data which occurred before the event that caused a DSO to trigger. Modern DSOs allow the user to view such data.

REAL TIME SAMPLING — Method of sampling used on a DSO, wherein the samples are taken at regular intervals that are determined by the sweep time setting. The sampling process proceeds independently of the input. The sampling rate must be at least twice the frequency of the input for meaningful waveform acquisition to occur. See "Equivalent Time Sampling".

RISE TIME — The time required for a signal to rise from 10% to 90% of its maximum amplitude. Faster rise times cause steeper leading edges of pulses, usually a desirable trait. The rise time specification for an oscilloscope refers to the minimum time that it takes the CRT beam to rise from the 10% mark on the CRT graticule to the 90% mark on the graticule. Oscilloscope rise time specifications are directly related to bandwidth.

SAMPLING — The process of digitizing on a DSO. Every time the scope "samples" an input waveform, it memorizes the voltage value at that instant and converts it to a binary number which can be stored in memory.

SAMPLING RATE — The rate at which sampling occurs in a DSO, usually expressed in samples per second. DSOs are typically rated by their maximum sampling rate, usually expressed in megasamples per second.

SWEEP — The motion of the CRT electron beam from left to right that causes the trace to appear. A sweep time of 0.1mS/div means that the beam moves across one division of the CRT in 0.1mS. Faster sweep speeds are required to view higher frequency signals. If the frequency of the input signal remains constant and the sweep speed is increased, the number of cycles (or portion of the waveform) that are displayed on the CRT will decrease (effectively magnifying the display).

SWEEP MAGNIFIER — Sometimes referred to as sweep expander. This feature allows a portion of a displayed waveform to be magnified (typically x10) without shortening the sweep time setting. This is an advantage over simply increasing the sweep speed because doing so can result in the desired portion of the waveform disappearing off the screen. Additionally, this feature increases the maximum sweep speed by the magnification factor (i.e. if the fastest sweep time/div setting of an oscilloscope is 0.5 mS/div and x10 magnification is selected, the sweep speed is increased to 0.05 mS/div).

TIME BASE — The calibrated sweep generator circuit within the oscilloscope which allows measurement of signal time period and frequency. The time base is calibrated in time/div. In other words, if the time base is 10 mS/div, it would take 100 mS for the electron beam to sweep across all 10 of the CRT's horizontal divisions.

TRIGGER — In an analog oscilloscope, the event or signal that causes the CRT beam to begin its sweep across the display. In a DSO, the event around which the storage process is referenced. Some DSOs place the trigger in the center of the storage memory, so that there are equal amounts of pre- and post-trigger data stored. In both analog and digital scopes, great versatility is provided in setting the trigger source, level, and slope.

TV SYNC — see "Video Sync".

VERTICAL MAGNIFICATION — A feature on many oscilloscopes in which the vertical input signal is amplified, or magnified. The typical magnification factor is 5 times. This increases sensitivity and makes the oscilloscope more useful for measuring very low level signals.

VERTICAL SENSITIVITY — The signal level required to cause a single division of vertical deflection. For example, for a vertical attenuator setting of 5 mV/div, a 5 mV peak signal will produce a single division of vertical deflection.

VERTICAL ATTENUATOR — The precision input circuit that controls the level of the input signal so that the signal provides an amount of vertical deflection that can be easily measured on the CRT screen. Usually this circuit consists of calibrated steps in a 1-2-5 sequence (10 mV/div, 20 mV/div, 50 mV/div, etc.), which allow the oscilloscope to display signals with levels from many volts to only a few millivolts.

VIDEO SYNC — Sometimes referred to as TV sync. This feature allows vertical (TV V) or horizontal (TV H) video sync pulses to be selected for triggering. Vertical sync pulses are selected to view vertical fields or frames of video and horizontal sync pulses are selected for viewing horizontal lines of video.

X-AXIS — The horizontal axis, when oscilloscope is not in sweep mode.

X-Y DISPLAY — Mode of operation which displays a graph of two voltages. The Y axis is the vertical axis and the X-axis is the horizontal axis.

Y-AXIS — The vertical axis.

Y-AXIS OUTPUT — A sample of the vertical axis signal which is available at a rear panel output jack.

Z-AXIS — Also referred to as intensity modulation. This feature allows an external signal to control the intensity of the CRT beam.

OSCILLOSCOPE SAFETY — The ac and dc resistance that a signal "sees" at the oscilloscope input. Typically, input impedance is expressed in terms of dc resistance (measured in megohms) and capacitance (measured in picofarads).

Oscilloscope Safety

Review and follow the guidelines on this page to use your oscilloscope safely and responsibly.

Preventing Electric Shock

1. Using an oscilloscope may often involve working inside equipment that contains high voltage. Under such conditions, you should observe the following:

   a. Don’t expose high voltage needlessly.

   b. Be familiar with the location of the high voltage points, and remember that high voltage may appear at an unexpected point in effective equipment.

   c. Use an insulated floor material or insulated work surface.

   d. Keep one hand in your pocket when using a scope probe.

   e. Remember that ac power may be present in the equipment even when it is turned off.

   f. Use an isolation transformer whenever the equipment’s power plug is two-prong only.

   g. Have someone nearby, preferably with CPR training.

2. Don’t operate the oscilloscope with the cover removed.

3. Keep the scope grounded with the 3-wire power plug. Don’t attempt to defeat the third prong or "float" the scope.

Preventing Damage to the Oscilloscope

1. Don’t leave the oscilloscope set at high brightness for long intervals. A bright spot or line left in one position can permanently burn the screen.

2. Keep the ventilation holes clear.

3. Don’t apply excessive voltage to the scope’s input jacks. Voltage limits are clearly stated in your operating manual and usually on the scope itself.

4. Connect the ground clip of a scope probe only to earth ground or isolated common in the equipment under test.

5. Keep the scope away from:

   a. Direct sunlight.

   b. High temperature/humidity.

   c. Mechanical vibration.

   d. Electrical noise and strong magnetic fields.

CONTROLS AND INDICATORS

This chapter describes typical controls and indicators found on modern oscilloscopes. It starts with the basic functions common to most units and proceeds to more sophisticated features.

BASIC ANALOG OSCILLOSCOPES

Refer to Fig. 1 for typical oscilloscope controls and indicators.

General Function Controls

1. **CRT and Graticule**. This is the area where the trace is displayed. The graticule is a grid, generally 10 divisions wide and 8 divisions high. Each division is usually one square centimeter, although this may vary on "mini" scopes. The graticule is used to make voltage and time measurements from the waveform. It usually also has 10% and 90% marks, which are used for rise time measurements.

2. **Intensity Control.** Adjusts the intensity, or brightness, of the trace.

3. **Trace Rotation Control.** The earth's magnetic field changes from one location to the next which may affect the trace tilt. Oscilloscopes have a trace rotation control that can be used to compensate for the earth's magnetic field and adjust the trace to a perfectly horizontal position. This control is often a screwdriver-type adjustment.

4. **Focus Control.** Adjusts trace focus.

5. **Cal Terminal.** Sometimes called "Probe Adjust". This terminal produces a square wave (usually 1kHz) signal that is useful for probe compensation adjustment. This terminal can also be used as a general check of oscilloscope calibration accuracy. However, it should not be used as a source for calibrating the instrument.

6. **Ground Jack.** Oscilloscope chassis ground, and earth ground via three-wire ac power cord.

Vertical Controls

On dual-trace oscilloscopes, there are two each of items 7 through 11, one for each channel.

7. **Vertical Attenuator (Volts/Div) Control.** Vertical input attenuator. Provides step adjustment of vertical sensitivity in a 1-2-5 sequence. When the variable control (item 8) is set to the calibrated position, vertical sensitivity is calibrated, i.e. it corresponds to dial setting. In the X-Y mode of operation, the Volts/Div controls of the two channels provide step adjustment of the sensitivity of the two axes, X and Y.

8. **Variable Attenuator**. Rotation provides vernier (fine) adjustment of vertical sensitivity. This allows the waveform to be adjusted to an exact number of divisions, although vertical measurements are then uncalibrated. Many oscilloscopes have an auxiliary push-pull function for this control, PULL X5 MAG, in which the vertical sensitivity is magnified by a factor of five times when the switch is pulled. Thus, 5 mV/div sensitivity becomes 1 mV/div. sensitivity. Bandwidth is usually reduced when the X5 MAG function is activated.

9. **Input Jack.** Vertical input. One channel also functions as X-input and the other as Y-input for X-Y operation.

10. **Input Coupling Switch.** Allows selectable coupling of signal to oscilloscope as follows:

    AC: Input signal is capacitively coupled; dc component is blocked.

    Ground: Opens signal path and grounds input to vertical amplifier. This provides a zero-volt base line, the position of which can be used as a reference when performing dc measurements.

    DC: Direct coupling of input signal; both ac and dc components of signal produce vertical deflection.

11. **Vertical Position Control.** Rotation adjusts vertical position of trace. This control usually includes a push-pull switch on either channel 1 or channel 2 to invert the polarity of the signal (PULL INV).

12. **Vertical Mode Control**. Selects display mode of operation (channel 1 displayed, channel 2 displayed, dual-trace, etc.). May also have additional functions as explained below. Configuration of this control may vary from unit to unit, but, generally, it is as follows:
    Channel 1: Single channel display of the channel 1 signal.
    Channel 2: Single channel display of the channel 2 signal.
    Dual: Dual channel display of channel 1 and channel 2 signals. The two traces are displayed in either alternate or chop mode, as explained below.
    Alt/Chop: Selects alternate or chopped mode of dual-trace display.

In alternate mode, the oscilloscope first draws the sweep of the channel 1 signal, then draws the sweep of the channel 2 signal, then repeats in an alternating manner. When fast sweep speeds are selected, the delay between these sweeps is not noticeable to the human eye. However, when slower sweep speeds are selected, the delay becomes quite noticeable.

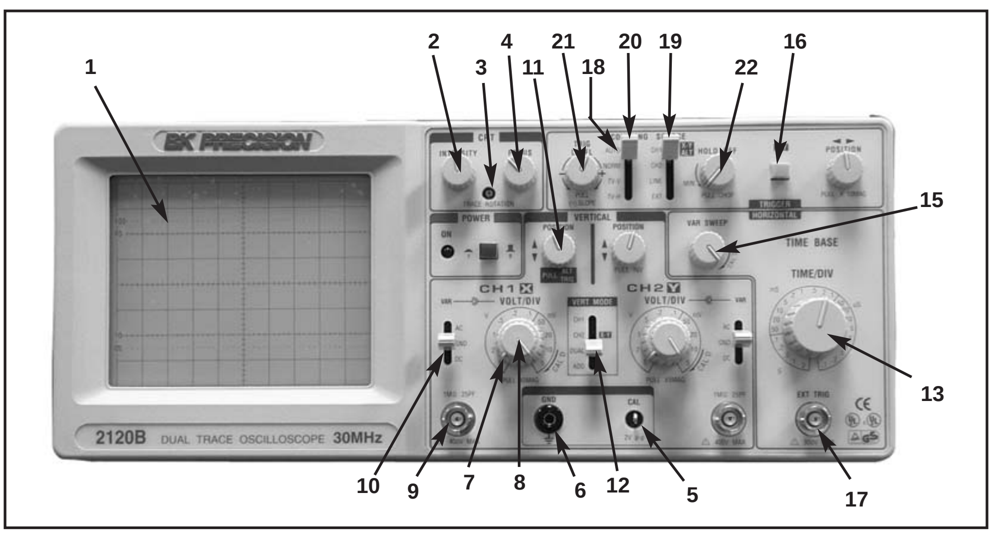

Fig 1. Basic controls and indicators.

CONTROLS AND INDICATORS

In chop mode, the oscilloscope draws a small part of the channel 1 signal, then a small part of the channel 2 signal, and so on, continually switching back and forth until both sweeps are completed. The switching rate is very fast, and this "chopping" is not noticeable to the human eye when slow sweep speeds are selected.

Note:
Some oscilloscopes automatically select chop or alternate display based on the setting of the time base control, enabling chopped display at slower sweep speeds and alternating display at faster speeds.

Add: The channel 1 and channel 2 signals are algebraically combined, and the result is displayed on the CRT as a single trace. This combined signal then represents channel 1 plus channel 2. If one channel is inverted, say channel 2, the result is the algebraic difference, channel 1 minus channel 2.

Horizontal Controls — Sweep Group

13. **Time Base (Time/Div)** Control. Provides step selection of sweep rate for the time base. As with the vertical attenuator, steps are arranged in a 1-2-5 sequence. When the variable time base control (item 14) is set to the calibrated position, sweep rate is calibrated, i.e. it corresponds to dial setting.

14. **Variable Time Base Control.** Rotation of this control provides vernier (fine) adjust ment of the sweep rate. This allows the waveform to be adjusted to an exact num ber of divisions, although horizontal meas urements are then uncalibrated.

15. **Horizontal Position / X10 Magnification Control.**

Horizontal Position: Rotation controls horizontal position of trace.

X10 Magnification: Selects ten times sweep magnification, i.e. if time base is set to 0.1 mS/div, selecting X10 magnification increases this setting to 10nS/div. This is useful for closer inspection of a specific part of the waveform.

16. **X-Y Switch.** Selects X-Y operating mode. In X-Y operation, the CRT display becomes an electronic graph of two instantaneous voltages. One input channel is displayed on the X-axis, and the other on the Y-axis.

Horizontal Controls — Triggering Group

17. **External Trigger Input Jack.** This input allows an external signal to be applied as the trigger source.

18. **Automatic-Normal Trigger Control:** Selects automatic triggering mode, wherein the scope generates a sweep (free runs) in the absence of an adequate trigger signal. It automatically reverts to triggered sweep operation when an adequate trigger signal is present. Auto triggering differs from normal triggered operation in that in normal operation, the sweep does not trigger when a trigger signal is not present. Auto-triggering is handy when first setting up the unit to observe a waveform.

19. **Trigger Source Switch**. Selects the source of the sweep trigger. Some common trigger sources are:

Channel 1: The channel 1 input signal becomes the sweep trigger, regardless of the vertical mode control setting.

Channel 2: The channel 2 input signal becomes the sweep trigger, regardless of the vertical mode control setting.

Alternate: The trigger source alternates between the two traces in dual-trace operation.

External: The signal connected to the external trigger input jack becomes the trigger signal.

20. **Trigger Coupling Switch.** Selects the method by which the trigger signal is coupled to the triggering circuits. Several common trigger coupling modes are:

AC: Trigger signal is capacitively coupled; dc component is blocked.

DC: Trigger signal is direct-coupled. Used for low-frequency (below 20Hz) triggering or to stabilize triggering on a signal with ac and dc components. Not available on all scopes.

TV-H (HF): Used for triggering from video horizontal sync pulses. Also sometimes serves as low frequency reject coupling.

TV-V (LF): Used for triggering from video vertical sync pulses. Also sometimes serves as high frequency reject coupling.

LINE: Signal derived from input line voltage (50/60 Hz) becomes trigger.

21. **Trigger Level / Slope Switch.**

Trigger Level Control: Determines the point on the waveform where the sweep is triggered. Rotation in the (–) direction selects more negative point of triggering, and rotation in the (+) direction selects more positive. Note that rotation too far in either direction may inhibit triggering completely.

Trigger Slope Switch: Selects positive-going slope or negative-going slope as the triggering point on the trigger waveform. In many scopes this control is implemented as a push-pull action on the Triggering Level control. Rear Panel Controls (not shown) Fuse Holder/Line Voltage Selector. Contains fuse and selects line voltage. Sometimes a separate control is used to select line voltage, or, in the case of a switching type power supply, no selection is necessary.

CONTROLS AND INDICATORS

ADVANCED ANALOG OSCILLOSCOPES

Refer to Fig. 2. Higher-end analog oscilloscopes offer a host of features more advanced than those found on basic units. The most prominent advanced features are increased bandwidth, delayed sweep, and component test. Others include variable holdoff, Z-axis (intensity) modulation, bandwidth limiter, and scale illumination.

22. Holdoff Control. Adjusts holdoff time, which is a period after each sweep is completed during which the next sweep is inhibited. Useful for stabilizing complex waveforms that have several possible triggering points.

23. Sweep Mode Switch. Enables the various modes of delayed sweep operation.

Main: Only the main sweep is displayed; the delayed sweep is blanked.

Delay: Only the delayed sweep is displayed.

MIX: The main and delayed sweep share a single trace; the main sweep occupies the left portion of the display, while the delayed sweep occupies the right portion of the display. The "Delay Time" control determines the starting point of the delayed sweep, that is, the percentage of the display that is main sweep and the percentage of the display that is delayed sweep. The main sweep is often brighter than the delayed sweep due to the faster moving beam of the delayed sweep. Delayed sweep cannot be slower than the main sweep.

X-Y: Most delayed-sweep oscilloscopes locate the X-Y switch in this grouping of controls. This switch enables X-Y operating mode as previously mentioned under item 16.

24. Main Time Base (Time/Div) Control. Same as item 13. Provides step selection of sweep rate for the main time base.

25. Delayed Time Base (Time/Div) Control. Provides step selection of sweep rate for the delayed sweep. For meaningful results with delayed sweep, this control should be set to a faster sweep speed than the main sweep time.

26. Delayed Position Control. Adjusts the starting point of the delayed sweep with respect to the start of the main sweep. Sometimes implemented as a rotational control, sometimes as a press-and-hold electronic switch.

27. Scale Illumination Control. On oscilloscopes that have a lighted graticule, this control is provided to control the brightness of that illumination.(Not shown)

28. Beam Finder Switch. This function, found on some units, compresses the vertical and horizontal size of the trace and brings it toward the center of the CRT. This is useful when setting up the oscilloscope and the trace can't be located because the amplitude of the signal pushes the trace off the CRT (or the position controls have been incorrectly adjusted).

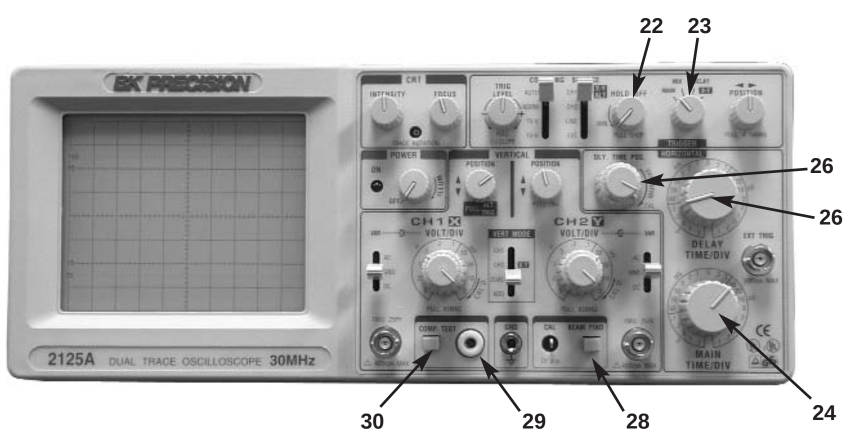

Fig 2. Controls on an advanced analog oscilloscope.

29. Component Test Jacks. Usually two banana jacks; provide input for component test function that produces a component "signature" on the CRT by applying an ac signal across a device. Rather than the usual oscilloscope display of voltage versus time, the display shows a graph of voltage versus current. The signatures thus produced are characteristic of the device being tested — resistor, capacitor, etc., and can be used to detect defective components.

30. Component Test Switch. Turns component test mode on or off.

Additional Controls (not shown in the figure):

Bandwidth Limiter. Reduces the bandwidth of some high-frequency models. Helps to eliminate radio-frequency noise when making low-frequency measurements.

Y-Axis Output Jack (on rear panel). Output terminal where a sample of the channel 2 (may be channel 1 on some oscilloscopes) is available. Amplitude of this signal is usually 50 mV/div of vertical deflection on the CRT, when terminated into 50 ohms. Useful for triggering frequency counters from a low level signal.

Z-Axis Input Jack (on rear panel). Sometimes called "External Blanking Input". Input jack for intensity modulation of the CRT electron beam.

CONTROLS AND INDICATORS

DIGITAL STORAGE OSCILLOSCOPES (DSO)

Refer to Fig. 3 for typical DSO controls and indicators.

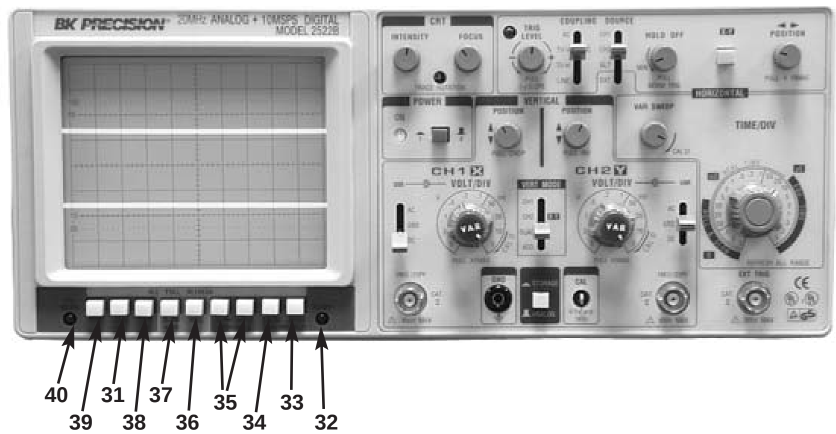

Fig 3. Cursor and readout controls

31. Storage Push Button. Switches the oscilloscope from analog to digital storage operation. When all other digital storage mode switches are released, the scope operates in "Refresh" mode. In "Refresh" mode, the memory is continuously strobed onto the display. When the memory is filled, the next trigger signal will cause the memory to be filled again (refreshed).

32. Ready Indicator. In "Single Sweep" mode of digital storage, this indicator lights when the Reset switch is pressed and goes off when the trigger arrives.

33. Reset Pushbutton. In "Single Sweep" mode, readies the scope to store a one-time event. After the Reset button is pressed, the next trigger will cause a single sweep and the memory will be filled.

34. Single Pushbutton. Enables the "Single Sweep" mode.

35. Pre-Trigger Pushbuttons. Allows a portion of the waveform before the trigger to be displayed. Selections of 0%, 25%, 50%, and 75% are possible. Pre-Trigger operation is applicable to "Single Sweep" mode only

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36. Roll Pushbutton. Selects the "Roll" mode, wherein the waveform rolls through the memory. This mode is applicable only to slowly changing waveforms and permits viewing of the entire waveform, which would not be possible on an analog oscilloscope.

37. Slow X100 Pushbutton. Expands the time base by a factor of 100 times for very slow sweep time, up to 50 seconds per divisions.

38. Save Pushbuttons. Freezes the channel 2 waveform or all waveforms, respectively. The channel 2 waveform can be saved for comparison to the waveform from another piece of equipment. Both waveforms can be saved, usually in preparation for plotting.

39. Plot Pushbutton. Enables the channel 1 output, channel 2 output, and Pen Down output on the rear panel of the scope. Permits plotting on an analog plotter.

40. Pen Down Indicator. In "Plot" mode, lights when the plotter output cycles to the "Pen Down" condition. Goes off at the end of the plot.

