Oscilloscope

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An **oscilloscope** (also known as a **scope**, **CRO**, **DSO** or, an **O-scope**) is a type of electronic test instrument that allows observation of constantly varying signal voltages, usually as a two-dimensional graph of one or more electrical potential differences using the vertical or 'Y' axis, plotted as a function of time, (horizontal or 'x' axis). Although an oscilloscope displays voltage on its vertical axis, any other quantity that can be converted to a voltage can be displayed as well. In most instances, oscilloscopes show events that repeat with either no change, or change slowly.

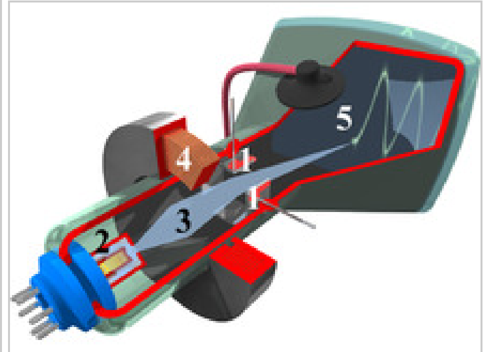

Illustration showing the interior of a cathode-ray tube for use in an oscilloscope. Numbers in the picture indicate: 1. Deflection voltage electrode; 2. Electron gun; 3. Electron beam; 4. Focusing coil; 5. Phosphor-coated inner side of the screen

A Tektronix model 475A portable analog oscilloscope, a very typical instrument of the late 1970s

Oscilloscopes are commonly used to observe the exact wave shape of an electrical signal. In addition to the amplitude of the signal, an oscilloscope can show distortion, the time between two events (such as pulse width, period, or rise time) and relative timing of two related signals.[1]

Oscilloscopes are used in the sciences, medicine, engineering, and telecommunications industry. General-purpose instruments are used for maintenance of electronic equipment and laboratory work. Special-purpose oscilloscopes may be used for such purposes as analyzing an automotive ignition system, or to display the waveform of the heartbeat as an electrocardiogram.

Originally all oscilloscopes used cathode ray tubes as their display element and linear amplifiers for signal processing, (commonly referred to as CROs) however, modern oscilloscopes have LCD or LED screens, fast analog-to-digital converters and digital signal processors. Although not as commonplace, some oscilloscopes used storage CRTs to display single events for a limited time. Oscilloscope peripheral modules for general purpose laptop or desktop personal computers use the computer's display, allowing them to be used as test instruments.

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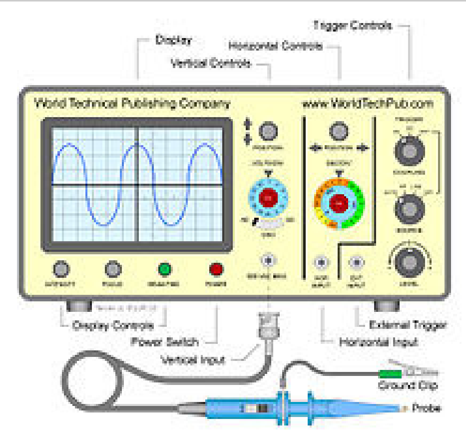


Basic Oscilloscope

Description

Display and general external appearance

The basic oscilloscope, as shown in the illustration, is typically divided into four sections: the display, vertical controls, horizontal controls and trigger controls. The display is usually a CRT or LCD panel which is laid out with both horizontal and vertical reference lines referred to as the graticule. In addition to the screen, most display sections are equipped with three basic controls, a focus knob, an intensity knob and a beam finder button.

The vertical section controls the amplitude of the displayed signal. This section carries a Volts-per-Division (Volts/Div) selector knob, an AC/DC/Ground selector switch and the vertical (primary) input for the instrument. Additionally, this section is typically equipped with the vertical beam position knob.

The horizontal section controls the time base or “sweep” of the instrument. The primary control is the Seconds-per-Division (Sec/Div) selector switch. Also included is a horizontal input for plotting dual X-Y axis signals. The horizontal beam position knob is generally located in this section.

The trigger section controls the start event of the sweep. The trigger can be set to automatically restart after each sweep or it can be configured to respond to an internal or external event. The principal controls of this section will be the source and coupling selector switches. An external trigger input (EXT Input) and level adjustment will also be included.

In addition to the basic instrument, most oscilloscopes are supplied with a probe as shown. The probe will connect to any input on the instrument and typically has a resistor of ten times the oscilloscope's input impedance. This results in a .1 (-10X) attenuation factor, but helps to isolate the capacitive load presented by the probe cable from the signal being measured. Some probes have a switch allowing the operator to bypass the resistor when appropriate.[1]

Size and portability

Most modern oscilloscopes are lightweight, portable instruments that are compact enough to be easily carried by a single person. In addition to the portable units, the market offers a number of miniature battery-powered instruments for field service applications. Laboratory grade oscilloscopes, especially older units which use vacuum tubes, are generally bench-top devices or may be mounted into dedicated carts. Special-purpose oscilloscopes may be rack-mounted or permanently mounted into a custom instrument housing.