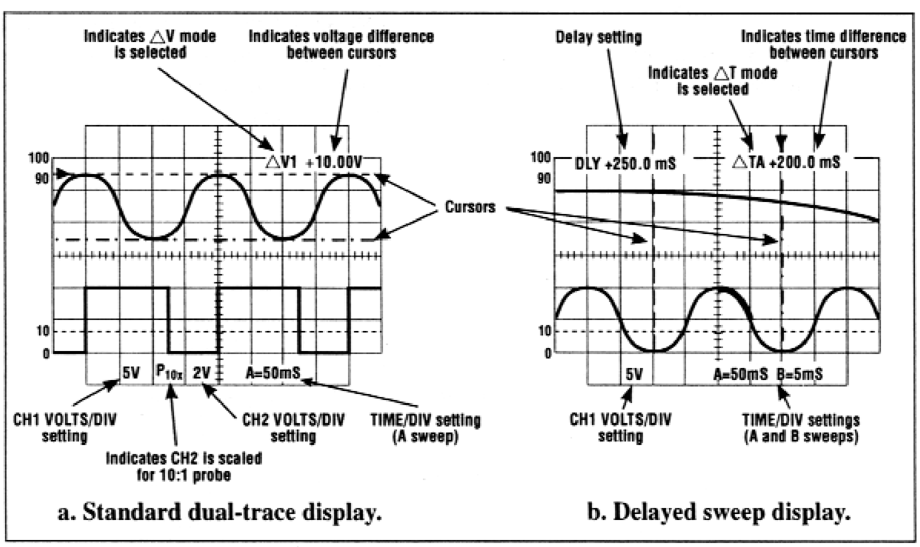

Fig 4. Cursor and readout displays.

OPERATING AN OSCILLOSCOPE

BASIC ANALOG OSCILLOSCOPES

This chapter provides a complete step-by-step procedure on oscilloscope operation. It begins with basic scope operation and proceeds to more advanced features.

Initial Startup Procedure

The first step in using any oscilloscope, from a simple dual-trace unit to the most sophisticated DSO, is turning it on and obtaining a trace.

1. The following basic controls should be present in some form on any scope. Set them as follows:

   a. Channel 1 input coupling switch (AC-GND-DC switch): GND.

   b. Channel 1 vertical position control: centered.

   c. Horizontal position control: centered.

   d. Auto trigger control: auto triggering on.
   e. Vertical mode control: channel 1 (single trace).

   f. Intensity control: minimum intensity.

   g. TIMEJDIV control: 0.5 mS/Div.

These settings prepare the unit for a single-trace display of a zero-volt base line, centered vertically and horizontally. At this point, no signal needs to be connected.

Fig. 1 shows these control settings on a typical unit, a **B+K Precision** Model 2120B.

2. Plug the scope into ac power and turn the Power switch on. Allow the unit a few seconds to warm up.

3. Slowly bring the Intensity control up. You should see a horizontal trace somewhere near the center of the screen.

4. You can adjust the trace sharpness with the Focus control, and, if necessary, adjust the trace tilt with the Trace Rotation control.

Displaying a Signal

This procedure displays a waveform on channel 1. The exact same process can be used for a single-trace display on channel 2.

1. Connect a signal to the channel 1 input jack. This can be a point in a test circuit connected via a scope probe, or the output of a function generator, via a BNC-to-BNC cable. If probing in a test circuit, first connect the probe's ground clip to the chassis or common of the equipment under test. Then connect the probe tip to the point of interest.

Tips:

Always use the probe ground clips attached to a circuit ground point near the point of measurement. Do not rely solely on an external ground wire in lieu of the probe ground clips, as undesired signals may be induced.

The probes should be compensated. Compensation matches the probe to the input of the scope. It should be adjusted initially, and then the same probe always used with the same channel. The chapter on "Oscilloscope Probes" discusses compensation.

When using a signal generator whose output has fast edges such as square waves or pulses, terminate the output into its characteristic impedance to minimize ringing. For example, a 50-ohm generator output should be terminated into an external 50-ohm resistor and connected to the scope with 50-ohm coaxial cable.

2. Set the channel 1 input coupling switch to AC.

3. If no waveforms appear, increase the sensitivity by turning the channel 1 vertical attenuator (Volts/Div.) clockwise to a position that gives 2 to 6 divisions vertical deflection.

4. The display on the screen may be unsynchronized, that is, not locked in place. You should be able to steady it using the Trigger Level control. Use the sweep time control (Time/Div.) to display the desired number of cycles. The "Triggering" and "Time Base" sections of this chapter discuss these controls in more detail.

Dual-Trace Display

The capability of an oscilloscope to display two simultaneous waveforms, dual-trace mode, is a very useful feature. In observing simultaneous waveforms on channels 1 and 2, the waveforms are usually related in frequency, or one of the waveforms is synchronized to the other, although the basic frequencies are different. For example, Fig. 5 depicts the waveforms associated with a simple flip-flop circuit, wherein the first trace shows the clock waveform and the second the output waveform. The scope clearly shows that the output is a divide-by-two of the clock, and that output changes always take place on the negative-going edge of the clock.

To obtain a dual-trace display:

1. Connect probes to both the channel 1 and channel 2 input jacks of the oscilloscope.

2. Connect the ground clips of the probes to the chassis or common of the circuit under observation. Connect the tips of the probes to the two circuit points of interest.

3. Locate the control that activates dual-trace mode on your oscilloscope. Some scopes simply have a position in the "Vertical Mode" switch labeled "Dual". However, many units have two distinct positions called "Alt" and "Chop". These activate two different kinds of dual-trace sweep, as follows:

   a. "Alt" stands for "alternate" sweep. The oscilloscope first draws the complete sweep of the channel 1 signal, then draws the complete sweep of the channel 2 signal, then repeats in an alternating manner. When fast sweep speeds are selected, the two traces appear to the human eye as simultaneous. The fact that they really aren't becomes more and more evident as sweep rate is decreased.

   b. "Chop" stands for "chopped" sweep. The scope draws a small part of the channel 1 signal, then a small part of the channel 2 signal, and so on, continually switching back and forth until both sweeps are complete. When slow sweep speeds are

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selected, the chopping is much faster than the sweep and is unnoticeable. If chop mode is used at very high sweep rates, the chop rate becomes a significant portion of the sweep and may become visible in the displayed waveform. Chopping may also become noticeable if the input signal frequency is close to, or a sub-multiple of, the chop frequency.

Note:

Alternate and chop sweep techniques are actually used in all multi-trace oscilloscopes. However, many units automatically choose alt or chop depending on the time base setting you select. These are the units that have one single "Dual" switch instead of separate "Alt" and "Chop" facilities.

4. Adjust the channel 1 and 2 vertical position controls to position the two traces as desired. Channel 1 is usually positioned above channel 2, as in Fig. 5.

5. Set the channel 1 and channel 2 vertical attenuators (Volts/Div.) so that the wave forms are the desired height.

6. Set the time base (Time/Div.) control for the desired number of cycles of the waveforms. If the display is unsynchronized ("rolling"), attempt to lock it with the Trigger Level control. Consult the section on "Triggering" later in this chapter for more information on obtaining a stable waveform.

The Vertical Attenuator (Volts/Div) Controls

On dual-trace scopes, there are two of these, one each for channel 1 and channel 2. These controls adjust the vertical height of the waveform on the screen. They do this by attenuating the input signal by a selected amount before it is applied to the scopes vertical amplifier. The amount of attenuation is always rendered on the dial in a 1-2-5 sequence, and is calibrated in volts/division. Here, "division" means the squares on the scope graticule, generally 1 cm in area. (It does not refer to the smaller subdivisions on the center graticule lines.) Therefore, for example, if the channel 1 vertical attenuator is set to 2 volts/division, and a sine wave is

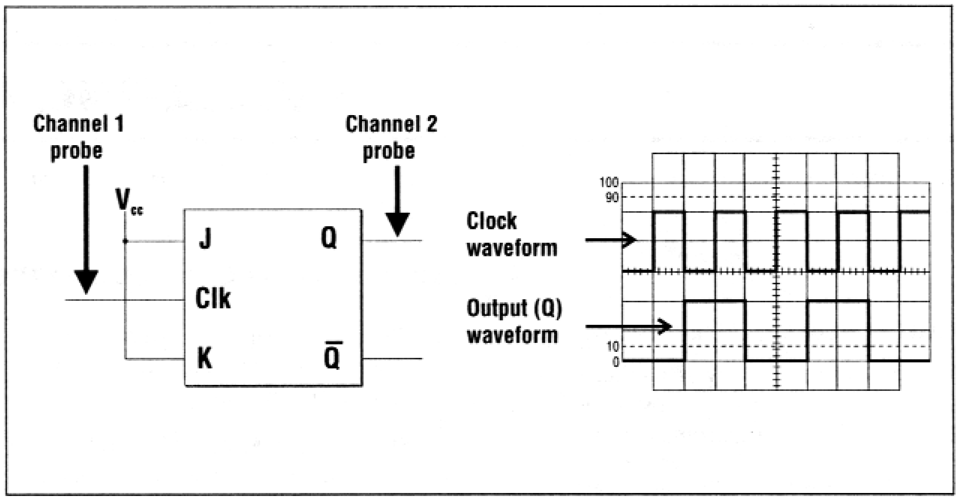

Fig. 5 A simple dual-trace display

displayed which covers 4 divisions from top to bottom, then that sine wave has a peak-to-peak amplitude of 8 volts.

Two things should be noted in this regard. First, there usually is a Variable control associated with the vertical attenuator. This must be set to the "Calibrated" position in order for measurements to be accurate. The Variable control allows you to smoothly vary the waveform height between calibrated settings of the attenuator. Some units have a built-in LED which lights to inform you that measurements are not calibrated because of this control's setting.

Second, the use of a 10:1 probe multiplies the vertical attenuator dial setting by 10. For example, if the attenuator is set to 0.2 volts/division, and a 10:1 probe is being used, the actual value being obtained from the screen is 2 volts/division. A detailed discussion of probes is given in the chapter on "Oscilloscope Probes".

The chapter on "Applications" gives more information about on-screen voltage measurements; see "Instantaneous DC Voltage Measurements" and "Peak-to-Peak Voltage Measurements", in that chapter.

The Time Base (Time/Div) Control

This control adjusts the sweep speed of the oscilloscope. Its settings are calibrated in a 1-2-5 sequence, in units of time per division. These indicate how long the dot takes to travel horizontally across one square division on the graticule. For example, if the time base control is set to 2 mS/division, and an event on the screen, say the positive half of a square wave, extends for 3 divisions, then that event is 6 milliseconds long. This is an example of determining a "time interval" with the scope. Frequency can also be determined. Both are discussed in more detail in the "Applications" chapter.

As with the vertical attenuators, there is usually a Variable control which must be set to "Calibrated" for horizontal measurements to be accurate.

Use the time base control to display the desired number of cycles of a waveform. If there are too many cycles displayed for good resolution, switch to a faster sweep time. If only a line is displayed, try a slower sweep time. When the sweep time is faster than the waveform being observed, only part of it will be displayed, which may appear as a straight line for a square wave or pulse waveform.

Some more advanced scopes have a second time base control; this is discussed in the section on "Delayed Sweep Operation", later in this chapter.

Triggering

The trigger is the event or signal that causes the oscilloscope CRT beam to begin its sweep across the display. Without an adequate trigger, the display starts at unrelated points on the waveform, and the result is a display that is unsynchronized, or "rolls". For the display to be synchronized, or stable, the trigger event should

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be related in some way to the displayed waveform. Many times it is the waveform itself. Modern oscilloscopes provide versatility in selection of trigger signal, method of coupling the trigger signal into the scope, and positioning of the actual trigger point on the trigger signal waveform.

Normal vs. Auto Triggering

Virtually all oscilloscopes provide these two triggering modes; each works as follows:

Normal: The sweep remains at rest until the trigger occurs. That trigger causes one sweep to be generated, after which the sweep again remains at rest until the next trigger. If an adequate trigger signal is not present, no trace is displayed.

Auto: The sweep generator continually gen erates a sweep even if no trigger signal is present. However, it automatically reverts to triggered sweep operation in the presence of a suitable trigger signal.

Auto triggering is handy when first setting up the scope to observe a waveform; it provides a sweep for waveform observation until other controls can be properly set. (Once the controls are set, the scope is often switched to normal triggering mode because that mode is generally more sensitive.) Auto triggering must be used for dc measurements and signals of such low magnitude that they will not trigger the sweep.

Typically, in the normal triggering mode, signals that produce even 1/2 division of vertical deflection are adequate to produce a display.

Level and Slope Controls

A sweep trigger is developed when the trigger source signal crosses a preset threshold level. Every oscilloscope has a Trigger Level control which shifts the threshold level "up" or "down" (i.e. positive or negative) on the trigger waveform. Refer to Fig. 6. The Level control adjusts the start of the sweep to almost any desired point on the waveform. When the control is centered, the threshold level is set at the approximate average of the trigger signal. On sinewave signals, the phase at which sweep begins is variable in this fashion. Note that if the Trigger Level control is rotated toward its extreme (+) or (–) setting, no sweep will be developed in the normal trigger mode because the triggering threshold exceeds the peak amplitude of the trigger signal.

The Trigger Slope switch, also present on every scope, selects the slope of the trigger signal at the threshold. Refer again to Fig. 6. If Trigger Slope is set to the (+) position, sweep is developed from the trigger signal as it crosses the threshold level in a positive-going direction. In the (–) position, sweep is developed as the signal crosses the threshold in a negative-going direction.

On many units the Slope and Level functions are combined into one control, usually a push-pull action (Slope) on a rotary knob (Level).

Trigger Source Selection

Oscilloscopes generally permit you to choose which signal is to be used as the trigger signal.

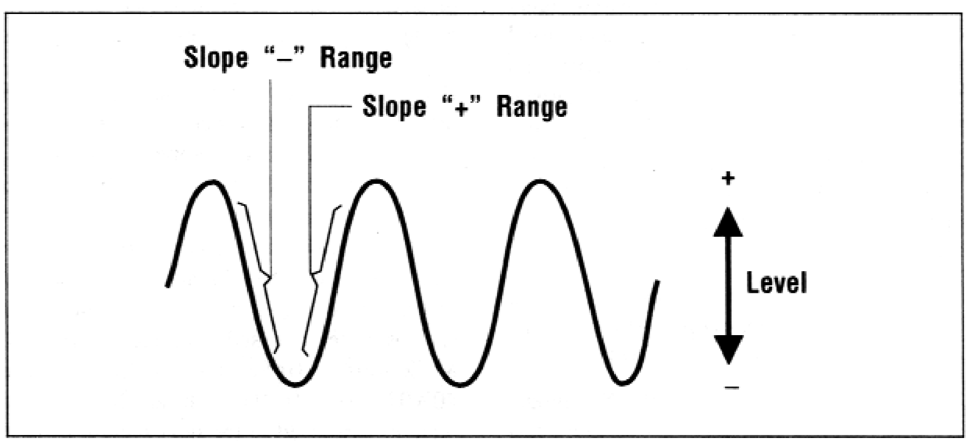

Fig. 6 Function of SLOPE and LEVEL controls

Oftentimes a scope's seeming inability to trigger is actually due to the operators having forgotten to select the appropriate signal as trigger.

The Trigger Source selector is usually a multi-position switch. Among modern scopes common offerings are:

Channel 1: The channel 1 signal is connected to the triggering circuits. In many units this can be so even if the channel 1 signal is not displayed. Thus, you could use channel 1 to trigger a channel 2 display. If they are related to each other in frequency, this will probably result in a stable display. Also, channel 1 could be used to trigger a dual-trace display of both channel 1 and channel 2. Again, if they are related, both traces will be stable.

Channel 2: Channel 2 is used for trigger, with the same considerations as channel 1 above.

Alternate: In dual-trace mode, the channel 1 trace is triggered by channel 1 and the chan nel 2 trace by channel 2. In this situation, you should realize that, although both waveforms are shown as stable traces, you cannot determine their phase or timing relationship to each other. This is because they are not triggering from a common source.

External: An external signal can be used as the trigger signal. This is usually applied to the "External Trigger" jack. This is useful when you wish to use a signal other than those displayed as the trigger, possibly because it may be a more suitable source (e.g. more amplitude, sharper edge).

Line: A signal internally developed from the input line voltage (50/60 Hz) becomes the trigger signal. This is useful when you are trying to observe power line "hum" on a signal with other components present. The "hum" component becomes more stable and hence, more clearly visible.

Trigger Coupling Selection

Besides being able to select which signal is to be trigger source, you are also able to choose the manner in which that signal is coupled to the trigger circuits. Modes commonly available are:

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AC: This is used for viewing most types of waveforms. The trigger signal is capacitively coupled (dc component blocked) and may be used for all signals from below 30 Hz (depending on the unit) to the top frequency of the particular scope.

DC: Couples both the ac and dc component of the trigger signal. This is useful for viewing signals with frequency lower than the cutoff of the "AC" position above, or when you need to include the dc component for proper stabilization of the signal.

TV-H: Used for viewing horizontal sync pulses in composite video waveforms. A high-pass filter is employed, which couples through only higher-frequency components such as horizontal sync pulses. This position can also be used as a general high-pass (low-fre quency reject) position, and as such is sometimes labeled "HF".

TV-V: Used for viewing vertical sync pulses in composite video waveforms. A low-pass filter is employed, which couples through only lower-frequency components such as vertical sync pulses. This position can also be used as a general low-pass (high-frequency reject) position, and as such is sometimes labeled "LF".

Video: On some scopes, this general setting is provided instead of the two previous ones. Coupling is automatically switched between horizontal or vertical sync pulses depending on the setting of the main time base.

Vertical and Horizontal Magnifiers

Most scopes permit magnification of the on-screen waveform in both the vertical and horizontal direction.

Vertical magnifiers are usually implemented as a push-pull action on the Variable control for each vertical attenuator. Generally a factor of X5, this magnification can also be thought of as extending the sensitivity of the unit by one or two ranges. For example, if a scope has a minimum vertical attenuator setting of 5 mV/division, the X5 multiplier can provide two extra ranges: 2 mV/division (on the regular 10 mV/division setting) and 1 mV/division (on the regular 5 mV/division setting).

With this increase in ranges, however, come two performance degradations. First, the bandwidth of the scope is reduced when the magnifier is active. The reduction may he drastic; a 60 MHz unit may be limited to 10 MHz in this mode. (For a discussion of the bandwidth concept, see the "Bandwidth" section of this chapter.) Secondly, using the magnifier on the most sensitive settings results in increased noise on the waveform. The trace appears thicker and out-of-focus.

Horizontal magnification is usually achieved through a push-pull action on either the Variable Time Base control or the Horizontal Position control. Magnification factor is usually X 10. This feature is helpful in viewing a portion of a waveform that might disappear off the right of the screen if the Time Base setting is increased. Even though the waveform is magnified, rotating the Horizontal Position control can still enable you to observe every portion of it.

The Add and Invert Functions

A very common feature on modern oscilloscopes is the Add mode, which permits the channel 1 and channel 2 signals to be algebraically combined and displayed as one trace. This feature is particularly useful when used in conjunction with the "Invert" function. Invert takes one of the input channels and reverses its polarity on the display. For example, the highs of a sine wave are shown as lows, and vice versa. Any dc offset is also inverted (i.e. a positive dc offset becomes a negative one), assuming that the scope is set for dc coupling.

In effect, when an uninverted channel is added to an inverted one, the result is the algebraic difference. This is handy for differential measurements (when you wish to observe a signal not referenced to ground) and elimination of undesired signal components. Both uses are discussed in the "Applications" chapter of this manual.

The Add function is usually implemented on the same control that selects single-trace or dual-trace mode, i.e. the Vertical Mode control. The Invert function may be implemented on channel 1 or channel 2, depending on the particular scope, and may be a Vertical Mode control, a secondary function of the Variable attenuator, or a separate switch.

X-Y Operation

X-Y operation permits the oscilloscope to perform many measurements not possible with conventional sweep operation. The CRT display becomes an electronic graph of two instantaneous voltages. One voltage deflects the beam vertically (Y), and the other deflects it horizontally (X). The sweep aspects of the scope are disabled. Thus, with no signals connected, the display is merely a dot.

The signals being applied may be two voltages, such as stereoscope display of stereo signal outputs. However, the X-Y mode can be used to graph almost any dynamic characteristic if a transducer is used to change the characteristic (frequency, temperature, velocity, etc.) into a voltage. One common application is frequency response measurements, where the Y axis corresponds to signal amplitude and the X axis to frequency.

The controls used to implement X-Y mode vary among different scopes. However, the general procedure for using it is as follows:

1. Locate the switch that enables X-Y mode. This may be a separate switch, or the last position of the Time Base selector. On scopes with delayed sweep capability, it is usually one of the Sweep Mode selections. Turn on the X-Y mode. Make sure the trace intensity is not set too high; a bright stationary dot in one spot on the screen can be damaging if left there for a long time.

2. The channel 1 and channel 2 inputs now become X and Y inputs, though not necessarily in that order. Apply the desired signals to these channels.

3. The vertical attenuators now become the X and Y attenuators, i.e. one controls the height of the waveform, and the other its width. The Variable attenuator controls function similarly.

4. Positioning of the X-Y waveform is as follows:

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a. Generally, the Vertical Position control of whichever channel is the Y-axis becomes the vertical positioning control for X-Y displays.
b. Horizontal positioning is accomplished by either the vertical control for the other channel, or the Horizontal Position control for the scope.

The "Applications" chapter discusses two common uses of X-Y mode, phase measurements and frequency response measurements.

Bandwidth

Bandwidth, or frequency response, is one of the most important characteristics of an oscilloscope. It is often the determining factor in preferring one unit over another.

By convention, bandwidth, which is measured in MHz, is the frequency at which signal amplitude "rolls off" by 3 dB from its value at 1 kHz. For example, assume that a 1 kHz signal produces a waveform six divisions high on a given Volts/Div setting. If that signal is increased in frequency (but input amplitude is kept constant), the frequency at which the display is reduced to 4.24 divisions (–3 dB, or 70.7%) is the bandwidth of the scope.

Bandwidth is important because it dictates the highest frequency at which accurate measurements can be made with a given oscilloscope. As might be expected, the scope buyer pays more for higher bandwidth. The range of applications and measurements goes up as the bandwidth does, and the availability of advanced features also increases. Basic oscilloscopes such as those discussed so far are generally 20 MHz or 30 MHz units. Higher bandwidths include 40 MHz, 60 MHz, 100 MHz, and beyond. The features discussed in the next section usually imply a minimum bandwidth of 40 MHz.

Using an Oscilloscope with 1 millivolt Sensitivity

Many oscilloscopes have a X5 MAG (5 times magnification of the vertical input signal) feature. With X5 magnification, the 10 mV/div attenuator setting becomes 2 mV/div sensitivity, and the 5 mV/div attenuator setting becomes 1 mV/div sensitivity. At these high sensitivity settings, special care must be taken for reliable low level measurements. Keep the following points in mind when measuring very low level signals.

- Placement of the ground clip may become critical if the signal ground circuitry carries appreciable current. Voltage differences of several millivolts are common from one side of a chassis to another. Attach the ground clip to a ground point nearest the point of signal measurement (the probe tip). This usually gives the smallest error. You may need to move the ground clip as you move the probe to other points of measurement.

- It may be difficult to eliminate the pickup of stray 60 Hz signals, especially in high impedance circuits. Be sure to use shielded test cables. If necessary, shield the area around the probe tip.Wideband measurements become more difficult at 1 mV/div and 2 mV/div because of the inherent thermal noise of electronic components. The trace may appear "fuzzy" or wide and out of focus.

- Noise that appears as peaks or spikes may be caused by electromagnetic pickup of external interference, such as automotive ignition, computer clock pulses, etc. Such noise may also cause erratic triggering. If possible, shield the unit under test from external interference.

- Radio interference may be picked up in strong RF signal areas, such as a nearby AM broadcast station, CB radios, or other transmitting devices. Unshielded probes and test cables can act as antennas to magnify this type of interference.

- Use the lowest sensitivity possible for the measurement. Do not use 1 mV/div sensitivity if the measurement can be made at 5 mV/div sensitivity. Perhaps the probe can be switched to X1 instead of using X5 MAG, however, be aware that the probe's bandwidth is sharply reduced at X1 and its input impedance is much lower.

- Thermal drift may be apparent at high sensitivity if the test connections are across a semi-conductor junction or two dissimilar metals. The trace may drift as the junction temperature changes.

ADVANCED ANALOG OSCILLOSCOPES

This section discusses advanced features generally found on higher-bandwidth oscilloscopes, such as delayed sweep, variable holdoff, etc. However, B+K Precision offers a deluxe 30 MHz oscilloscope with many of the advanced features described here, including delayed sweep, component test, Y-axis output, and Z-axis input. This scope is Model 2125A.

Delayed Sweep

The delayed sweep feature permits the operator to magnify a portion of the trace for closer examination. While this can be done by using the horizontal magnifier as mentioned previously, delayed sweep provides higher orders of magnification, many more degrees of magnification, and the means to observe both the magnified and original waveforms simultaneously.

The feature is called "delayed sweep" because the magnification is achieved by delaying the beginning of the trace for a period determined by the operator. After this delay, the sweep then runs at a speed which the operator sets via a second Time Base control, separate from the main Time Base. By adjusting both the delay time and the sweep speed, the operator varies the position and the width of the magnified portion.

The delayed sweep (often referred to as the B sweep) begins immediately after the delay period selected by the operator is over. Adjustment range of the delay time is "continuous".

Note:

To obtain meaningful results with delayed sweep, the delayed sweep must be set to a faster sweep speed than the main sweep. This makes sense, since we are magnifying a portion of the original waveform.

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1. Initially set the unit for normal sweep operation. On most units this will be called "Main", and is most likely found as a position of a "Sweep" mode switch.

2. Connect a signal to one of the input channels. You may want to stay in single channel mode, to avoid clutter of too many waveforms on the screen. Set the oscilloscope as usual for a normal, stable display.

3. Turn on delayed sweep operation. On most units this is a position labeled "MIX" on the "Sweep" mode switch.

4. The display will show the main sweep on the left portion of the trace and the delayed sweep on the right portion of the trace, as shown in Fig. 7. The main sweep portion is usually brighter than the delayed sweep portion.

5. The beginning point of the delayed sweep can be adjusted using the "Delay Time" control.

6. The delayed sweep only may be viewed by switching the "Sweep" mode switch to the "Delay" position.

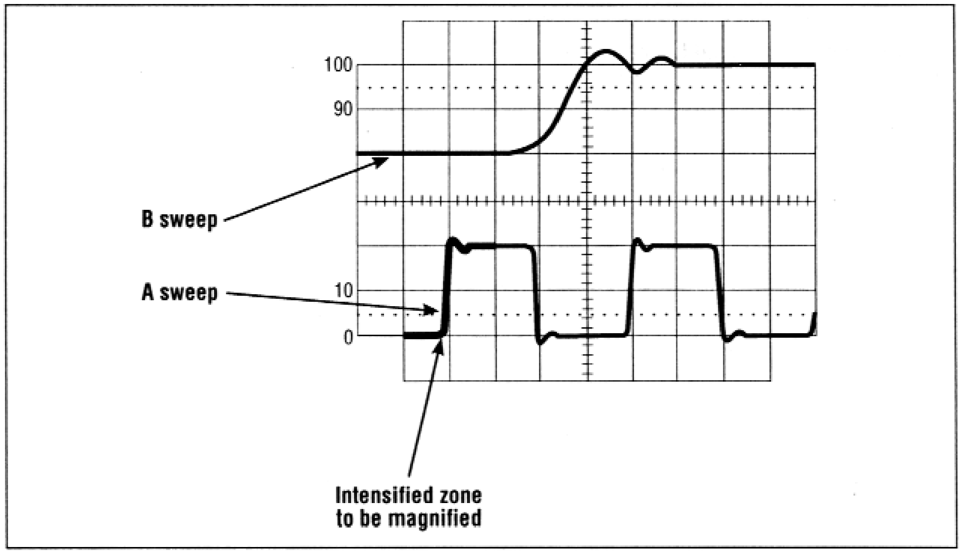

Fig. 7 Delayed sweep display.

Variable Holdoff

A "holdoff" period occurs immediately after the completion of each sweep and is a period during which triggering of the next sweep is inhibited. The normal holdoff period varies with sweep rate, but is adequate to assure complete retrace and stabilization before the next sweep trigger is permitted. Some scopes provide a Holdoff control that allows this period to be extended by a variable amount, if desired.

The Holdoff control is used when a complex series of pulses appears periodically, such as in Fig. 8a. Improper sync may produce a double image, as in Fig. 8b. Such a display could be synchronized by adjusting the Variable Time Base control, but this is impractical because time measurements would then be uncalibrated. However, synchronization can be achieved with the Holdoff control. The sweep speed remains the same, but the triggering of the next sweep is "held off" for the duration selected by the Holdoff control.

Component Test

Some oscilloscopes include a component test function. In this mode, normal sweep is disabled and a component test pattern is displayed. A sine wave test signal is available at a pair of test jacks on the oscilloscope. Using test leads, this sine wave signal is applied to the component under test. The component may be out-of-circuit or in-circuit on a non-powered chassis. The displayed pattern (signature) is a dynamic plot of the impedance of the component with a sine wave signal applied. This test technique is very effective at locating defective components. The preferred method of testing is to use patterns from a known-good chassis for reference. Shorted, open, and leaky components produce patterns very dissimilar from reference patterns. Good components produce patterns identical or very similar to the reference patterns. Fig. 9 shows some typical patterns using component test.

Other Advanced Features

Y-Axis Output

This feature allows a sample of the vertical signal (usually channel 2, but may be channel 1 on some oscilloscopes) to be used externally. The output signal is buffered from a low impedance source, usually 50 ohms. The amplitude of the Y-axis output is usually 50 millivolts per division of the vertical deflection seen on the screen of the CRT when terminated into 50 ohms. When unterminated (or terminated into a high impedance), the output is 100 mV/div. The Y-axis output allows the oscilloscope to be used as a wideband preamplifier. One typical application is to amplify a low level signal adequately to drive a frequency counter. A 10 mV peak-to-peak signal (about 3.6 mV rms) is not adequate to drive most frequency counters, however, it is enough to give two vertical divisions amplitude on an

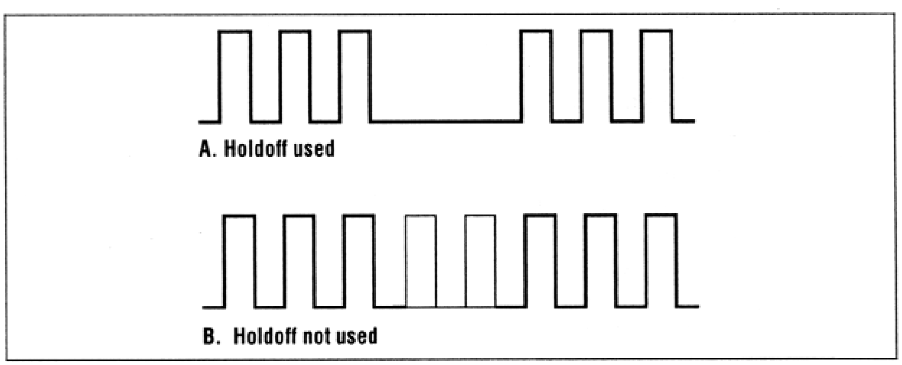

Fig. 8b Use of HOLDOFF control.

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oscilloscope set at 5 mV/div sensitivity. With two divisions deflection on the CRT, the output of the Y-axis output (terminated into 1 megohm input impedance of most counters) is 200 millivolts peak-to-peak or 71 millivolts rms. This is plenty to drive the frequency counter solidly.

Z-Axis Input

This feature is sometimes called intensity modulation. When a signal is applied to the rear-panel Z-Axis input jack, the electron beam (which produces the scope display) varies in intensity according to the amplitude of that input. Thus, the display can be intensity modulated in a manner similar to a video or television display. Usually, the front panel Intensity control can be adjusted so that TTL levels at the Z-Axis jack turn the beam on and off completely. The polarity of the modulation depends on the particular model of scope. Some displays grow brighter with a more positive voltage; others require a more negative voltage for a brighter display.

Beam Finder

This convenience feature helps you to find a trace that may be off the area of the screen. Beam Finder compresses the trace and "pulls" it into the CRT area, so that you may know in which direction the trace is off screen, Don't keep this momentary function on for too long, however; it also puts the trace at full intensity to help you locate it..

Bandwidth Limiter

On higher-frequency scopes, this switch allows the bandwidth to be scaled down. For example, a 100 MHz unit might offer a limiter that reduces it to 20 MHz. This feature is useful for filtering out higher-frequency noise, such as radio frequency interference, when using the scope for lower-frequency measurements.

Scale Illumination

This is a control, placed near the scope display, which causes the graticule to be illuminated for visibility in dark environments. This is usually done with small light bulbs placed around the perimeter of the display. The control varies the intensity of the illumination. The graticule is composed of a reflective substance that evens out the illumination over the total area of the grid

DIGITAL STORAGE OSCILLOSCOPES (DSO)

Description

The digital storage oscilloscope, or DSO, is a recent major development in the oscilloscope field. Instead of merely displaying a waveform on the CRT as it occurs, as does a standard analog oscilloscope, the DSO digitizes the incoming signal, stores it in memory, then continuously displays the contents of the memory on the screen. This enables the operator to capture and view one-time events, including activity immediately before the event itself (pre-trigger capture). DSOs are also excellent for displaying slow events that are difficult or impossible to view on standard analog oscilloscopes. DSOs can also store repetitive waveforms in memory, as well as one-time or slow waveforms, and transfer them to a plotter for future reference.

Although DSOs vary widely in features and operation, most DSOs include the basic features described in the following discussion, which is based on B+K Precision Model 2522B. The Model 2522B is a "hybrid" unit that can operate in conventional analog mode or in digital storage mode. The hybrid approach is often an advantage over full digital models in simplifying setup. The hybrid models can be adjusted in the familiar analog mode, then switched to digital storage operation for the actual waveform capture.

Digitizing One-time Events

One of the most powerful features of a digital storage oscilloscope is its ability to capture one-time events. To do this, single-sweep operation is employed, using the Single and Reset (or Arm) button. When the Reset button is pressed, it readies the digital storage circuit to receive a trigger signal—presumably the event to be captured or some other time-related occurrence. When the event arrives, it is stored in memory and displayed.

Capture of one-time events is an ideal use for a hybrid DSO. The triggering adjustments can be made in analog mode, and then the actual capture done in digital. The procedure is as follows:

1. Set the scope to analog mode. Set the Trigger Level control for normal (not auto) triggering, and adjust the level so that the unit triggers on the event to be captured. This usually involves making the event occur a few times with the scope in analog mode. Using normal triggering is important because even though the event may be too brief to readily observe in analog mode, it will cause one sweep to cross the screen in normal triggering mode. This is helpful in getting the Trigger Level set correctly.
2. Press the Storage switch to enter the storage mode.
3. Press the Single button, then the Reset (or Arm) button. The Ready indicator (or Armed indicator) lights while waiting for the trigger signal and goes off when the trigger of the one-time event occurs.
4. The one-time event that has been captured in memory is displayed continuously until Reset is pressed again to capture another one-time event or until the mode is changed.

Pre-trigger and Post-trigger View

One of the big advantages of a DSO is its ability to view occurrences before the trigger, or pre-trigger view, as well as occurrences after the trigger, or post-trigger view. For example, not only can a voltage spike be observed, but perhaps the activity that caused it. In a conventional analog oscilloscope, the sweep begins at the trigger. Thus, only post-trigger events can be viewed. In DSOs, waveform recording does not begin with the occurrence of a trigger, it is continuous. Rather, the trigger determines where the waveform recording stops. The operator can set the trigger to occur at the beginning of the memory (0% pre-trigger), at the middle of the memory (50% pre-trigger), or at other points in the memory (25% and 75% pre-trigger with Model 2522B). Fig. 10a shows a waveform with 0% pre-trigger, and Fig. 10b shows the same waveform with 50% pre-trigger. Note that in Fig. 10b, observance of the time period immediately before the trigger is possible.

Digitizing Repetitive Events

Though the capture of one-time events is probably the most powerful aspect of a DSO, many units can also digitize conventional repetitive waveforms, such as those observed on a standard analog scope. To do this, a DSO

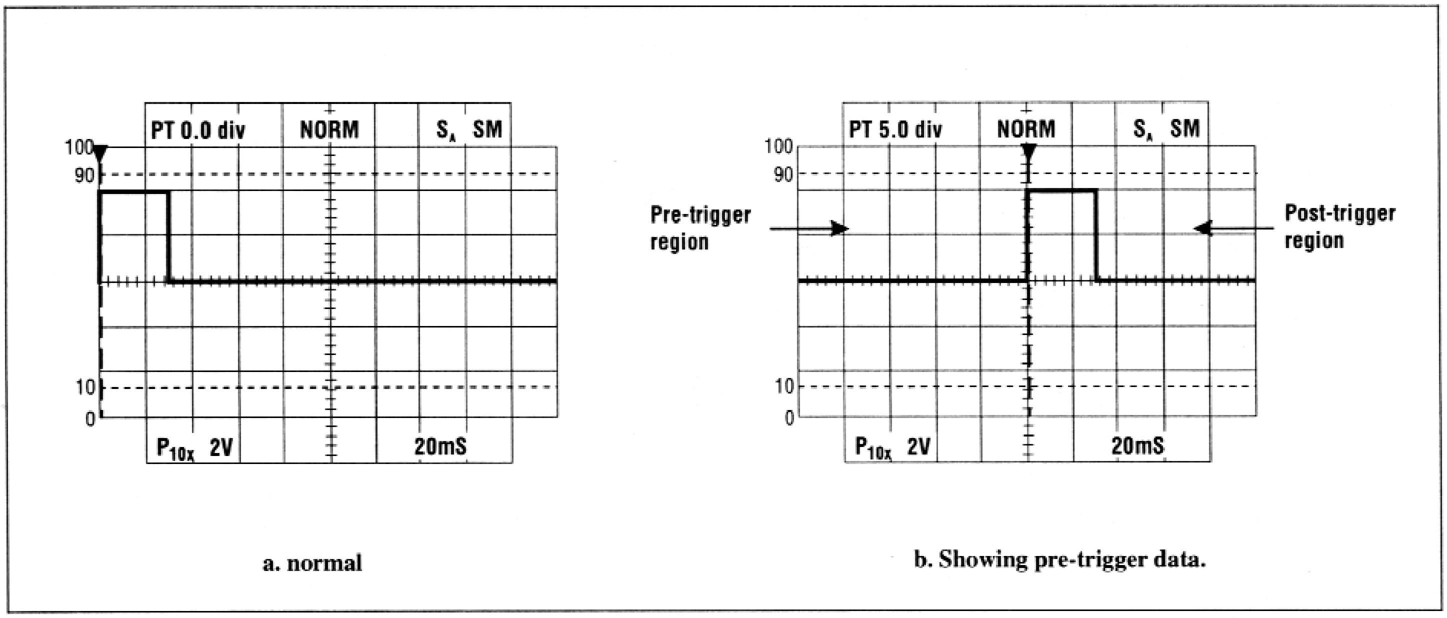

Fig. 10 Capture of a cone-time event.

uses what is commonly referred to as a "Refresh" mode, wherein the waveform is stored anew as each trigger signal arrives.
Although analog scopes are usually adequate to view repetitive events, some such signals can be viewed and measured much more effectively on a DSO. For example, a slow signal below 60 Hz may appear as a flickering waveform or just a moving dot on an analog scope. This same signal would be rendered as a bright, non-flickering, easily-viewed waveform on a DSO. Or again, a signal with a low repetition rate relative to the sweep rate may be too taint for viewing on an analog unit. On a DSO, the display is equivalent to a CRT with infinite persistence; the waveform may be easily viewed.

Typical use of Refresh mode is as follows:

1. Set up the oscilloscope to view a periodic waveform in the analog operating mode. Adjust the controls for a stable waveform.

2. Press the Storage button. The waveform appears on the display, relatively unchanged from the previously displayed analog version.In this mode the display is continually updated as long as a suitable trigger signal remains present.

3. Pressing the Save All button at any time "freezes" the current waveform on the screen for further observation.

Roll Mode

In this mode of operation, the waveform rolls across the screen from right to left (as opposed to the standard left to right trace) in the same manner as most strip chart recorders. It is most commonly used for viewing very slow events. Typical operation is as follows:

1. Set up the oscilloscope in analog mode so that the event to be observed is properly positioned on the display. You may wish to use Auto triggering so that the scope continues to draw a trace even if the event is especially slow.

2. Press the Storage button to enter the storage mode.

3. Press the Roll button.

4. Select a Time/Div setting that produces a roll at the desired speed. As the sweep speed is decreased, the waveform will move across the screen more slowly and the Roll feature will become more apparent. In the Roll mode, the Time/Div setting is typically slowed by a factor of 100 by using the slow X100 button.

5. The rolling display can be frozen at any time by pressing the Save All button.

Other DSO Modes

Other features which may be found on digital storage oscilloscopes are briefly discussed here.

Save Operation
When waveforms are acquired, they are stored in memory, which is revised at each trigger occurrence in Refresh mode, or at each arming in Single mode.

Pressing the Save All button will save the waveform in memory. It remains there, regardless of operating mode, until the scope is shut off or the user purposely overwrites it with another waveform.

The Save CH2 button can be used to capture a waveform for reference. For example, a waveform from a known-good piece of equipment can be applied to channel 2 and captured in the Refresh mode. Then, the Save CH2 button can be pressed to freeze the waveform on the screen. Next, a waveform from the same point in the equipment under test can be captured on channel 1. The waveforms can be compared to determine whether the waveform on channel 1 is normal.

Plot output
The captured waveforms from a DSO can be permanently recorded for future reference by transferring the memory output to an analog

OPERATING AN OSCILLOSCOPE

plotter. First, the waveforms are frozen by pressing the Save All button. Then, an analog plotter can be connected to the channel 1 output, channel 2 output, and Pen Down output jacks on the rear panel of the DSO. When interconnected, plotting can begin by pressing the Plot button. The plot cycle is one screenful on (pen down) and the next screenful off (pen up). The Pen Down indicator lights for the entire pen-down period of the plot cycle.

Unique Characteristics of DSOs

Digital storage oscilloscopes use a digital sampling technique to convert analog signals to a series of digital words that can be stored in memory. Digital sampling has disadvantages as well as advantages, and it is important to be aware of these unique characteristics of DSOs.
Real Time Sampling and Aliasing

The DSO uses a technique called Real Time Sampling at sweep speeds slower than about 20 ms/div. Real Time Sampling simply means that samples of the input signal are taken at equal spaces (e.g., every 0.25 mS when the 50 mS/div range is selected). With Real Time Sampling, a phenomenon called "aliasing" can occur when the input signal is not sampled often enough. This causes the digitized signal to appear to be of a lower frequency than that of the input signal. Unless you have an idea what the input signal is supposed to look like, you will usually be unaware that aliasing is occurring.

To see an example of aliasing, connect a 10 kHz signal to a DSO, set the Time/Div setting to 50 mS/div, and put the scope in Refresh mode. You should see about five divisions displayed. Now change the Time/Div setting to 20 mS/div, and slightly alter the frequency of the input signal. If you do this carefully, you should be able to obtain a display that shows just a few cycles at this low sweep speed. If you calculate the frequency now, it appears to be something like 50 Hz or below, which is obviously incorrect.

This occurs because the DSO is taking samples too slowly to accurately render the waveform on the CRT, possibly one sample per cycle of the input signal. If the input frequency is set just right, the samples come at a slightly different point on each cycle, resulting in a waveform that appears to be valid but in fact is not.

Aliasing can occur whenever at least two samples per cycle are not taken (whenever the Time/Div setting is much too slow for the input signal). Whenever the frequency of the input signal is unknown, always begin with the fastest sweep speed, or view the waveform in analog mode first.
Viewing of one-time events poses no problem with aliasing because aliasing can occur only with repetitive waveforms.

Equivalent Time Sampling
On sweep speeds of 10 mS/div or greater, many DSOs use a sampling method known as Equivalent Time Sampling. This method permits viewing of repetitive waveforms of frequencies higher than the scope’s sampling rate. When Equivalent Time Sampling is active, one sample is taken during each cycle. Of course, if that one sample is taken right at the trigger point on each cycle, a flat trace would be produced. Therefore, it is necessary to take each sample further (in time) from the trigger point than the last sample. This incremental delay is determined by the sweep Time/Div setting. To construct a complete waveform on the screen, the scope must sample as many cycles of the input signal as there are bytes in its memory.

Only repetitive waveforms should be observed in this mode. Irregularities that are present on an otherwise repetitive waveform are not likely to show up; with only one sample per cycle, glitches and other irregularities will most likely be skipped over.

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BASIC ANALOG OSCILLOSCOPES

The circuitry of a simple analog oscilloscope can be broken into three blocks as shown in Fig. 11. These three blocks are the vertical circuitry, the horizontal/trigger circuitry, and the display circuitry. By understanding each of these blocks on its own, it will become much easier to understand how they interact and why the oscilloscope's controls function the way that they do.

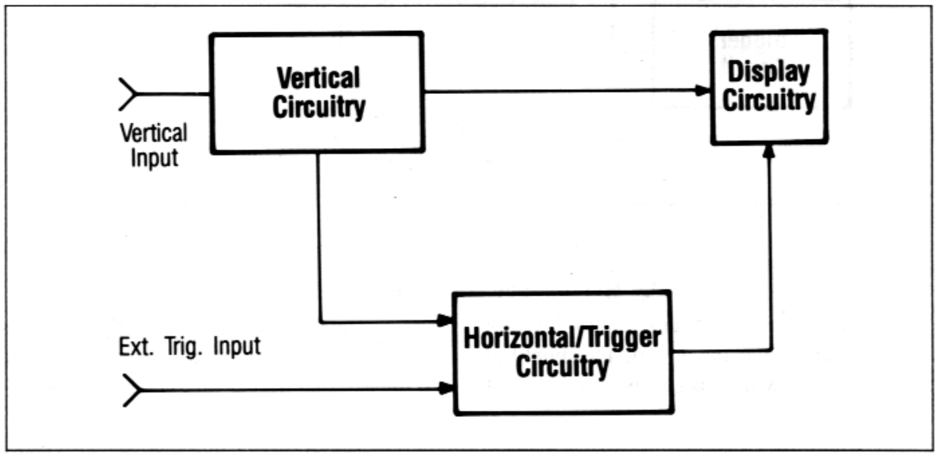


Fig. 11. Simplified oscilloscope block diagram.

Vertical Circuitry

Refer to Fig. 12.

The vertical circuitry controls the vertical axis of the display and consists of an input coupling circuit, the input attenuator, and the vertical amplifier (for dual trace oscilloscopes, there are two identical vertical circuits, one for each channel). All signals connected to the vertical input jacks are fed through at least part of the vertical circuitry before they are used by other oscilloscope circuits.

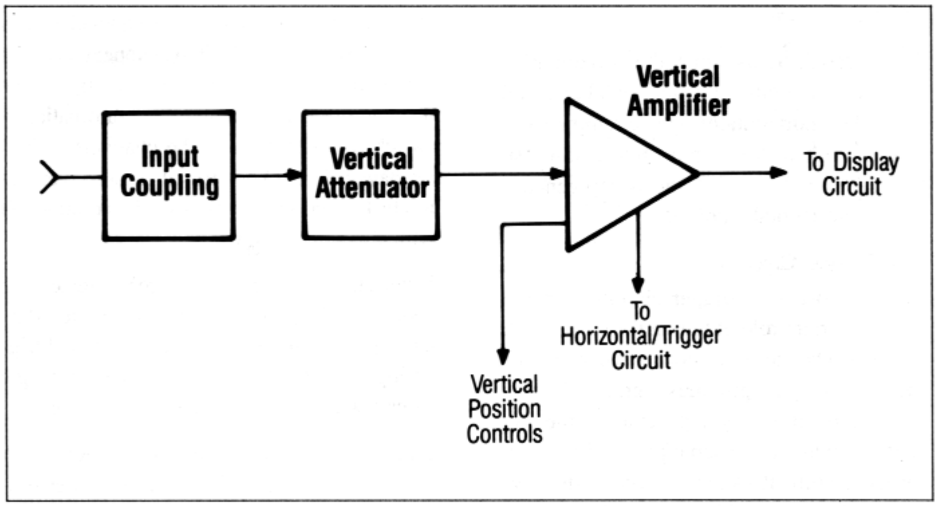


Fig. 12. Vertical circuitry block diagram.

The Input Coupling Circuit

The input coupling circuit allows the user to ground the oscilloscope's input, pass only the ac portion of the signal, or pass both the ac and dc portions of the signal. When the input coupling circuit is set to ground the scope input, the attenuator input is grounded, but the input jack is open (to prevent a short circuit at the probe). This mode is useful for setting the trace to a zero reference level. When the input coupling switch is set to pass only the ac, the scope input jack is capacitively coupled and any dc signal component is blocked. When the input coupling switch is set to pass both the ac and dc signal components, the oscilloscope input jack is directly coupled to the attenuator and both the dc and ac (dynamic) portions of the signal are passed.

The Input Attenuator Circuit

The input attenuator allows a wide range of signal levels to be applied to the oscilloscope by setting the vertical sensitivity of each channel. The basic sensitivity of an oscilloscope's vertical amplifier is typically 5 mV per division. Lower sensitivities, up to 5 volts per division, are achieved by attenuation of the input signal. Typically, input attenuator circuits are set up in a 1-2-5 sequence and allow measurements of signal levels from a few millivolts to tens of volts. In other words, input sensitivity might be switchable to 5 volts/div, 2 volts/div, 1 volt/div, 0.5 volts/div, etc.

In order to provide a calibrated voltage measurement on the display, vertical input attenuators must be highly accurate wideband networks, capable of passing all signals within the oscilloscope's measurement range (e.g. for a 20 MHz scope, these attenuators must provide a flat response for signals from dc all the way to 20 MHz).

In addition to the step attenuator controls, oscilloscopes also have a variable sensitivity control that allows the scope sensitivity to be set between step attenuator ranges. This control allows waveforms to be set to occupy an exact number of divisions, such as is necessary for rise time measurements, where the waveform must extend exactly from the 0% to 100% markers.

For input sensitivities greater than 5 mV per division (for example, 1 mV per division), an additional amplifier is switched into the circuit instead of an attenuator. The bandwidth is typically reduced when the amplifier is selected.

The Vertical Amplifier Circuit

From the input attenuator, the signal is fed to the vertical amplifier, where it is amplified to a level suitable for driving the CRT vertical deflection plates. Depending on the display mode (single- or dual-trace, chopped, or alternate display), the vertical amplifier stage also handles the switching of signals to facilitate

HOW THE OSCILLOSCOPES WORK

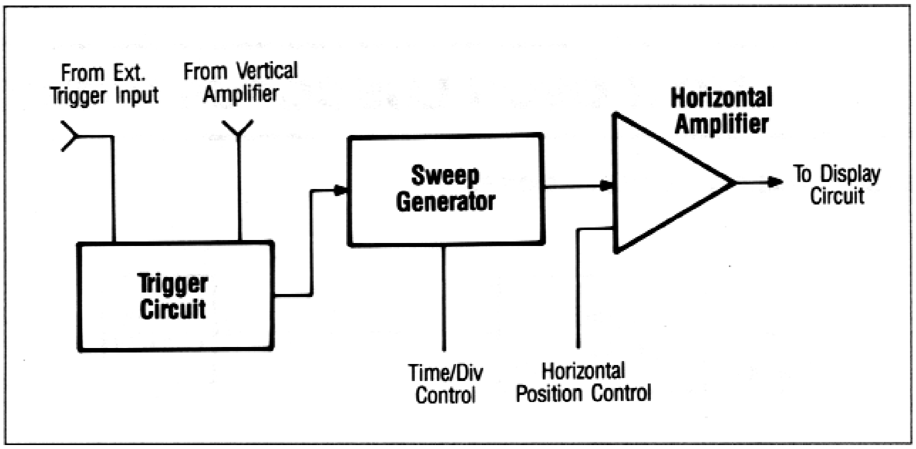


Fig. 13. Horizontal/trigger circuitry block diagram.

the display of channel 1, channel 2, dual-trace chopped, dual-trace alternate, etc.

Also, at a preamplifier stage, a portion of the signal is picked off and fed to the horizontal/trigger circuitry. Position controls adjust the dc bias of the amplifier circuit and allow the trace to be moved about vertically.

Horizontal/Trigger Circuitry

Refer to Fig. 13.
As suggested by its name, the horizontal/trigger circuitry controls the horizontal axis of the trace. The horizontal/trigger circuitry can be further broken down into three distinct sections: the trigger circuit, the sweep generator, and the horizontal amplifier.

The Trigger Circuitry
The oscilloscope's trigger circuitry plays the very important role of telling the scope's other circuitry when to start drawing the trace. Since the scope display provides a graph of voltage versus time, it is very important that the scope starts drawing at the same point on the waveform each time it sweeps across the display. If the oscilloscope could not precisely control the trigger point, it would be impossible to measure anything related to time. The sweep would start at a different point each time, and therefore, the waveform would be moving to a different position on the display each time the CRT was swept.

The trigger level and slope controls allow the scope user to select the exact point at which the sweep will be triggered. The slope control allows selection of either the positive- or negative-going slope, and the level control allows the selection of the exact point on that slope. Fig. 14 illustrates the way that the slope and level controls function.

The trigger circuits also perform the switching that selects the trigger source. Since it is frequently desired to trigger from an event other than the signal that is being viewed, oscilloscopes allow a selectable trigger source. This source can be internal (one of the channels being displayed) or external (the signal applied to the external trigger input jack), or line frequency.

When an internal trigger source is selected, a portion of the signal from one or more of the vertical preamplifiers is fed to the trigger circuits. This signal can be the channel that is being viewed on the CRT, a channel that is not being viewed, or, in the case of multiple trace display, the trigger source can automatically switch between each of the channels as it is displayed. This is known as alternate triggering and is used in conjunction with alternate display.

When an external trigger source is selected, the source is the signal that is applied to the external trigger input jack. Typically, external triggering is used for such things as viewing logic signals with reference to a known timing.

Line triggering uses the line frequency for triggering and is used for work on power supplies, or circuits that must be synchronized with line voltage.

Trigger coupling is also selected within the trigger circuitry. Typical trigger coupling modes are ac (trigger signal is capacitively coupled and all ac signal components are used), high frequency reject (trigger is capacitively coupled and a low-pass filter rejects all high-frequency signals), and low frequency reject (trigger signal is capacitively coupled and a high-pass filter rejects all low-frequency signals). The cutoff point for high and low pass filters varies between oscilloscope models and brands. Most scopes also have TV trigger coupling (using a sync separator) to trigger from horizontal or vertical TV sync pulses. This mode is useful for viewing frames (vertical sync pulses) or lines (horizontal sync pulses) of video signals.

The Sweep Generator (Time Base)
After the selected trigger event occurs, a linear sawtooth sweep generating circuit is turned on and produces the waveform shown in Fig. 15. The first part of the waveform is the linear sweep ramp that causes horizontal movement of the trace. As voltage is increased, the electron beam moves further to the right of the CRT. When the voltage reaches its peak level

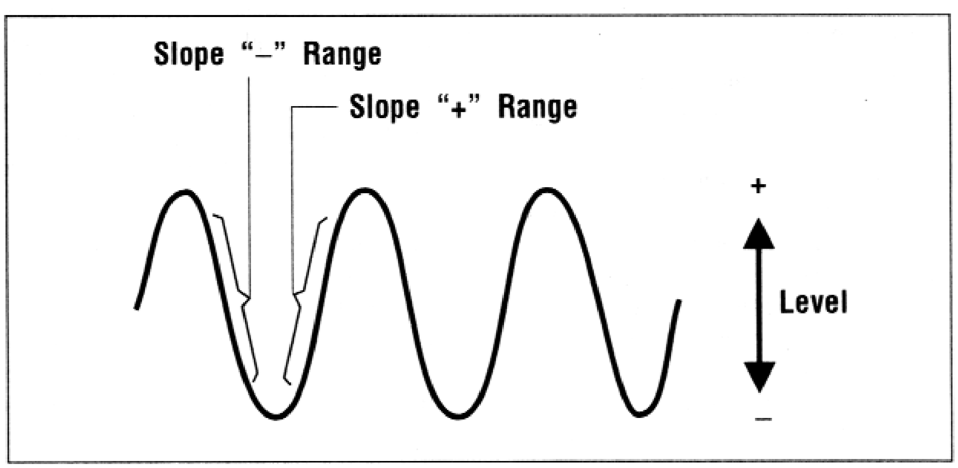


Fig. 14. Function of slope and level controls.

HOW THE OSCILLOSCOPES WORK

(the top of the ramp), the electron beam is at the right edge of the CRT. At this point, the electron beam is turned off (this is called retrace blanking) and the sweep voltage returns to the original level, thereby also returning the electron beam to the left side of the CRT.

The sweep ramp is typically generated by a circuit known as a Miller integrator. This circuit takes a dc voltage as its input and performs the mathematical process of integration on it. Integration of a dc level produces a linear ramp. Various combinations of resistance and capacitance are used to control the speed of the ramp, and hence, the sweep speed. When the ramp reaches a certain level, the dc voltage is removed from the input of the integrator, causing the ramp to reset. The dc input is sometimes provided by a flip-flop, and removal of the dc level simply involves applying a reset pulse to that flip-flop.

In Fig. 15, note the "holdoff" period that occurs immediately after the completion of each sweep. This is a period during which the next sweep is inhibited. Length of the holdoff period is controlled by the length of the reset pulse to the flip-flop mentioned above. The holdoff period varies with the sweep rate, but is adequate to assure complete retrace and stabilization before the next trigger occurs.

Since it is desirable to measure time on the horizontal axis, it is important that the sweep time (the time that it takes for the electron beam to move from the left edge to the right edge of the CRT) is linear (constant speed all the way across) and calibrated. The step time base control provides calibrated sweep times from seconds to micro- or nanoseconds. As with the step input attenuator, the time base control is usually arranged in a 1-2-5 pattern (0.1 S/div, 0.2 S/div, 0.5 S/div, 1.0 S/div, etc.). There is usually a variable time base control that allows for adjustment between step time base ranges (although use of this control causes the time base to become uncalibrated).

Most oscilloscopes also have a sweep magnification control that allows the entire trace to be magnified. For example, if the main step time base control is set to 0.5 mS/div and X10 magnification is selected, the actual time base becomes 0.05 mS/div (50 nS/div).

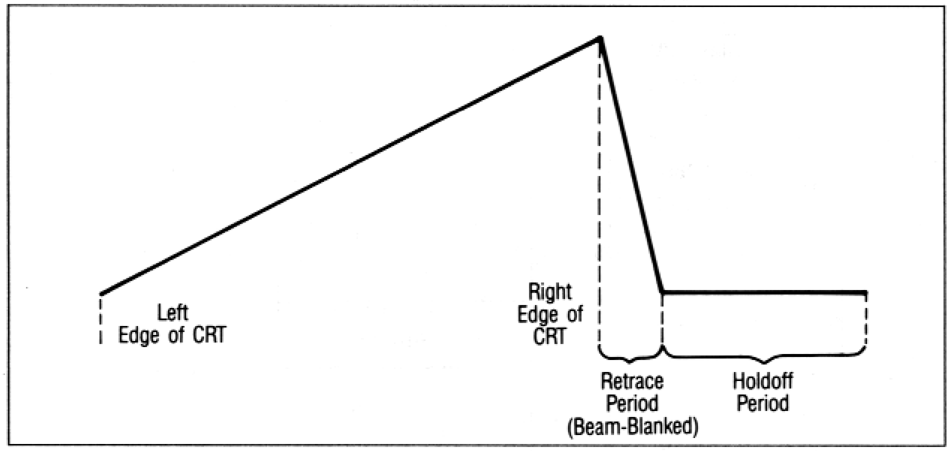


Fig. 15. Sweep waveform.

The Horizontal Amplifier
The horizontal amplifier simply boosts the signal to a level capable of driving the CRT's horizontal deflection plates. Since the sweep speeds can range from seconds to micro- or nanoseconds, this amplifier must have a relatively wideband width and must faithfully reproduce the linear sawtooth sweep waveform. Position controls adjust the amplifier's dc bias and allow the trace to be moved about horizontally.

The Display

The CRT
The CRT, or cathode-ray tube, is made of glass and contains a vacuum. Electrons are emitted from a heated element at the narrow end of the tube and are accelerated by a high voltage, typically 2000 volts or greater, towards the display end. On the way there, they are focused into a narrow beam whose direction is altered slightly by vertical and horizontal deflection plates. These deflections are controlled by the outputs of the vertical and horizontal amplifiers mentioned previously. Therefore, the beam moves up and down in relation to the input signal, and horizontally in relation to the time base circuitry. The display end of the tube is coated by a monochrome phosphor, usually green, which glows where it is struck by the electrons.

The Graticule
The oscilloscope display represents a graph of voltage versus time. As seen in Fig. 16 the horizontal component of the graph represents time and the vertical component represents voltage. Typically, oscilloscope displays have a graph, or graticule, that is divided into 10 horizontal and eight vertical divisions. Each of these divisions is usually broken into 5 minor divisions (subdivisions), represented by the "hash" marks along the center vertical and horizontal graduations. Additionally. the graticule

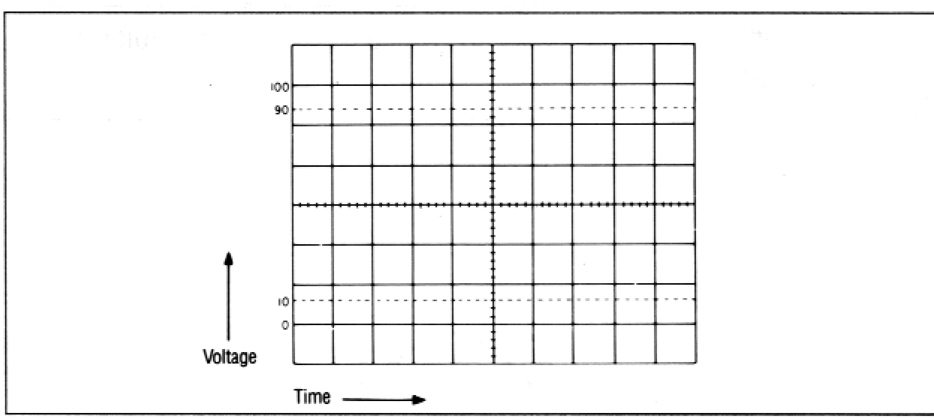


Fig. 16. Typical oscilloscope graticule

is marked with two dashed lines, labeled "10" and "90" and points marked "0" and "100" are also present. These four points are useful for rise time and fall time measurements, since rise time is defined as the time required for a signal to rise from 10% to 90% of its maximum amplitude. On almost all modern oscilloscopes, the graticule is etched directly onto the inside of the CRT. This eliminates parallax error that might occur from viewing the CRT from a slight angle.

ADVANCED ANALOG OSCILLOSCOPES

Delayed Sweep

Delayed sweep is a very important feature of many advanced scopes. It allows a portion of the trace to be magnified. The original trace is sometimes referred to as the A sweep, and the magnified trace as the B sweep.

Fig. 17 shows a block diagram of the delayed sweep circuit and a representation of the process. The trigger starts the A sweep generator and several cycles of the square wave input are displayed. The trigger is also applied through a variable delay network, the Delay Position control, which is adjustable by the operator. In the Mix sweep mode, the delayed trigger starts the B sweep generator at a later point in time. The delay is typically adjustable from one division to ten divisions on the screen. When the B sweep starts, the display is switched to view the faster B sweep for the balance of the trace. Since the B sweep is faster, that portion of the waveform is expanded.

When the Sweep Mode Switch is set to the Delay position, only the faster B sweep is viewed. The starting point of the waveform is still adjustable with the Delay Time control.

Variable Holdoff

As mentioned previously, all scopes have some degree of holdoff between CRT sweeps. This is necessary to provide time for the beam to return to the left edge of the screen. Many advanced units also provide a variable holdoff, which allows this interval to be lengthened by the user. This is useful for synchronizing on complex pulse trains.

As discussed in "Basic Analog Oscilloscopes" above, holdoff depends on the width of a reset pulse applied to the flip-flop, which drives the Miller integrator. Variable holdoff is achieved by varying the width of that reset pulse.

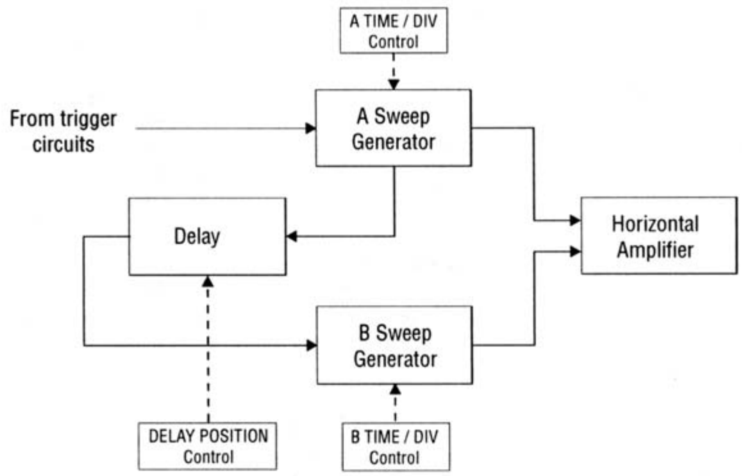
Other Features

Delay Line
Many high bandwidth oscilloscopes have a delay line in the vertical amplifier. This delay line actually slows the signal down (by a fraction of a microsecond) so that the oscilloscope can start the sweep before the vertical signal starts to deflect the CRT's electron beam. This allows the scope to display the signal, including the trigger edge. It is generally needed only in cases where the rise time (or fall time, if trigger occurs on a falling edge) of a very fast signal needs to be observed. That is why only high bandwidth scopes usually have delay lines; if the bandwidth of the scope is not high enough to view a very fast rise time, a delay line offers no advantage.

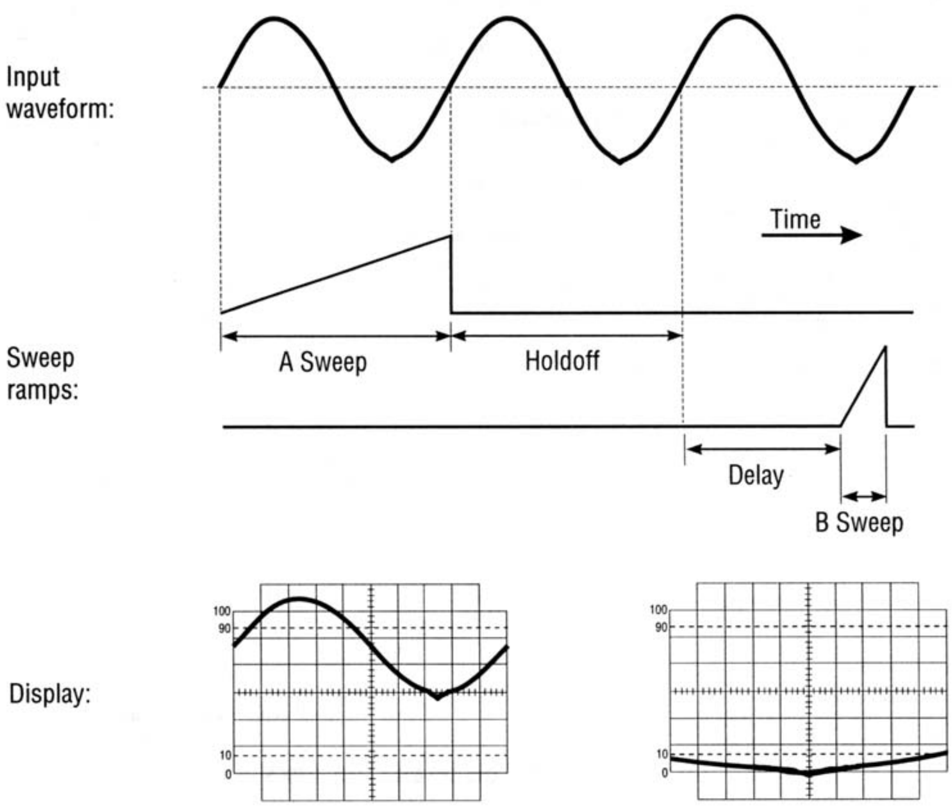
Higher CRT Voltages
A typical 20 MHz or 30 MHz oscilloscope has a CRT acceleration voltage of 2000 volts. Higher voltages deliver brighter traces and are essential for wideband scopes. As the time that it takes for the electron beam to sweep across the CRT is decreased (higher bandwidth scopes have higher maximum sweep rates), the voltage must be increased in order for the trace to still be easily visible. Some 100 MHz units employ voltages as high as 15 kV or 20 kV.

HOW OSCILLOSCOPES WORK

Fig. 17. Delayed sweep.



a. Block diagram.



b. Physical process and resultant displays.

HOW THE OSCILLOSCOPES WORK

DIGITAL STORAGE OSCILLOSCOPES (DSO)

DSO OPERATION

Real-Time Sampling

The block diagram of Fig. 18 is meant to show the inner workings of a DSO in simplified form only. Also, it depicts a single channel; many of the blocks are duplicated in a two-channel DSO. A signal from the vertical preamplifier is fed to a relay or switch, which routes the signal according to whether the scope is in analog or storage mode. In analog mode, it merely sends the signal on to the main vertical amplifier. In storage mode, however, it sends it through the blocks of Fig. 18.

The signal progresses through a signal scaler, which attenuates the signal so that it doesn’t exceed the limits of the A/D (analog-to-digital) converter. Optimum scaling equates the A/D limits with the upper and lower edges of the CRT display. Thus, the scaler works in concert with the Volts/Div setting.

The sample-and-hold switch operates under the control of the microprocessor. It may be sampling as quickly as possible, in real-time sampling mode, or it may be sampling at very specific intervals, in equivalent-time sampling (see the next section). The capacitor on its output is critical; it holds the sampled voltage between samples. The output of the sample-and-hold is fed through a unity buffer to the A/D (analog-to-digital) converter.

The A/D converter is generally a flash type which operates at at least 10 MHz. Its conversions are controlled by the microprocessor in sync with the sample-and-hold switch. It converts the analog voltage applied into a digital quantity eight or twelve bits wide (or more). In the diagram, the wide gray arrows indicate digital buses.

The digital words are stored in a memory which is controlled by the microprocessor, which increments the address counter as each sample is acquired. The memory is generally twice as long as the number of samples required to fill the display. This is because the scope must be able to show not only the data after the trigger event, but as much as a full screen of "pretrigger" data, if specified by the operator. During data acquisition, the microprocessor places the memory in "write" mode via the R/W (read/write) control line.

In order to be useful, the data must be able to be read out from the memory and displayed. The microprocessor reads from the memory with the R/W line set for "read", and applies the data to a D/A (digital-to-analog) converter, which changes it back to an analog voltage. This is sent to the main vertical amplifier for display. The microprocessor also sends separate binary quantities to another D/A converter which connects to the main horizontal (sweep) amplifier. In this case, the microprocessor controls the X-position of the CRT electron beam as well as its vertical deflection.

As stated previously, this description is one of basics only. All the blocks involved are connected through extensive electronic logic. There may be more than one microprocessor involved, one for data acquisition and another for display.

Equivalent Time Sampling

Equivalent time sampling enables a DSO to digitize waveforms of a higher frequency than its sampling rate, provided that the waveform is repetitive. Instead of taking many samples per cycle, the scope acquires one sample per cycle, or perhaps even one sample per group of cycles, of the input signal. The sampling point is moved in time along the waveform, and after a sufficient number of cycles have occurred, enough samples have been stored to construct a picture of the waveform.

The process is depicted simply in Fig. 19. The

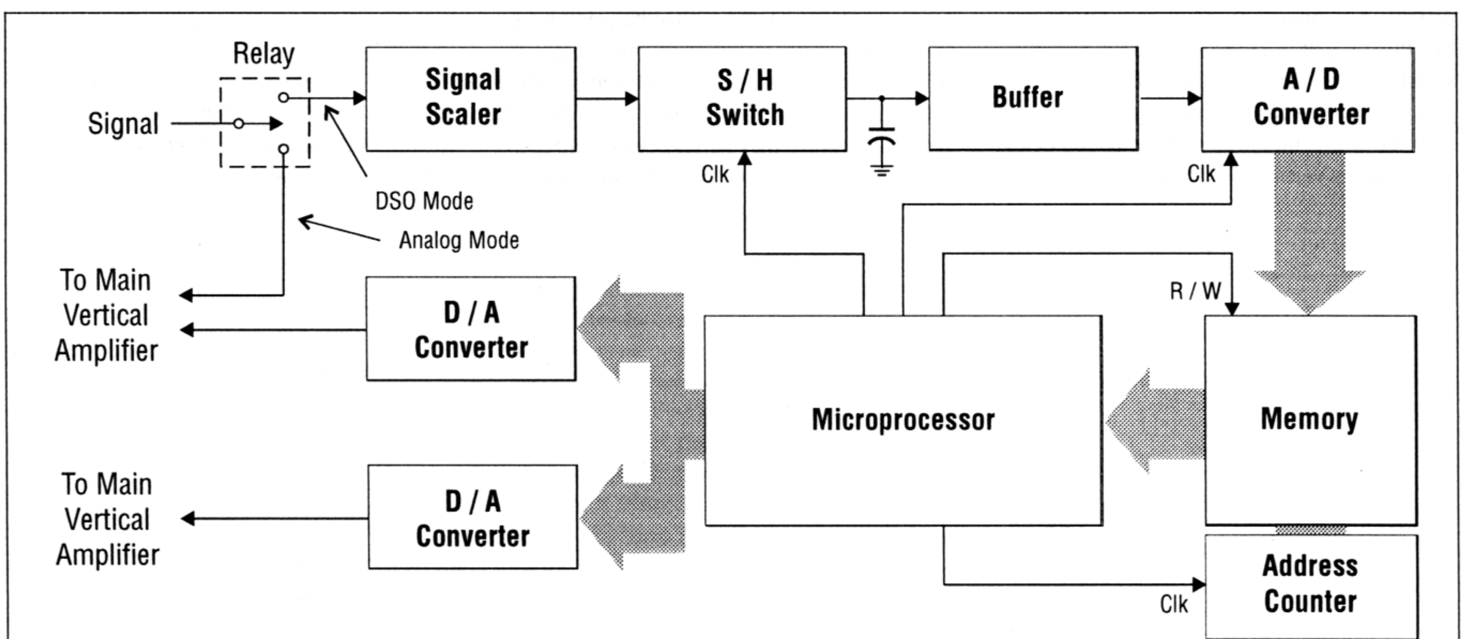


Fig. 18. DSO block diagram

sweep ramp from the horizontal circuits is used. The process is depicted simply in Fig. 19. The sweep ramp from the horizontal circuits is used. This ramp resets with each trigger event; in this case the trigger is set for the positive zero-crossing. Instead of sampling in a free-run fashion as before, the microprocessor and sample-and-hold circuit now acquire a sample only when the sweep ramp crosses a comparison voltage which is stepping upwards as shown.

This comparison voltage is derived by using a binary counter to count the trigger events, and increment by one for each trigger. The count state is fed to a D/A (digital-to-analog) converter which transforms it into an analog voltage. This is the slowly stepping comparison voltage shown in Fig. 19. The end result is that the intersection point of this voltage and the sweep ramp moves further to the right with each cycle of the input, and so does the sampling point on the input waveform.

This process is actually a controlled use of aliasing, which is a generally undesired result of sampling a waveform too slowly. Aliasing often occurs accidentally in real-time sampling mode, usually due to operator error. The user may not even be aware that the display is totally false, because it appears as a valid waveform. In the case of equivalent-time operation, however, the process is monitored and controlled by the sophisticated logic and software of the DSO and becomes a useful tool.

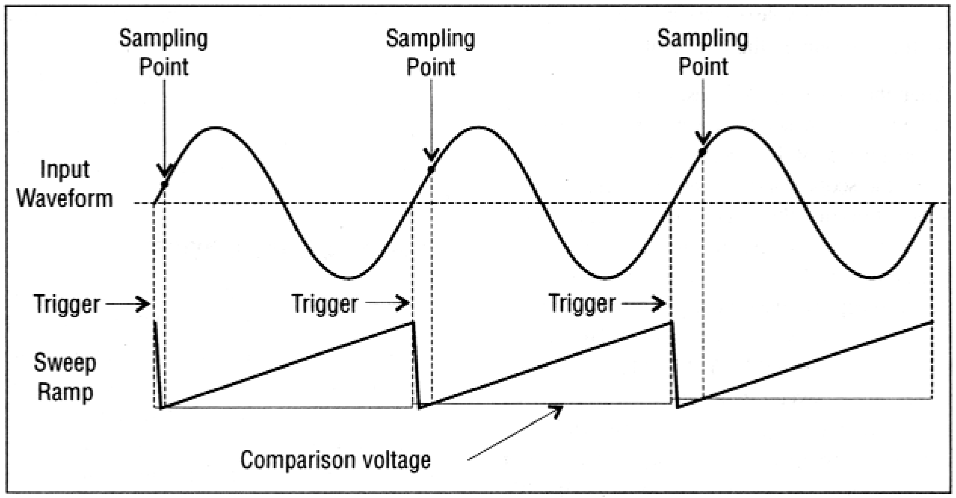


Fig. 19. Equivalent time sampling.

OSCILLOSCOPE PROBES

The Need for Probes

While some signals can be measured directly into the oscilloscope's input, this method loads the circuit being measured with the oscilloscope's input resistance and capacitance. Under certain conditions (such as where the signal being measured is across a very high impedance, is of high frequency, or possesses fast rise time), this occurrence would produce unwanted results and cause even an expensive, high precision oscilloscope to produce inaccurate measurements. To prevent this, probes are usually used to connect signals to the oscilloscope's inputs. Proper selection and compensation of oscilloscope probes plays a very important role in allowing the oscilloscope to operate at its listed specifications.

Probe Types

Below are some typical probe types and their characteristics:

Probe Type	Characteristics
1:1	Low-bandwidth; full loading of measurement by scope's input (usually 1 megohm). Allows direct reading of amplitude.
10:1	Improved bandwidth (typically 60 MHz to 150 MHz), increased input resistance and lowered capacitance (usually 10 megohms). Lowers circuit loading. Increases maximum measurable voltage by a factor of 10. Must account for attenuation factor of 10 when reading displayed amplitude (for example, 0.2 V/div becomes 2 V/div).
100:1	Very high bandwidth (up to 250 MHz), increased input resistance (typically 100 megohms) and lowered capacitance (vs. scope direct input). Greatly lowers circuit loading. Increases maximum measurable input voltage by a factor of 100. Must account for attenuation factor of 100 when reading displayed amplitude (for example, 0.2 V/div becomes 20 V/div).

Probe Selection

The bandwidth rating of a probe should always be higher than the bandwidth rating of the oscilloscope.

Since most oscilloscopes are supplied with probes, selecting the proper oscilloscope probe is not something most electronic technicians and engineers often think about. However, since several different grades of oscilloscopes may be used in the same area, it is important not to interchange incompatible probes. It may seem that any probe rated at the oscilloscope's bandwidth or higher should be compatible. This is not true, however, since the probe's rise time and oscilloscope's rise time are cascaded. In order to find the approximate system rise time, the oscilloscope's rise time and the probe's rise time must be calculated using the following formula:

$$T_{system} = \sqrt{(T_{probe})^2 + (T_{scope})^2}$$

Therefore, if a probe with a rated rise time of 3.5 nS were used with a 100 MHz oscilloscope (with a rated rise time of 3.3 nS), the approximate system rise time would be 5 nS. That would produce a system bandwidth of only approximately 70 MHz. Thus, by using an insufficient probe, you have just turned your 100 MHz oscilloscope into a 70 MHz unit. This illustrates the importance of selecting a probe with a bandwidth substantially higher than the rated bandwidth of the oscilloscope. As a rule, it is best to use the probe supplied with the oscilloscope. However, this may not always be possible or practical.

Another important thing to consider when selecting oscilloscope probes is the input impedance and attenuation factor of the probe. Since electrical signals should be measured with a probe that has a much higher input impedance than the impedance of the circuit being measured, it is important to take probe impedance into consideration. Typically, a 10 megohm probe should be sufficient for most measurements. However, since some circuits require even higher probe impedance, 100 megohm probes are optional accessories offered by most Oscilloscope manufacturers. It is also important to use an attenuator probe when measuring signals that have too high of a level to measure on an oscilloscope. For example, if you want to measure a 50 V peak-to-peak signal, and the oscilloscope's highest input attenuator range is 5 V/div, it is necessary to attenuate the signal before applying it to the oscilloscope input. Otherwise, the 50 V signal would deflect off the display (since 50 V at 5 V/div would produce 10 divisions of vertical deflection). Most oscilloscopes are supplied with probes that have a 10:1 attenuation ratio, and probes with attenuation ratios higher than 10:1 are available.

Proper Probe Compensation

(Refer to Fig. 20)

A probe's impedance can be optimized to that of a scope input channel by adjusting the compensation trimmer found on the probe. Since the specific impedance characteristic of a scope input channel varies from scope to scope, and even from channel to channel on a single scope, it is very important to make sure that probes are compensated for the specific oscilloscope and channel. Once a probe is compensated, it should be continuously used with the same scope and same channel compensated for. Each time a probe is connected to a different channel or oscilloscope, compensation should be adjusted as follows:

1. Connect the probe to the input jack. On switchable X1/X10 probes, set the switch to X10.

2. Touch the tip of the probe to the probe adjust output (CAL terminal) on the oscilloscope, and adjust the oscilloscope controls for 3 or 4 cycles of the waveform at 5 or 6 divisions of vertical amplitude.

3. Adjust the compensation trimmer on the probe for the optimum square wave (see Fig. 20 for illustration showing minimum overshoot, rounding off, and tilt).

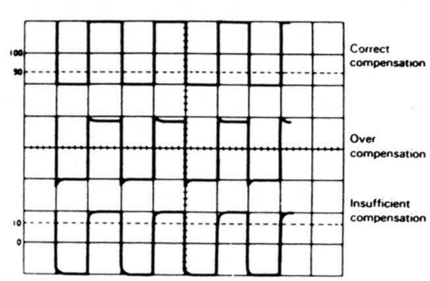


Fig. 20. Probe compensation adjustment

APPLICATIONS

BASIC OSCILLOSCOPE APPLICATIONS

DC Voltage Measurements

Measurement of a Simple DC Voltage
(Refer to Fig. 21)

This technique is used to measure the level of a simple dc voltage where no waveform is present. This would result, for example, from connecting the scope directly to the output of a dc power supply. The example uses +5 volts dc, which is a common supply voltage used in digital circuits. Though this measurement can be performed on either scope channel, this example uses channel 1.

1. Set the scope to display channel 1, single-trace. Set triggering for auto. This will produce a trace even when only dc voltage is present.

2. Set the channel 1 input coupling switch to the ground position. Adjust the horizontal and vertical position controls to obtain a straight line trace, as in Fig. 21a. This horizontal line becomes the zero volt reference line for the measurement. This example uses a line near the bottom of the screen; your choice may depend on how much resolution is desired, or whether negative voltages may be encountered.

3. Once the vertical position is adjusted, do not disturb the vertical position control.

4. Connect the oscilloscope ground clip to a suitable ground point and connect the channel 1 probe to the point where the dc voltage is to be measured.

5. Set the channel 1 input coupling switch to DC. Adjust the channel 1 Volts/Div switch to display a straight line trace, as in Fig. 21b. If the voltage is a positive dc voltage, the line will display above the zero reference position, as in the figure. If the trace does not immediately appear. it may be deflected off the screen; readjust the Volts/Div control to a less sensitive setting until a trace is obtained. For best accuracy, try to use a setting that gives at least three divisions of deflection from the ground reference.

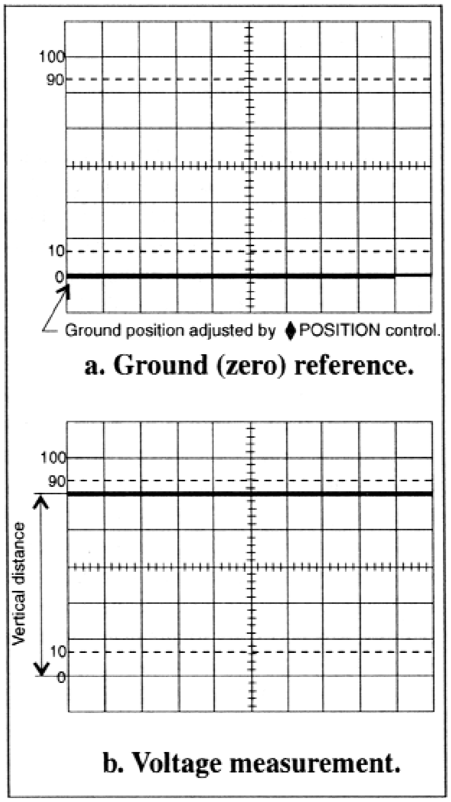


Fig. 21. DC voltage measurement.

Note:

Changing the Volts/Div setting may slightly alter the reference level. When you change Volts/Div, you should also momentarily switch the input coupling switch back to ground and readjust the reference level as required.

6. Make sure that the VARIABLE Volts/Div control is set to the CAL position. Measure the vertical distance from the zero reference level to the displayed trace.

7. Multiply the distance measured above by the Volts/Div setting and the probe attenuation ratio as well. Voltages above the reference level are positive and voltages below the reference level are negative.

The measurement is summarized by the following equation:

DC level = Vert Div x Volts/Div x Probe.

For the example shown in Fig. 21, the point being measured is 5.0 divisions from the reference level (ground potential). If the Volts/Div control is set to 0.1 V and a 10:1 probe is used, the dc voltage level is calculated as follows:

DC level = 5.0 (div) x 0.l (V/div) x 10=5.0 V.

Instantaneous DC Voltage Measurements

(Refer to Fig. 22)

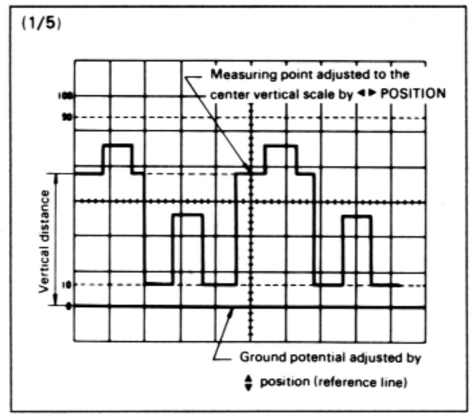


Fig. 22. Instantaneous DC voltage measurement.

This technique may be used to measure an instantaneous dc level at some point on a waveform, such as that in Fig. 22. Though this measurement can be performed on either scope channel, this example uses channel 1.

1. Connect the signal to be measured to the channel 1 input jack, and set the oscillo scope to display channel 1, single-trace. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. The variable input attenuator control must be set to the CAL position.

2. Select auto triggering and set the input coupling switch to the ground position. This establishes the zero-volt reference trace. Using the vertical position control, adjust the trace to the desired reference level position, making sure not to disturb this setting once it is made.

3. Set the channel 1 input coupling switch to the DC position to observe the waveform,

including its dc component. If an inappropriate reference level position was selected in step 2, or an inappropriate Volts/Div setting was made, the waveform may not be visible at this point (deflected completely off the screen). This is especially true when the dc component is large with respect to the waveform amplitude. If so, reset the Volts/Div control and repeat steps 2 and 3 until the waveform and the zero reference are both on the screen.

4. Use the horizontal position control to bring the portion of the waveform to be measured to the center vertical graduation line of the graticule scale.

5. Measure the vertical distance from the zero reference level to the point to be measured (at least 3 divisions desirable for best accuracy). The reference level can be rechecked by momentarily returning the input coupling switch to the ground position.

6. Multiply the distance measured above by the Volts/Div setting and the probe attenuation ratio as well. Voltages above the reference level are positive and voltages below the reference level are negative.

The measurement is summarized by the following equation:

Instantaneous DC level =
Vert Div x Volts/Div x Probe.

For the example shown in Fig. 22, the point being measured is 3.8 divisions from the reference level (ground potential). If the Volts/Div control is set to 0.2 V and a 10:1 probe is used. the dc voltage level is calculated as follows:

Instantaneous DC level =
3.8 (div) x 0.2 (V/div) x 10 = 7.6 V.

Peak-To-Peak Voltage Measurements
(Refer to Fig. 23)

This procedure may be used to measure peak-to-peak voltages, or for measuring the voltage difference between any two points on a waveform.

1. Connect the signal to be measured to the input connector, set the oscilloscope to display the channel that you wish to use, and set the input coupling switch to the AC position. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. The variable input attenuator control must be set to the calibrated position.

2. Using the vertical position control, adjust the waveform position such that one of the two points falls on a major horizontal graduation line.

3. Using the horizontal position control, adjust the second point to coincide with the center vertical graduation line.

4. Measure the vertical distance between the two points (at least 3 divisions desirable for best accuracy). Multiply the number of divisions by the setting of the Volts/Div control. If a probe is used, further multiply this by the probe attenuation ratio.

The measurement is summarized by the following equation:

Voltage =Vert Div x Volts/Div x Probe.

For the example shown in Fig. 23, the two points are separated by 4.4 divisions vertically. If the Volts/Div control setting is 20 mV and a 10:1 probe is used, the voltage is calculated as follows:

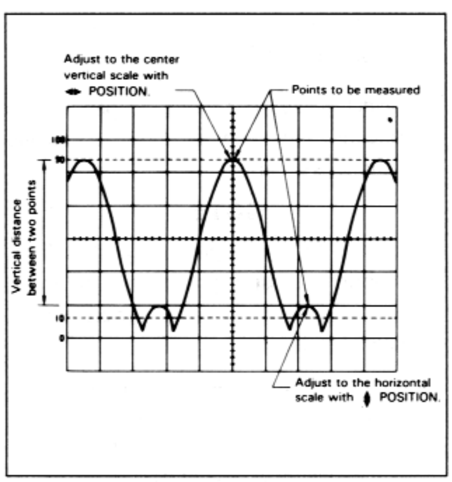


Fig. 23. Voltage measurement.

Voltage =
4.4 (div) x 20 (mV/div) x 10 = 880 mV.

Add Mode Applications
Differential Measurements
(Refer to Figs. 24 and 25)

The oscilloscope's "add" mode can be conveniently used to measure a signal with a reference point other than earth ground. For example, if you wanted to measure the signal present across R2 in Fig. 24, you would use the following technique:

1. Connect the channel that can be inverted to the desired reference point and connect the other channel to the desired point of measurement.

2. Select the subtract mode of operation by selecting the add mode and inverting the channel connected to the reference point.

3. Adjust the Volts/Div controls for both channels and adjust the Time/Div control to obtain a normal display of the waveform to be measured. The variable input attenuator controls must both be set to the calibrated position to make voltage measurements. Also, make sure that both Volts/Div controls are set the same.

4. Using the vertical position controls, adjust the waveform position such that one of two points fall on a major horizontal graduation line.

5. Using the horizontal position control, adjust the second point to coincide with the center vertical line.

6. Measure the vertical distance between the two points (at least 3 divisions desirable for best accuracy). Multiply the number of divisions by the setting of either Volts/Div control. If probes are used, further multiply this by the attenuation ratio of either probe (make sure that both probes are of the same attenuation ratio).

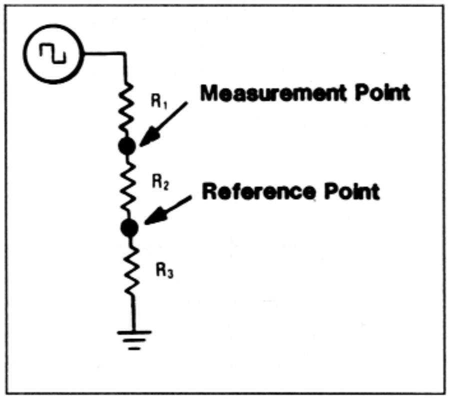


Fig. 24. Voltage measurement with reference other than earth ground.

The measurement is summarized by the following equation:

Voltage =
Vert Div x Volts/Div x Probe.

For the example shown in Fig. 25, the two points are separated by 4.5 divisions vertically. If the Volts/Div setting is 0.1 V and 10:1 probes are used, the voltage is calculated as follows:

Voltage =
4.5 (div) x 0.1 (V/div) x 10 = 4.5 V

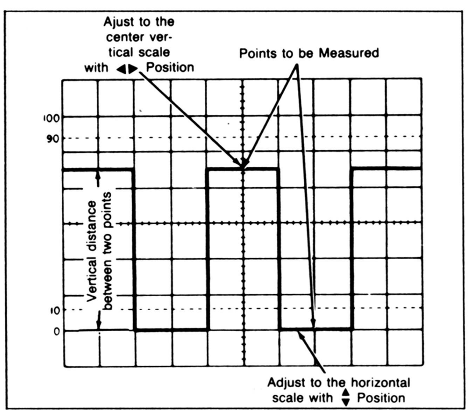


Fig. 25. Differential voltage measurement.

Elimination of an Undesired Signal Component
(Refer to Fig. 26)

Another application of the add mode is to cancel out the effect of an undesired signal component which is superimposed on the signal you wish to observe (for example, undesired 60 Hz hum superimposed on an rf signal). The first waveform of Fig. 26 shows such a composite waveform, although in this simplified illustration the two signals are relatively close to each other in frequency.

1. Apply the signal containing an undesired component to one channel (the channel that cannot be inverted) and the undesired signal itself alone to the other channel (the channel that can be inverted).

2. Select the dual-trace and chop display modes and set the trigger source switch to the channel that can be inverted. Adjust the controls to display two signals. Verify that one of the traces represents the unwanted signal in reverse polarity. If not, reverse the polarity of that channel using the invert function.

3. Now set the oscilloscope for single-trace display: Set the trigger source for the channel that is connected to the undesired signal by itself and set the scope for the add mode of operation. Adjust the Volts/Div and variable input attenuator controls for the channel that can be inverted so that the undesired signal component is canceled as much as possible. The remaining signal should be the signal you wish to observe alone, free of the unwanted signal. Such a result is shown in the bottom waveform of Fig. 26.

Push-Pull Amplifier Measurements

The oscilloscope's add mode can also be conveniently used to make signal measurements and check for proper balance at the outputs of push-pull amplifiers.

1. Connect one channel to one amplifier output and the other channel to the other amplifier output.

2. Select the subtract mode of operation by selecting the add mode and inverting one channel's polarity.

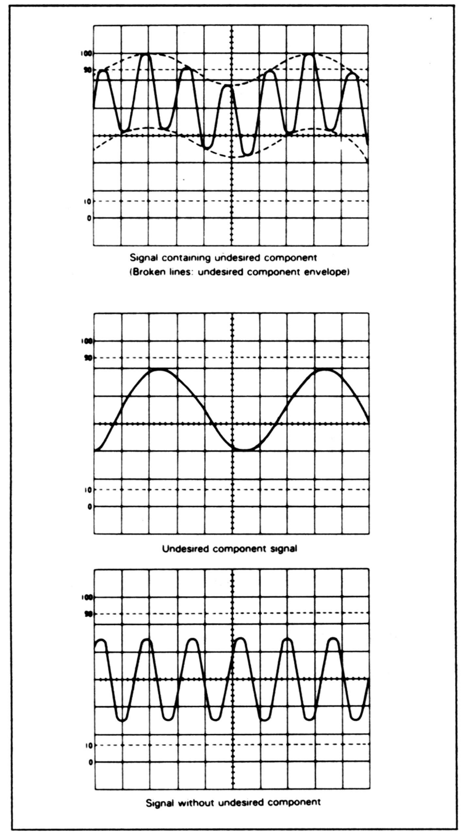


Fig. 26. Eliminating an undesired signal component

Note:

Because the two outputs of a push-pull amplifier are out of phase, they tend to subtract. It is necessary to invert one channel to cause the signals to add.

3. Adjust the Volts/Div and time base controls to obtain a normal display of the waveform to be measured. The variable input attenuator controls must both be set to the calibrated position to make voltage measurements. Also, make sure that both step input attenuator controls are at the same settings.

4. Make peak-to-peak signal measurements by performing steps 4 through 6 of "Differential Voltage Measurements".

5. To check amplifier balance, return the inverted channel to normal polarity and observe the display. If the amplifier is perfectly balanced, the two outputs should fully cancel each other. The

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resulting displayed waveform should be a flat trace. Any displayed signal equals the imbalance.

Time Measurements

(Refer to Fig. 29)

This is the procedure for making time (period) measurements between two points on a waveform. The two points may be the beginning and ending of one complete cycle if desired.

1. Connect the signal to be measured to the input connector and set the oscilloscope to display the channel to be used. Set the Volts/Div and Time/Div controls to obtain a normal display of the waveform to be measured. Be sure the variable time base control is set to the calibrated position.

2. Using the vertical position control, set one of the points to be used as a reference to coincide with the horizontal center line. Use the horizontal position control to set this point at the intersection of any vertical graduation line.

3. Measure the horizontal distance between the two points (at least 4 divisions desirable for best accuracy). Multiply this by the setting of the step main time base control to obtain the time between the two points. If Xl0 magnification is used, multiply this further by 1/10.

The measurement is summarized by the following equation:

Time =
Hor Div x Time/Div
(x 1/10 if X10 Mag is used)

For the example shown in Fig. 27, the horizontal distance between the two points is 5.4 divisions. If the Time/Div control setting is 0.2 mS and magnification is not used, the time period is calculated as follows:

Time = 5.4 (div) x 0.2 (mS/div)
= 1.08 mS.

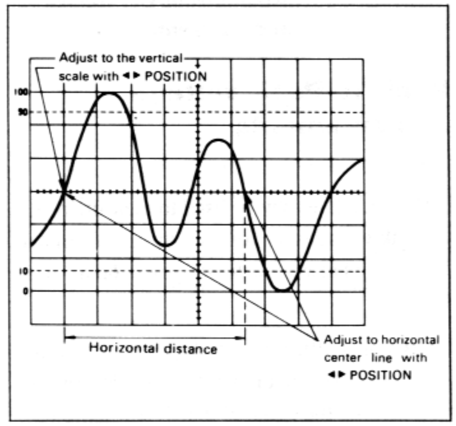

Fig. 27. Time measurement.

Frequency Measurements

Method No. 1

(Refer to Fig. 28)

Frequency measurements are made by measuring the time period of one cycle of a waveform and calculating the frequency, which equals the reciprocal of the time period.

1. Set up the oscilloscope to display one full cycle of the waveform (see Fig. 28).

2. Measure the time period of one cycle and calculate the frequency as follows:

Freq = 1/Period

In the example shown in Fig. 28, a period of 40 mS is observed. Substituting this value into the above equation, the frequency is calculated as follows:

$$\text{Freq} = \frac{1}{40 \times 10^{-6}}$$

$$= 2.5 \times 10^{4}$$
$$= 25 \text{ kHz}$$

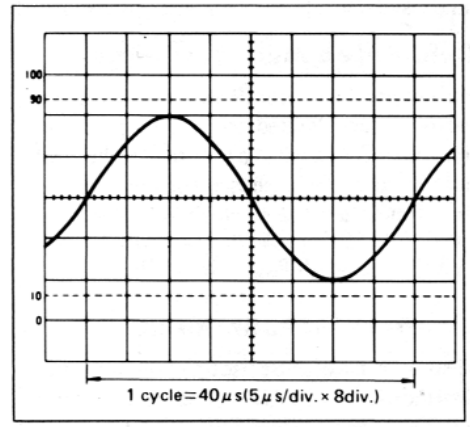

Fig. 28. Frequency measurement.

Method No. 2

(Refer to Fig. 29)

While the previously described method relies on direct period measurement of one cycle, the frequency can also be measured by counting the number of cycles present in a given time period.

1. Set up the oscilloscope to display several cycles of the waveform. The variable time base control must be set to the calibrated position.

2. Count the number of cycles of waveform between a chosen set of vertical graduation lines (see Fig. 29).

3. Multiply the number of horizontal divisions by the Time/Div control setting to calculate the time span. Multiply the reciprocal of this value by the number of cycles present in the time span. If X10 magnification is used, multiply this further by 10. Note that errors will occur for displays having only a few cycles.

The measurement is summarized by the following equation:

$$\text{Freq} = \frac{\text{No of Cycles (x 10 for X10 Mag)}}{\text{Hor Div x Time / Div}}$$

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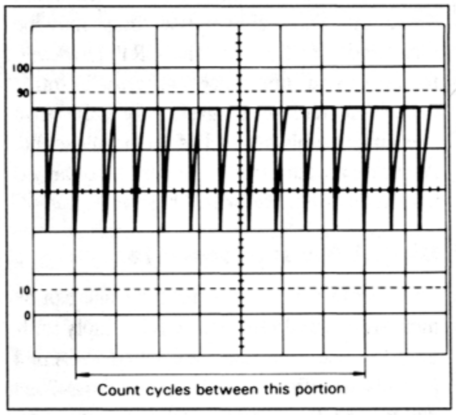

Fig. 29. Alternate method of frequency measurement.

For the example shown in Fig. 29, there are 10 cycles within 7 divisions. If the Time/Div control setting is 5 mS and magnification is not used, the frequency is calculated as follows:

$$\text{Freq} = \frac{10\ (\text{cycles})}{7\ (\text{div}) \times 5\mu S} = 205.7\ \text{kHz}$$

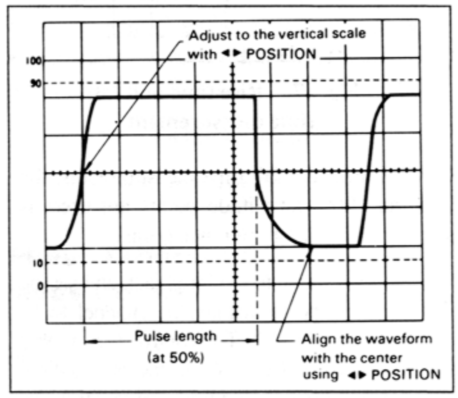

Fig. 30. Pulse width measurement.

Pulse Width Measurements

(Refer to Fig. 30)

1. Apply the pulse signal to one of the oscilloscope's input jacks and set the scope to display the channel to be used.
2. Use the Volts/Div and Time/Div controls to adjust the display so the waveform is easily observed. Use the vertical position control to position the pulse over the center horizontal graduation line. Use the horizontal position control to align the leading edge of the pulse with one of the vertical graduation lines.
3. Measure the distance between the leading edge and trailing edge of the pulse (along the center horizontal graduation line). Be sure that the variable time base control is set to the calibrated position. Multiply the number of horizontal divisions by the step main time base control setting and if Xl0 magnification is used, further multiply this value by 1/10.

The measurement is summarized by the following equation:

Pulse Width =
Hor Div x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 30, the pulse width at the center of the pulse is 4.6 divisions. If the time/div control setting is 0.2 mS and X10 magnification is used, the pulse width is calculated as follows:

Pulse Width =
4.6 (div) x 0.2 (mS/div) x 1/10
= .092 mS or 92 mS.

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Pulse Rise Time and Fall Time Measurements

Method No. 1
(Refer to Fig. 31)

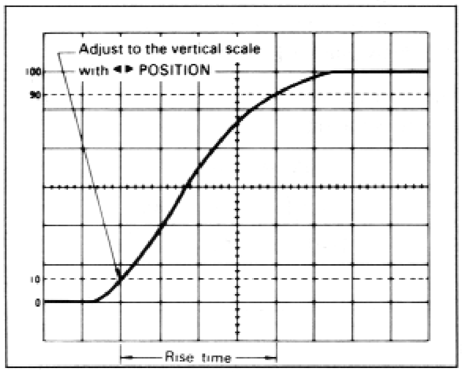

Fig. 31. Rise time and fall time measurement

For rise time and fall time measurements, the 10% and 90% amplitude points are used as starting and ending reference points.

1. Apply a signal to the input jack and set the oscilloscope to display the channel to be used. Use the Volts/Div control, the variable input attenuator control, and the vertical position control to adjust and position the waveform on the 0% and 100% markers. Ignore any overshoot or aberrations.

2. Set the Time/Div control to as fast a setting as possible while still being able to observe both the 10% and 90% points. Set the variable time base control to the calibrated position.

3. Use the horizontal position control to adjust the 10% point to coincide with a vertical graduation line and measure the horizontal distance in divisions between the 10% and 90% points on the waveform. Multiply this by the Time/Div control setting and also by 1/10 if the X10 magnification mode was used.

Note:

Be sure that the correct 10% and 90% lines are used. For such measurements, the 0, 10, 90, and 100% points are marked on the CRT screen.

IMPORTANT CONSIDERATIONS FOR RISE TIME AND FALL TIME MEASUREMENTS

Error in Observed Measurements
The observed rise time (or fall time) as seen on the CRT is actually the cascaded rise time of the pulse being measured and the oscilloscope's own rise time. The two rise times are combined in square law addition as follows:

$$T_{observed} = \sqrt{(T_{pulse})^2 + (T_{scope})^2}$$

The effect of the oscilloscope's rise time is almost negligible when its rise time is at least three times as fast as that of the pulse being measured. Thus, slower rise times may be measured directly from the CRT. However, for faster rise time pulses, an error is introduced that increases progressively as the pulse rise time approaches that of the oscilloscope. Accurate measurements can still be obtained by calculation as described below.

Direct Measurements
To determine the fastest rise time that can be measured directly from the CRT, simply multiply the rise time rating of the oscilloscope by a factor of 3. This will tell you the minimum allowable duration of rise time measurable directly from the CRT. However, since the rise time of the signal you are observing is not known, it is easier to determine the minimum number of divisions that the rise time pulse should occupy so that it can be measured directly from the CRT. Most rise times are measured at the fastest sweep speed and using X10 magnification. If you are using a 100 MHz oscilloscope with a rise time of 3.5 ns and the maximum sweep speed is 2 ns/div with X10 Mag, you would not want to make direct rise time measurements of less than 10.5 ns, or 5.25 divisions.

Calculated Measurements
For observed rise times of less than three times the oscilloscope's rise time, the pulse rise time should be calculated to eliminate the error introduced by the cascaded oscilloscope rise time. Calculate pulse rise time as follows:

$$T_{observed} = \sqrt{(T_{pulse})^2 - (T_{scope})^2}$$

Limits of Measurement
Measurements of pulse rise times that are faster than the scope's rated rise time are not recommended because a very small reading error introduces significant error into the calculation. This limit is reached when the "observed" rise time is about 1.3 times greater than the scope's rated rise time.

Probe Considerations
For fast rise time measurements that approach the limits of measurement, direct connection via 50-ohm coaxial cable and 50-ohm termination is recommended where possible. When a probe is used, its rise time is also cascaded in square law addition. Thus, the probe rating should be considerably faster than the oscilloscope if it is to be disregarded in the measurement.

The measurement is summarized by the following equation:

Rise Time = Hor Div x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 31, the horizontal distance is 4.0 divisions. The Time/Div control setting is 2 mS. The rise time is calculated as follows:

Rise Time =
4.0 (div) x 2 (µS/div) = 8 µS

Method No. 2
(Refer to Fig. 32)
The following step can be substituted for step 3 in Method No. 1:

Use the horizontal position control to set the 10% point to coincide with the center vertical graduation line and measure the horizontal distance to the point of the intersection of the waveform with the center horizontal line. Let this distance be D1. Next, adjust the waveform position so that the 90% point coincides with the vertical centerline and measure the distance from that line to the intersection of the waveform with the horizontal centerline. Let this distance be D2. The total horizontal distance is D1 plus D2.

The following equation summarizes the measurement:

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Rise Time = (D1 + D2) x Time/Div
(x 1/10 if X10 Mag is used).

For the example shown in Fig. 32, D1 is 3.8 divisions and D2 is 2.2 divisions. If the Time/Div control setting is 2 ms, the rise time is calculated as follows:

Rise Time = (1.8 + 2.2) x 2 (µS/div)=8 µS

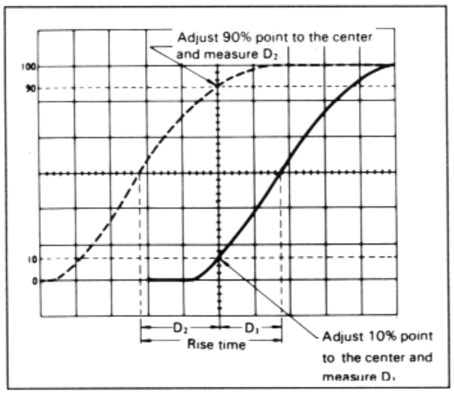

Fig. 32. Alternative rise time and fall time measurement

Percentage of Modulation Measurements

(Refer to Fig. 33)

This procedure is useful in measuring the percentage of modulation in an AM (amplitude modulation) signal.

1. Connect the modulated signal to the channel 1 input jack.

2. Adjust the oscilloscope controls for a stable display of several cycles of the modulated signal.

3. Adjust the Volts/Div and variable input attenuator controls so that several divisions of vertical amplitude are displayed. Since this measurement simply calls for a ratio, it is not necessary to be concerned with the scale factor (Volts/Div).

The percentage of modulation is determined by dividing two times the modulation depth by the unmodulated carrier level and multiplying the result by 100. The following equation summarizes the measurement:

Percent of Modulation =

$$\frac{2B}{A} \times 100$$

where:
A = Unmodulated carrier level (in divisions)
B = Modulation depth (in divisions)

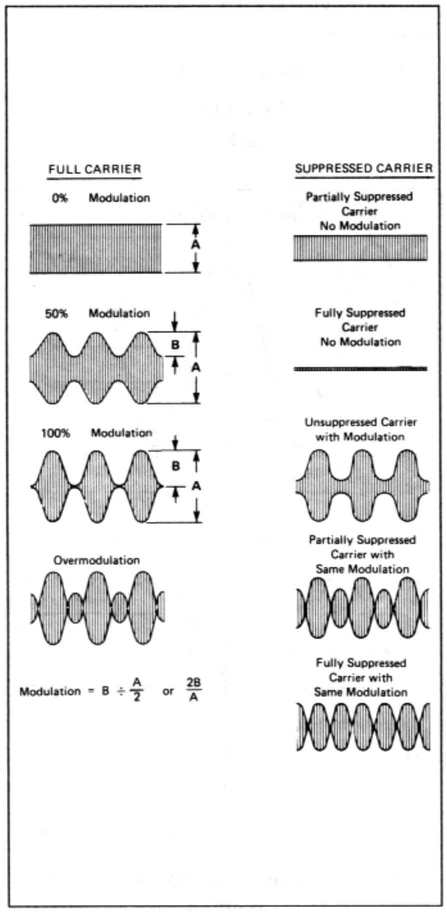

Fig. 33. Percent of modulation measurement

For the first example shown in Fig. 33, there is no modulation depth so the percentage of modulation is obviously zero. The waveform in the second example in Fig. 33 has a modulation depth of 1 division and an unmodulated carrier level of 4 divisions. The percentage of modulation is 50%, which was calculated as follows:

$$\frac{2 \times 1}{4} \times 100 = 50\%$$

The waveform in the third example of Fig. 33 has a signal with a modulation depth of 2 divisions and an unmodulated carrier level of 4 divisions. The percentage of modulation is 100%, which was calculated as follows:

$$\frac{2 \times 2}{4} \times 100 = 100\%$$

The fourth and final example in Fig. 33 represents an overmodulated signal. Once modulation exceeds 100%, there is no need to calculate the percentage.

Time Difference Measurements

(Refer to Fig. 34)

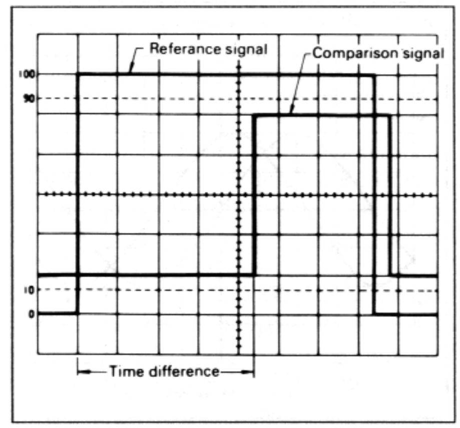

Fig. 34. Time difference measurement.

This procedure is useful in measurement of time difference between signals that are synchronized to one another but skewed in time.

1. Apply the two signals to the oscilloscope's input jacks and select the dual-trace display mode (either the chop or alternate display mode). Chop is usually chosen for low-frequency signals and alternate for high-frequency signals.

2. Set the scope to trigger on the channel that gives the most stable display. Use the Volts/Div and Time/Div controls to obtain an easily observed display of both signals.

3. Use the vertical position controls to superimpose both waveforms to intersect the center horizontal graduation line as shown in Fig. 34. Use the horizontal position control to set the reference signal coincident with one of the vertical graduation lines.

4. Measure the horizontal distance between the two signals and multiply this distance (in divisions) by the step main time base setting. If

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X10 magnification is used, multiply this again by 1/10.

The measurement is summarized by the following equation:

Time = Hor Div x Time/Div
(x 1/10 if X10 Mag is used)

For the example shown in Fig. 34, the horizontal distance measured is 4.4 divisions. If the Time/Div control setting is 0.2 mS and X10 magnification is not used, the time difference is calculated as follows:

Time = 4.4 (div) x 0.2 (mS/div)
= 0.88 µS or 880 µS

Phase Difference Measurements

Method No. 1
(Refer to Fig. 35)

This procedure is useful in measuring the phase difference of signals of the same frequency.

1. Apply the two signals to the oscilloscope's input jacks and select the dual-trace display mode (either alternate or chop display mode).

2. Select the signal which is leading in phase as the trigger source and use the Volts/Div and variable input attenuator controls to adjust the two waveforms so they are equal in amplitude.

3. Use the vertical position controls to position the waveforms in the vertical center of the display. Use the Time/Div and variable time base controls to adjust the display so that one cycle of the reference signal occupies 8 divisions horizontally (see Fig. 35). The trigger level and horizontal position controls are also useful in achieving this display. The display should be as shown in Fig. 35, where one division now represents 45° in phase.

4. Measure the horizontal distance between corresponding points on the two waveforms. Multiply the distance (in divisions) times 45° per division to obtain the phase difference.

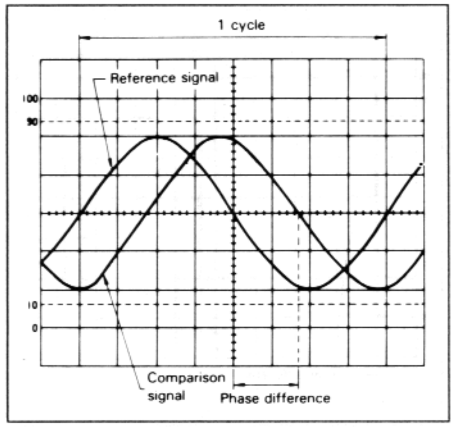

Fig. 35. Phase difference measurement.

The measurement is summarized by the following equation:

Phase Difference = Hor Div x 45°/Div

For the example shown in Fig. 35, the horizontal distance is 1.7 divisions. Thus, the phase difference is calculated as follows:

Phase Difference = 1.7 x 45°/div = 76.5°

Method No. 2
(Refer to Fig. 36)

The above procedure allows 45° per division, which may not give the desired resolution for small phase differences.

If greater accuracy is required, the Time/Div control setting may be changed to expand the display as shown in Fig. 35, but the variable time base control setting must not be touched. If necessary, the trigger level may be readjusted. For this type of operation, the relationship of one division to 45° no longer holds. Instead, the following equation must be used:

$$\text{Phase Difference} = \text{Hor Div} \times 45°/\text{Div} \times \frac{A}{B}$$

where:
A = New step main time base control setting.
B = Original step main time base control setting.

A simpler method of obtaining more accuracy quickly is to simply use X10 magnification for a scale factor of 4.5°/division.

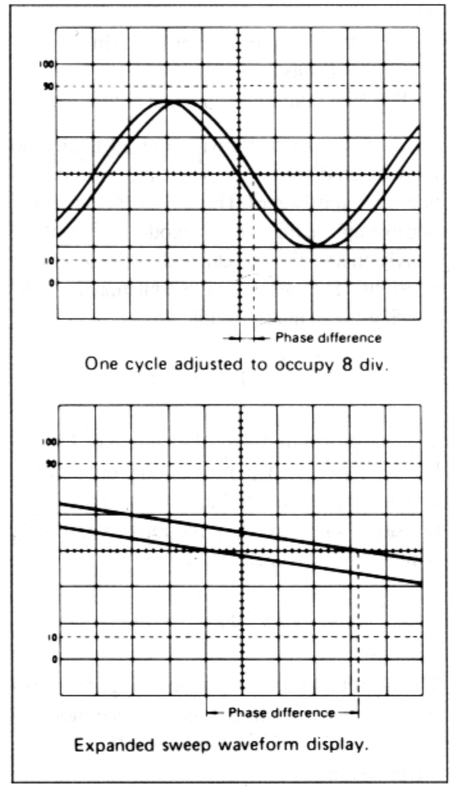

Fig. 36. Measuring small phase difference.

Relative Measurements

If the amplitude and period of some reference signal are known, an unknown signal may be measured for amplitude and period without the variable input attenuator and variable time base controls set to the calibrated position. The measurement is made in units relative to the reference signal.

Relative Voltage Measurements
(Refer to Fig. 37)

1. Apply the reference signal to the input jack and adjust the oscilloscope for a normal waveform display. Adjust the Volts/Div and variable input attenuator controls so that the amplitude of the reference signal occupies a fixed number of divisions. After adjusting, be sure not to disturb the variable input attenuator control setting.

2. Calculate the vertical calibration coefficient as follows:

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$$\text{Vertical Coefficient} = \frac{C}{D \times E}$$

where:
C = Amplitude of reference signal (in volts).
D = Amplitude of reference signal (in divisions).
E = step input attenuator setting.

3. Remove the reference signal and apply the unknown signal to the input jack, using only the Volts/Div control to adjust the amplitude for easy observation (do not disturb the variable input attenuator setting).

4. Measure the amplitude of the displayed waveform, in divisions. Multiply the number of divisions by the Volts/Div control setting and the vertical coefficient from above to find the value of the unknown voltage.

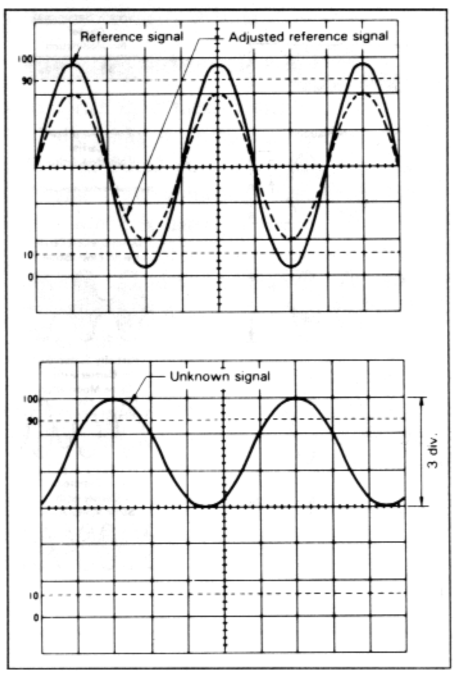

Fig. 37. Voltage measurement, relative, method

The measurement is summarized by the following equation:

Unknown Voltage =
Vert Div x Volts/Div x Vert Coefficient.

For the example shown in Fig. 37, the variable input attenuator control is adjusted so the amplitude of the reference signal is 4 divisions. If the reference signal is 2.0 V p-p, and the Volts/Div control setting is 1 V, the vertical coefficient is 0.5, which was calculated as follows:

Vertical Coefficient =

$$\frac{2\ (V)}{4\ (div) \times 1\ (V/div)} = 0.5$$

For the example shown in Fig. 37, the amplitude of the unknown signal is 3 divisions, and the previously calculated vertical coefficient is 0.5. If the Volts/Div control setting is 5 V, the unknown signal is 7.5 V p-p. which was calculated as follows:

Unknown Voltage =
3 (div) x 5 (V/div) x 0.5 (vert coef)
=7.5 V

Note:
It is preferable that the reference voltage be the peak-to-peak value, as in the previous example. The measurement holds true for all waveforms if a p-p reference is used. It is also possible to use an rms value for the reference voltage. The unknown voltage value will also be in rms, but the measurement holds true only if both the reference and unknown signals are undistorted sine waves.

Relative Period Measurements
(Refer to Fig. 38)

1. Apply the reference signal to the input jack and adjust the display for a normal waveform display. Using the Time/Div and variable time base controls, adjust one cycle of the reference signal to occupy a fixed number of horizontal divisions. After this is done, be sure not to disturb the variable time base control setting.

2. Calculate the sweep (horizontal) calibration coefficient using the following equation:

$$\text{Sweep Coefficient} = \frac{F}{G \times H}$$

where:
F = Period of reference signal (seconds).

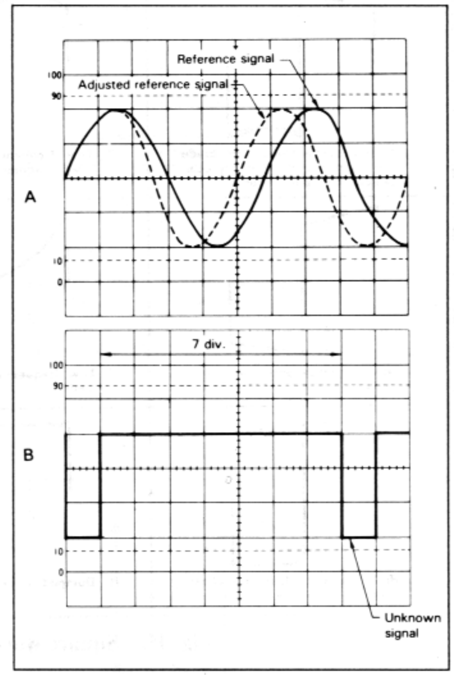

Fig. 38. Period measurement, relative, method

G = Horizontal width of reference signal (divisions).
H = Step main time base control setting.

3. Remove the reference signal and apply the unknown signal to the input jack, using only the Time/Div control to adjust the width of the display (do not disturb the variable time base control setting).

4. Measure the width of one cycle of the displayed waveform, in divisions. Multiply the number of divisions by the Time/Div control setting and the sweep coefficient from above to find the period of the unknown waveform.

The measurement is summarized by the following equation:

Unknown Period =
Horizontal Divisions x Time/Div
x Sweep Coefficient.

For the example in Fig. 38a, the variable time base control is adjusted so the reference signal occupies 5 horizontal divisions. If the reference signal is 1.75 kHz and the Time/Div control setting is 0.1 mS, the sweep coefficient is calculated as follows:

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Sweep Coifficent =

$$\frac{1.75 \text{ kHz-1}}{5 \text{ (div)} \times 0.1 \text{ (ms/div)}} = 1.143$$

For the example in Fig. 38b, the width of the unknown signal is 7 divisions, and the previously calculated sweep coefficient is 1.143. If the Time/Div control setting is 0.2 mS, the period is calculated as follows:

Unknown Period =
7 (div) x 0.2 (mS/div) x
1.143 (sweep coef)
= l.6 ms.

Using Square Waves To Test Amplifiers

(Refer to Fig. 39)

A square wave generator and an oscilloscope can be used to display various types of distortion present in electronic circuits. A square wave of a given frequency contains a large number of odd harmonics of that frequency. If a 500 Hz square wave is injected into a circuit, frequency components of 1.5 kHz, 2.5 kHz, and 3.5 kHz are also produced. Since most amplifiers do not have uniform gain throughout a wideband width, it is difficult to amplify and reproduce a square wave faithfully. Junction capacitances, stray capacitances, and limited device response are a few of the factors which prevent faithful reproduction of a square wave signal. A well designed amplifier can minimize the nonlinearities caused by these limitations, but a poorly designed or defective amplifier can introduce these nonlinearities to the point where its performance is unsatisfactory.

By injecting a 500 Hz sine wave into an amplifier, response is evaluated only at 500 Hz. However, since a square wave contains a large number of harmonics, by injecting a 500 Hz square wave into an amplifier, we can determine amplifier response for inputs from 500 Hz up to the 21st harmonic.

The need for square wave evaluation becomes apparent if we realize that during normal use, some audio amplifiers will be required to pass a large number of different frequencies simultaneously. With a square wave, we have a controlled signal with which we can evaluate the input and output quality of a signal of many frequencies (the harmonics of the square wave), much like the amplifier sees when amplifying complex waveforms of musical instruments or voices.

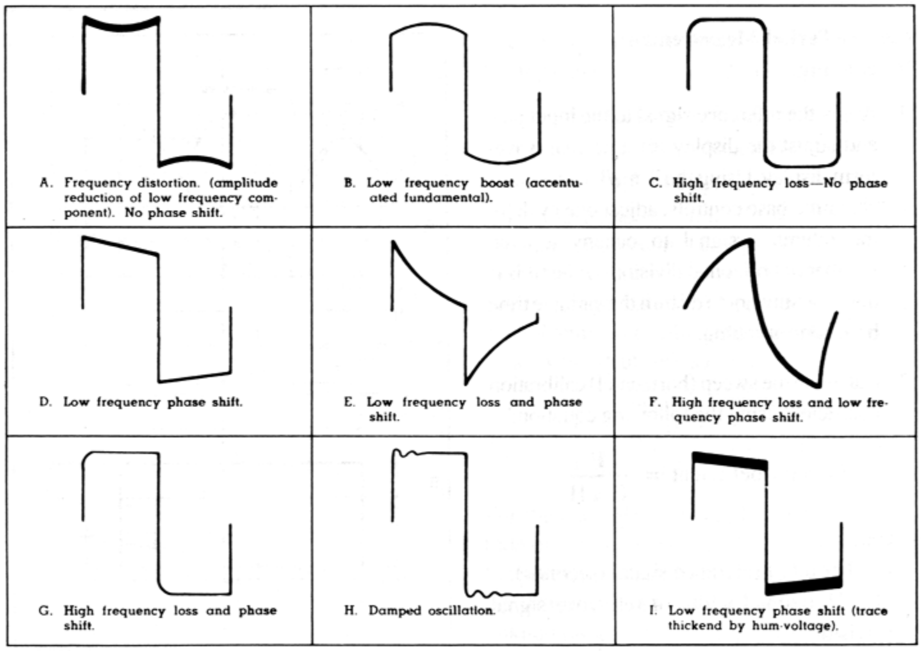

Fig. 39. Square wave analysis waveform.

The square wave output of the signal generator must be close to ideal (no tilting or aberrations) so that it does not contribute to any aberration that may be observed when evaluating amplifier response. The oscilloscope vertical input coupling should be set to DC as it will introduce the least distortion, especially at low frequencies. When checking amplifier response, the frequency of the square wave input should be varied from the low end of the amplifier bandpass up toward the upper end of the bandpass. However, because of the harmonic content of the square wave, distortion of the waveform will occur before the upper end amplifier bandpass is reached.

It should be noted that the actual response check of an amplifier should be made using a sine wave signal. This is especially important in limited bandwidth amplifiers. The square wave signal provides a quick check of amplifier performance and will give an estimate of overall amplifier quality. The square wave also will reveal some deficiencies not readily apparent when using a sine wave signal. Whether a sine wave or square wave is used for testing the amplifier, it is important that the manufacturer's specifications be known in order to properly judge its performance.

1. Connect the output of a square wave generator to the input of the amplifier to be tested.

2. Connect a probe to the oscilloscope's channel 1 input. Connect the probe tip to the output of the amplifier being tested (use a resistive load).

3. If the DC component of the circuit being tested is sufficiently low to allow both the AC and DC components of the signal to be viewed simultaneously, use DC input coupling. The AC position may be used without affecting results, except at very low frequencies (below 5 Hz).

4. Adjust the oscilloscope controls for a stable display of one complete cycle of the square wave at a convenient height.

5. For a close-up view of a portion of the square wave, use the X10 magnification and horizontal position control to bring the desired portion to the center of the CRT.

Refer to Fig. 39 for an analysis of waveforms likely to appear during square wave testing of amplifiers. Distortion can be classified into three distinct categories:

- The first is frequency distortion and refers to the change from normal amplitude of a complex waveform. In other words, the introduction in an amplifier circuit of resonant networks or selective filters created by a combination of reactive components will create peaks or dips in an otherwise flat frequency response curve.
- The second is non-linear distortion and refers to a change in waveshape produced by the application of the waveshape to non-linear components or elements.
- The third is delay or phase distortion, which is distortion produced by a shift in phase between one or more components of a complex waveform.

In actual practice, a reduction in amplitude of a square wave component (sinusoidal harmonic) is usually caused by a frequency-selective network which includes capacitance, inductance, or both. The presence of C or L introduces a difference in phase angle between components, creating phase distortion or delay distortion. Therefore, in square wave testing of practical circuitry, we will usually find that the distorted wave includes a combination of amplitude and phase distortion clues. The different waveforms in Fig. 39 sum up the clues as follows:

A. If the combination of elements in the amplifier circuitry were such as to only depress the low frequency components of the square wave, a display similar to Fig. 39A would be obtained.

B. If the opposite condition were the case and the amplifier circuitry boosted only low frequency components of the square wave, a display similar to Fig. 39B would be obtained.

C. The short rise time which occurs at the beginning of the half-cycle is created by the in-phase sum of all the medium and high frequency sine wave components. The same holds true for the rapid droop at the end of the half cycle from maximum amplitude to zero amplitude. Therefore, a reduction in amplitude alone of the high frequency components should produce a rounding at all four points of one square wave cycle as shown in Fig. 39C.

D. If the combination of elements in the amplifier circuitry were such as to only shift the phase of the low frequency components of the square wave, a display similar to Fig. 39D would be obtained.

E. Since a reduction in amplitude of the low frequency components is usually caused by reactive components, a shift in the phase of the low frequency components would be likely to occur in addition to the attenuation of low frequency components. This would cause a display similar to Fig. 39E.

F. If the combination of elements in the amplifier circuitry were such as to decrease the high frequency components of the square wave and cause phase shift to the low frequency components, a display similar to Fig. 39F would be obtained.

G. If the combination of elements in the amplifier circuitry were such as to attenuate and shift the phase of the high frequency components of the square wave, a display similar to Fig. 39G would be obtained.

H. If the amplifier circuitry boosted the high frequency components of the square wave but the network in the amplifier were damped, a display similar to Fig. 39H would be obtained. Lighter damping would cause more oscillation (the sinusoidal shape at the beginning of the leveling off period) and heavy damping would decrease oscillation.

I. If the combination of elements in the amplifier circuitry were such as to shift only the phase of the low frequency components of the square wave, but power supply filtering were also poor (thus introducing line voltage hum) a display similar Fig. 39I would be obtained.

X-Y Mode Applications

Phase Measurements

(Refer to Fig. 40)

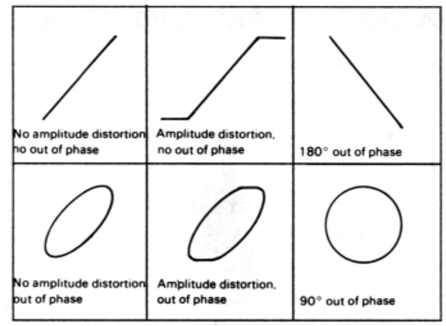

Fig. 40. Typical X-Y phase measurement displays

A dual-trace method of phase measurement was previously described. A second method of phase measurement requires calculations based on the Lissajous patterns obtained using X-Y operation. Distortion due to non-linear amplification can also be displayed.

A sine wave is applied to the audio circuit being tested. The same sine wave is also applied to the vertical input of the oscilloscope, and the output of the tested circuit is applied to the horizontal input of the oscilloscope. The amount of phase difference between the two signals can be calculated from the resulting waveform.

1. Using an audio generator with a pure sinusoidal signal, apply a sine wave test signal at the desired test frequency to the audio network being tested.

2. Set the signal generator output for the normal operating level of the circuit being tested. If desired, the circuit's output may first be observed on the oscilloscope with normal sweep operation. If the test circuit is over driven, the sine wave display on the oscilloscope is clipped and the signal level must be reduced.

3. Connect channel 1 to the input and channel 2 to the output of the test circuit. Set channel 1 and 2 Volts/Div and variable input attenuator controls for exactly the same amplitude waveforms on the display in normal sweep operation.

4. Select X-Y operation.

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5. If necessary, repeat step 3, readjusting the channel 1 and 2 gain controls for a suitable viewing size. Some typical results are shown in Fig. 40.

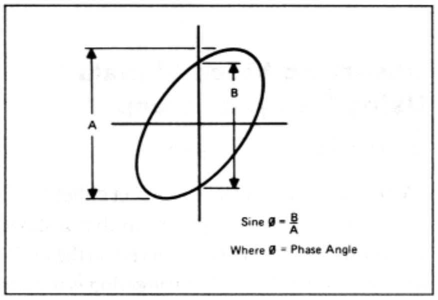

Fig. 41. Phase measurement, X-Y operation.

If the two signals are in phase, the oscilloscope trace is a straight diagonal line. If the vertical and horizontal gain are properly adjusted, this line is at a 45° angle. A 90° phase shift produces a circular oscilloscope pattern. Phase shift of less (or more) than 90° produces an elliptical oscilloscope pattern. The amount of phase shift can be calculated from the oscilloscope trace as shown in Fig. 41.

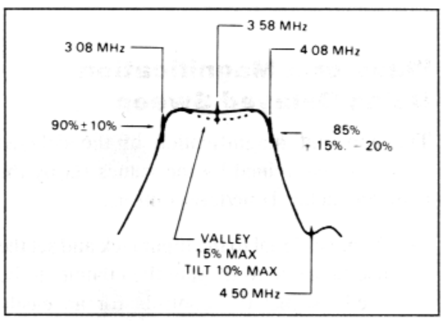

Fig. 42. Frequency response measurement.

Frequency Response Measurements
(Refer to Figs. 42 and 43)

A sweep generator and the X-Y mode of the oscilloscope maybe used to measure the audio or rf frequency response of an active or passive device, such as an amplifier, band pass filter, coupling network, etc.

1. Refer to Fig. 42. Connect the audio or rf output of the sweep generator to the input of the circuit under test and the output of the test circuit to Y axis input (vertical axis) of the oscilloscope. A demodulator probe will give a "text book" frequency response display as shown in Fig. 43, but a standard probe can be used which will result in an envelope display.

2. Connect the sweep ramp voltage of the sweep generator to the X axis input of the oscilloscope.

3. Set the oscilloscope for X-Y operation and adjust the channel 1 and 2 controls for a suitable viewing size.

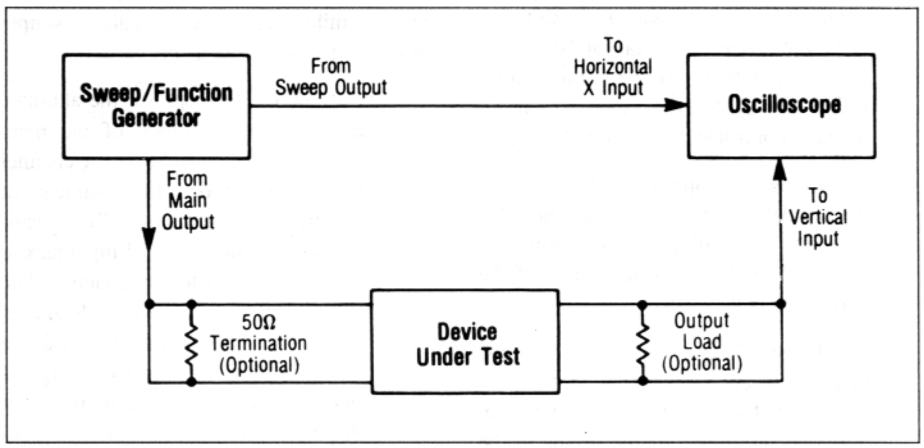

Fig. 43. Frequency response test set-up.

APPLICATIONS

DELAYED SWEEP APPLICATIONS

Waveform Magnification Using Delayed Sweep

The apparent magnification of the delayed sweep is determined by the values set by the main and delay Time/Div controls.

1. Apply a signal to the input jack and set the oscilloscope to display the channel to be used. Adjust the controls for an easily observed display of the waveform.

2. Set the Time/Div control so that several cycles of the waveform are displayed.

3. Set the scope to delayed sweep. Use the delay time position control to adjust the delayed sweep portion of the display. Use the delay Time/Div control to set the desired sweep speed for the magnified portion.

4. Set the oscilloscope to view both the main and delayed sweep (Mix sweep mode), or set it to view only the magnified portion (delayed sweep).

5. Time measurements are performed in the same manner for the delayed sweep as for the main sweep (but remember to use the delay Time/Div control setting as the sweep speed for calculations).

Pulse Jitter Measurements

(Refer to Fig. 44)

1. Apply the signal to one of the input jacks and set the oscilloscope to display the channel to be used. Use the Volts/Div control to adjust the waveform so that it is easy to observe. Special care should be taken to adjust the trigger controls for a stable display. Set the variable input attenuator control to the calibrated position.

2. Set the oscilloscope to display both the main and delayed sweep. Adjust the delay Time/Div and delay time position controls so that the entire jitter area of the waveform is magnified.

3. Set the oscilloscope to display just the delayed sweep. Measure the width of the jitter area. The jitter time is the width in divisions multiplied by the setting of the step delay Time/Div control.

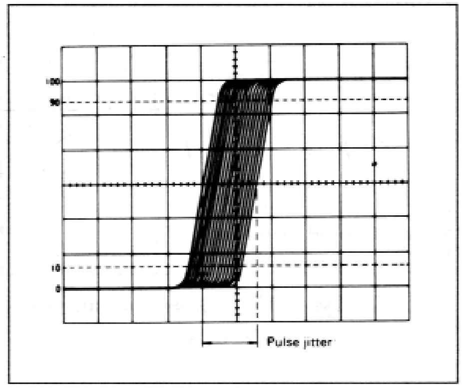

Fig. 44. Pulse jitter measurement

The following equation summarizes the measurement:

Pulse Jitter =
Jitter Width (Div) x Delay Time/Div.

For the example shown in Fig. 44, the jitter width is 1.6 divisions and the delay Time/Div control setting is 0.2 mS. The pulse jitter is 0.32 mS, which was calculated as follows:

Pulse Jitter = 1.6 x 0.2 mS = 0.32 mS

Observing Video Signals Using Delayed Sweep

(Refer to Figs. 45 through 49)

TV triggering allows you to select either vertical or horizontal sync pulses so that a stable video waveform may be observed on the oscilloscope display. When TV triggering is used in conjunction with delayed sweep (not all oscilloscopes have the delayed sweep feature and isolating a desired part of a video signal without using the delayed sweep is very difficult to do) the video signal can be observed and analyzed on an oscilloscope. The following instructions will help you set up a delayed sweep oscilloscope to view video signals. The section on "The NTSC Color Video Signal", at the end of this chapter, gives some basics for those who are unfamiliar with video signals or simply wish to refresh their memory.

1. Set up the oscilloscope for the alternate dual-trace display mode of the main sweep only and connect both the channel 1 and channel 2 probes to the same point in the circuit (if you wish, a "T" connector can be used at the channel 1 input jack to feed the same signal to each channel). The alternate dual-trace display mode aids in viewing the video signal because the "holdoff" period between sweep signals is increased enough that one field of video is displayed on channel 1 and the other field of video is displayed on channel 2. If only the single trace display mode were to be used, both fields of video would be displayed on one trace and the display would likely be unusable since the two fields usually differ.

2. Set the main Time/Div control to 0.2 mS/div (this setting will cause about 32 lines of video to be displayed). This will be a sufficient number of lines so that the Vertical Interval Test Signal (VITS) can be displayed along with the rest of the vertical interval blanking period and several lines of video information.

3. Select vertical TV trigger coupling (TVV), select the channel one signal as the trigger source, and select negative trigger slope. Adjust the trigger level control for a display such as that shown in the top line of Fig. 45 (although the waveform will be compressed horizontally, the waveform in the illustration is expanded for clarity).

4. Set the delay Time/Div control to about 0.2 ms/div and set the oscilloscope to display the delayed sweep signal or, if desired, a mix of the main sweep and the delayed sweep. (A setting of 20 mS/div will give a display of about three lines of video—further expansion to less than three lines of video is possible with faster sweep speeds.) Adjust the delay time position control until the desired line(s) of video are displayed. If you wish to view the VITS/VIR lines, they are the 17th, 18th, and 19th lines in a video frame. Fig. 45 shows the main and delayed sweep of both field 1 and field 2.

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Most network television signals contain a built-in test signal (called the Vertical Interval Test Signal, or VITS) that can be a very valuable tool in troubleshooting and servicing television sets. The VITS is transmitted during the vertical blanking interval and can be used to localize trouble to the antenna, tuner, i-f, or video sections. The signal appears as a bright white line above the top of the television picture when the vertical linearity or height is adjusted to view the vertical blanking interval (on TV sets with internal retrace blanking circuits, the blanking circuit must be disabled to see the VITS). The following procedure shows how to analyze and interpret the oscilloscope displays of the VITS.

The transmitted VITS may vary from channel to channel, but is similar to Fig. 46. The television networks use the precision signals for adjustment and checking of network transmission equipment, but the technician can use them to evaluate television performance. The first frame of the VITS (line 17) may begin with a "flag" of white video, followed by sine wave frequencies of 0.5 MHz, 1.5 MHz, 2 MHz, 3 MHz, 3.6 MHz (3.58 MHz) and 4.2 MHz. This sequence of frequencies is called the "multi-burst". The first frame of Field #2 (line 279) may contain an identical multiburst. This multi-burst portion of the VITS is the portion that can be the most valuable to the technician. The second frame of the VITS (lines 18 and 280), may contain the sine-squared pulse, window pulse, and the staircase of 3.58 MHz bursts at progressively lighter shading, which are valuable to the network, but have little value to the technician.

All frequencies of the multi-burst are transmitted at the same level, but should not be equally coupled through the receiver (due to its frequency response curve). Fig. 47 shows the desired response for a good television receiver, identifying each frequency of the multi-burst and showing the allowable amount of attenuation for each (remember that –6 dB equals one half of the reference voltage — the 2.0 MHz signal should be used as the reference).

To localize trouble, start by observing the VITS at the video detector. This will localize trouble to a point either before or after the detector. If the multi-burst is normal at the detector, check the VITS on other channels. If some channels look OK but others do not, you probably have tuner or antenna-system problems. Don't overlook the chance of the antenna system causing "holes" or tilted response on some channels. If the VITS is abnormal at the video detector on all channels, the trouble is probably in the i-f amplifier stages.

As another example, let us assume that we have a set on the bench with a very poor picture. Our oscilloscope shows the VITS at the video detector to be about normal except that the burst at 2.0 MHz is low compared to the burst on either side. This suggests that an i-f trap is detuned into the passband, chopping out frequencies of about 2 MHz below the picture carrier frequency. Switch to another channel carrying VITS; if the same thing is seen, then our reasoning is right, and the i-f amplifier requires realignment. If the poor response at 2 MHz is not seen on other channels, maybe an FM trap at the tuner is misadjusted or faulty, causing a bite on only one channel. Other traps at the input of the set could similarly be misadjusted or faulty.

If the VITS response at the detector output is normal for all channels, the trouble may be in the video amplifier. Check for open peaking coils, off-value resistors, solder bridges across foil patterns, etc.

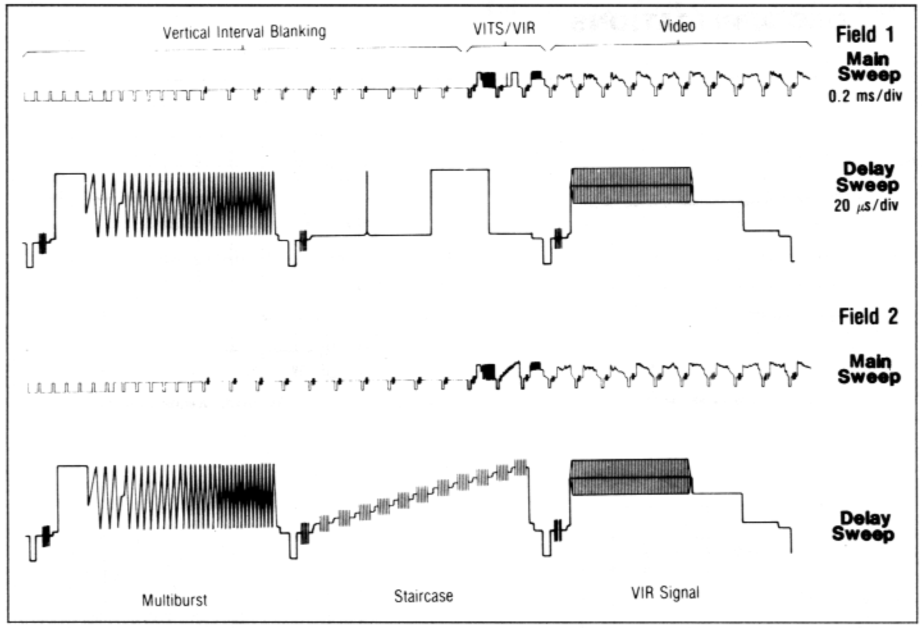

Fig. 45. Observing video signals using delayed sweep.

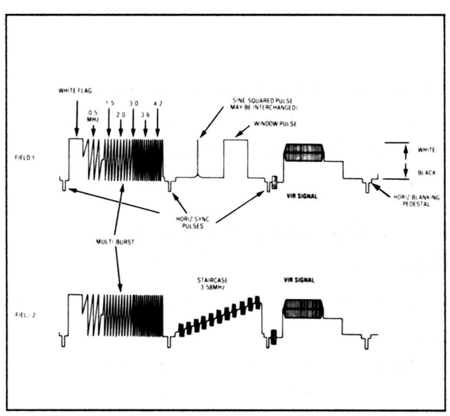

Fig. 46. Typical VITS signal

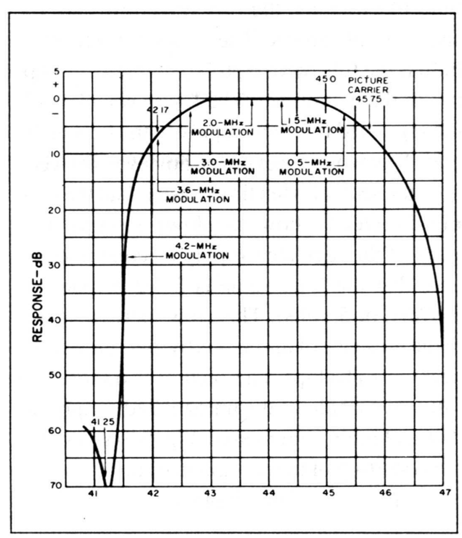

Fig. 47. Color TV IF amplifier response curve

DSO APPLICATIONS

The displays of Fig. 48 depict several examples of waveforms that were captured using the storage facilities of a digital storage oscilloscope (DSO).

Catching Rapid One-Time Events

Figs. 48a through 48c represent captures of quickly-occurring one-time events that would be difficult to observe on a standard oscilloscope due to their rapid and one-time nature.

Figs. 48a and 48b were obtained by probing inside a piece of electronic equipment and recording waveforms as it was powered up. In both illustrations, the two waveforms are the same circuit points. The upper waveform in both is the full-wave rectified unregulated supply in the equipment. The lower waveform is the regulated five-volt supply to the ICs in the unit. The two pictures differ, however, in sweep rate; the second is ten times faster than the first. Fig. 48a clearly shows the slow ramp-up to five volts of the regulated supply (second trace — note that the final value is 2-1/2 divisions x 2 V/div, or 5 volts). This slow increase is due to the presence of numerous by-pass capacitors near the TTL chips. This picture also shows the full-wave ripple of the unregulated supply, although highly compressed. Fig. 48b shows the rapid startup of the unregulated supply and an expanded view of the ripple.

Fig. 48c reference is the second horizontal line from the bottom of the graticule. The initial current spike, when the key is first turned, is a bit more than four divisions, representing eight hundred amperes. As the motor turns over, the magnitude of the current decreases until the key is released, at which time it drops back to the reference. The time base setting in this case is fairly slow, at 0.1 S/div.

The entire cranking process takes 0.8 seconds in this case.

The waveform of Fig. 48c was captured using the DSO in SINGLE mode, by first placing it in analog mode, turning auto triggering off, and starting the ignition a few times to get the scope triggering properly. Then the DSO was put in storage mode for the actual capture. In this particular case, the event could also be captured effectively by using the unit in roll mode. The next example shows a display that was obtained using that mode.

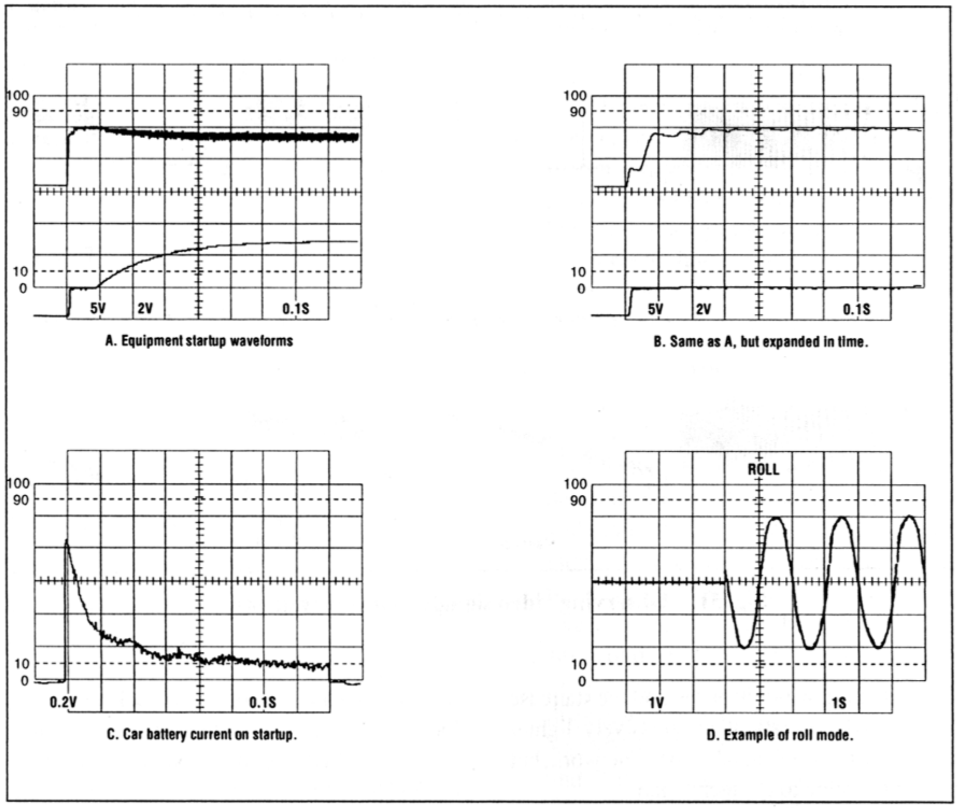

Fig. 48. DSO stored waveforms.

Catching Slow Events Using Roll Mode

The roll mode is appropriate for displaying events that occur too slowly for display on a standard scope.

On a conventional oscilloscope, slow events, even though they may be repetitive, pose a particular problem when timing measurements are required. This is because the waveform is often only a dot moving slowly across the screen, rather than a line. Conventional scopes use a short-persistence phosphor, that is, one that fades very quickly after the electron beam ceases or moves. Because of this, it is much more difficult to make graticule measurements on a moving dot than on a complete trace. Moreover, if the time base is increased to change the dot to a line, then this line is usually moving up and down in its entirety. While some vertical measurements may be obtained in this case, such as peak-to-peak excursion, there is no means of horizontal measurement.

A DSO in roll mode provides a solution because samples are taken at a very slow rate. Also, as each sample is taken, previous samples are shifted to the left; the earliest samples are the leftmost, with the newest being at the right. The effect is analogous to having a strip-chart recorder, with the paper moving slowly to the left, and the pen stationary on the right side of the scope screen. Of course, the pen is only stationary in the horizontal axis; it is free to follow the vertical excursions of the input waveform.

Fig. 48d shows a scope in roll mode displaying a switched sine wave at 0.5 Hz. When roll mode was first engaged, the sine wave was switched off (grounded), producing the flat line at the left. The sine wave was then switched on and the scope started following the input, tracing the sine wave as shown. The waveform was allowed to scroll slowly to the left, until the first positive zero crossing reached the center line. At that point, the waveform was held for measurement. In this case, it is easy to see that the period is just a bit longer than 2 seconds, yielding a frequency just under 0.5 Hz.

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THE NTSC COLOR VIDEO SIGNAL

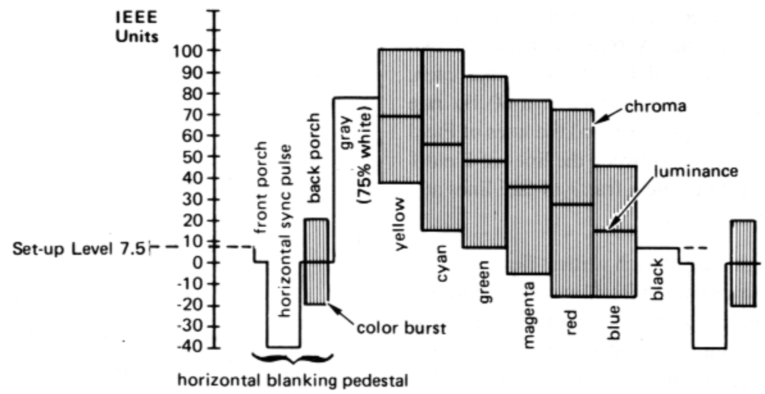
History

In 1953, the NTSC (National Television Systems Committee) established the color television standards now in use by the television broadcast industry in the United States and many other countries. It was, of course, compatible with the monochrome (black and white) systems that previously existed. The makeup of a composite video signal is dictated by NTSC specifications. These specifications include a 525-line interlaced scan, operating at a horizontal scan frequency of 15,734.26 Hz and a vertical scan frequency of 59.94 Hz. A 3.579545 MHz subcarrier contains the color information. The phase angle of the subcarrier represents the hue; the amplitude of the subcarrier represents saturation.

Horizontal Sync
(See Fig. 49)

The "beginning" of a line of horizontal scan occurs at the leading edge of the horizontal blanking pedestal. In a television receiver, the horizontal blanking pedestal starts as the electron beam of the CRT reaches the extreme right-hand edge of the screen (plus a little overscan in most cases). The horizontal blanking pedestal prevents illumination of the screen during retrace, that is, until the electron beam deflection circuits are reset to the left edge of the screen and ready to start another line of video display. The entire horizontal blanking pedestal is at the blanking level or the sync pulse level. In a television receiver, the blanking and sync pulse levels are the "blacker than black" levels that assure no illumination during retrace.

The horizontal blanking pedestal consists of three discrete parts: the front porch, the horizontal sync pulse, and the back porch. The front porch is a 1.40 microsecond period at blanking level. The front porch is followed by a 4.64 microsecond horizontal sync pulse at the –40 IEEE units level. An explanation of IEEE units follows in the "Amplitude" paragraph. When the horizontal sync pulse is detected in a TV receiver, it initiates flyback, which ends the horizontal scan and rapidly resets the horizontal deflection circuit for the next line of horizontal scan. The horizontal sync pulse is followed by a 4.79 mS back porch at the blanking level. When a color



IEEE Units											
LUMINANCE	0	-40	0	77	69	56	48	36	28	15	7.5
CHROMA AMPLITUDE	–	–	40	–	62	88	82	82	88	62	–
VECTOR (FROM B-Y)	–	–	180°	–	167°	284°	241°	61°	104°	347°	–

Fig. 49. One horizontal line of NTSC color bars signal.

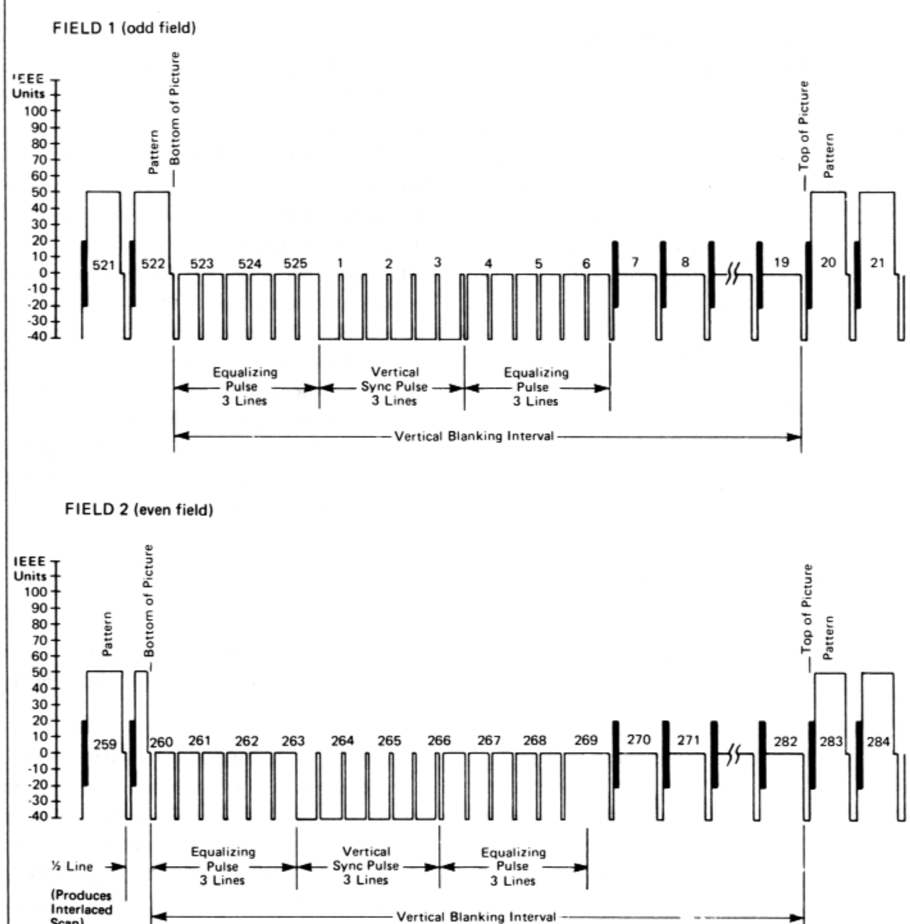


Fig. 50. Composite video signal showing vertical blanking interval.

signal is being generated, 8 to 10 cycles of 3.579545 MHz color burst occur during the back porch. The color burst signal is at a specific reference phase. In a color TV receiver, the color oscillator is phase locked to the color burst reference phase before starting each horizontal line of video display. When a monochrome signal is being generated, there is no color burst during the back porch.

Vertical Sync

(See Fig. 50)

A complete video image as seen on a TV screen is called a frame. A frame consists of two interlaced vertical fields of 262.5 lines each. The image is scanned twice at a 60 Hz rate (59.94 Hz to be precise), and the lines of Field 2 are offset to fall between the lines of Field 1 (interlaced) to create a frame of 525 lines at a 30 Hz repetition rate.

At the beginning of each vertical field, a period equal to several horizontal lines is used for the vertical blanking interval. In a TV receiver, the vertical blanking interval prevents illumination of the CRT during the vertical retrace. The vertical sync pulse, which is within the vertical blanking interval, initiates reset of the vertical deflection circuit so the electron beam will return to the top of the screen before video scan resumes. The vertical blanking interval begins with the first equalizing pulse, which consists of six pulses one half the width of horizontal sync pulses, but at twice the repetition rate. The equalizing pulse has an 8% duty cycle. The vertical sync pulse occurs immediately after the first equalizing pulse. The vertical sync pulse is an inverted equalizing pulse at 92% duty cycle. The wide portion of the pulse is at the –40 IEEE units level and the narrow portion of the pulse is at the blanking level. A second equalizing pulse at 8% duty cycle occurs after the vertical sync pulse, which is then followed by 13 lines of blanking level (no video) and horizontal sync pulses to assure adequate vertical retrace time before resuming video scan. The color burst signal is present after the second equalizing pulse.

Note that in Field 1 line 522 includes a full line of video, while in Field 2 line 260 contains only a half line of video. This timing relationship produces the interlace of Fields 1 and 2.

Amplitude

(See Fig. 49)

A standard NTSC composite video signal is 1 volt peak-to-peak, from the tip of a sync pulse to 100% white. This 1 volt peak-to-peak signal is divided into 140 equal parts called IEEE units. The zero reference level for this signal is the blanking level. The tips of the sync pulses are at –40 units, and a sync pulse is approximately 0.3 volt peak-to-peak. The portion of the signal that contains video information is raised to a set-up level of +7.5 units above the blanking level. A monochrome video signal at +7.5 units is at the black threshold. At +100 units the signal represents 100% white. Levels between +7.5 and +100 units produce various shadings of gray. Even when a composite video signal is not at the 1 volt peak-to-peak level, the ratio between the sync pulse and video must be maintained, 0.3 of total for sync pulse and 0.7 of total for 100% white.

There is also a specific relationship between the amplitude of the composite video signal and the percentage of modulation of an rf carrier. A television signal uses negative modulation, wherein the sync pulses (–40 units) produce the maximum peak-to-peak amplitude of the modulation envelope (100% modulation), and white video (+100 units) produces the minimum amplitude of the modulation envelope (12-1/2% modulation). This is very advantageous, because the weakest signal condition, where noise interference can most easily cause snow, is also the white portion of the video. There is adequate amplitude guard band so that peak white of + 100 units does not reduce the modulation envelope to zero.

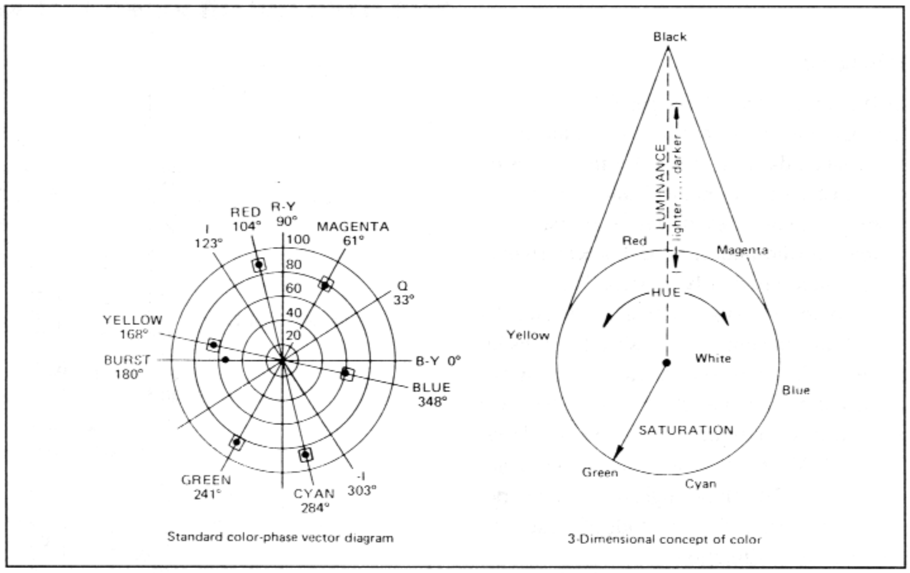


Fig. 51. Elements of color television signal.

Color

(See Fig. 51)

The color information in a composite video signal consists of three elements: luminance, hue, and saturation.

Luminance, or brightness perceived by the eye, is represented by the amplitude of the video signal. The luminance component of a color signal is also used in monochrome receivers, in which it is converted to a shade of gray. Yellow is a bright color and has a high level of luminance (is nearer to white), while blue is a dark color and has a low level of luminance (is nearer to black).

Hue is the element that distinguishes between colors, red, blue, green, etc. White, black, and gray are not hues. The phase angle of the 3.58 MHz color subcarrier determines the hue. The three primary video colors of red, blue, and green can be combined in such a manner to create any hue. A phase shift through 360° will produce every hue in the rainbow by changing the combination of red, blue, and green.

Saturation is the vividness of a hue, which is determined by the amount the color is diluted by white light. Saturation is often expressed as a percentage; 100% saturation is a hue with no white dilution, which will produce a very vivid shade. Low saturation percentages are highly diluted by white light and produce light pastel shades of the same hue. Saturation information is contained in the amplitude of the 3.58 MHz color subcarrier. Because the response of the human eye is not constant from hue to hue, the amplitude required for 100% saturation is not the same for all colors.

The combination of hue and saturation is known as chroma, or chrominance. This information is normally represented by a vector diagram.

Saturation is indicated by the length of the vector and hue is indicated by the phase angle of the vector. The entire color signal representation is three dimensional, consisting of the vector diagram for chrominance and a perpendicular plane to represent the amplitude of luminance.