Inputs

The signal to be measured is fed to one of the input connectors, which is usually a coaxial connector such as a BNC or UHF type. Binding posts or banana plugs may be used for lower frequencies. If the signal source has its own coaxial connector, then a simple coaxial cable is used; otherwise, a specialised cable called a "scope probe", supplied with the oscilloscope, is used. In general, for routine use, an open wire test lead for connecting to the point being observed is not satisfactory, and a probe is generally necessary. General-purpose oscilloscopes usually present an input impedance of 1 megohm in parallel with a small but known capacitance such as 20 picofarads.[2] This allows the use of standard oscilloscope probes.[3] Scopes for use with very high frequencies may have 50-ohm inputs, which must be either connected directly to a 50-ohm signal source or used with Z_0 or active probes.

Less-frequently-used inputs include one (or two) for triggering the sweep, horizontal deflection for X-Y mode displays, and trace brightening/darkening, sometimes called "Z-axis" inputs.

Probes

Main article: Test probe

Open wire test leads (flying leads) are likely to pick up interference, so they are not suitable for low level signals. Furthermore, the leads have a high inductance, so they are not suitable for high frequencies. Using a shielded cable (i.e., coaxial cable) is better for low level signals. Coaxial cable also has lower inductance, but it has higher capacitance: a typical 50 ohm cable has about 90 pF per meter. Consequently, a one meter direct (1X) coaxial probe will load a circuit with a capacitance of about 110 pF and a resistance of 1 megohm.

To minimize loading, attenuator probes (e.g., 10X probes) are used. A typical probe uses a 9 megohm series resistor shunted by a low-value capacitor to make an RC compensated divider with the cable capacitance and scope input. The RC time constants are adjusted to match. For example, the 9 megohm series resistor is shunted by a 12.2 pF capacitor for a time constant of 110 microseconds. The cable capacitance of 90 pF in parallel with the scope input of 20 pF and 1 megohm (total capacitance 110 pF) also gives a time constant of 110 microseconds. In practice, there will be an adjustment so the operator can precisely match the low frequency time constant (called compensating the probe). Matching the time constants makes the attenuation independent of frequency. At low frequencies (where the resistance of R is much less than the reactance of C), the circuit looks like a resistive divider; at high frequencies (resistance much greater than reactance), the circuit looks like a capacitive divider.[4]

The result is a frequency compensated probe for modest frequencies that presents a load of about 10 megohms shunted by 12 pF. Although such a probe is an improvement, it does not work when the time scale shrinks to several cable transit times (transit time is typically 5 ns). In that time frame, the cable looks like its characteristic impedance, and there will be reflections from the transmission line mismatch at the scope input and the probe that causes ringing.[5] The modern scope probe uses lossy low capacitance transmission lines and sophisticated frequency shaping networks to make the 10X probe perform well at several hundred megahertz. Consequently, there are other adjustments for completing the compensation.[6][7]

Probes with 10:1 attenuation are by far the most common; for large signals (and slightly-less capacitive loading), 100:1 probes are not rare. There are also probes that contain switches to select 10:1 or direct (1:1) ratios, but one must be aware that the 1:1 setting has significant capacitance (tens of pF) at the probe tip, because the whole cable's capacitance is now directly connected.

Good oscilloscopes allow for probe attenuation, easily showing effective sensitivity at the probe tip. Some of the best ones have indicator lamps behind translucent windows in the panel to prompt the user to read effective sensitivity. The probe connectors (modified BNCs) have an extra contact to define the probe's attenuation. (A certain value of resistor, connected to ground, "encodes" the attenuation.)

There are special high-voltage probes which also form compensated attenuators with the oscilloscope input; the probe body is physically large, and one made by Tektronix requires partly filling a canister surrounding the series resistor with volatile liquid fluorocarbon to displace air. At the oscilloscope end is a box with several waveform-trimming adjustments. For safety, a barrier disc keeps one's fingers distant from the point being examined. Maximum voltage is in the low tens of kV. (Observing a high-voltage ramp can create a staircase waveform with steps at different points every repetition, until the probe tip is in contact. Until then, a tiny arc charges the probe tip, and its capacitance holds the voltage (open circuit). As the voltage continues to climb, another tiny arc charges the tip further.)

There are also current probes, with cores that surround the conductor carrying current to be examined. One type has a hole for the conductor, and requires that the wire be passed through the hole; it's for semi-permanent or permanent mounting. However, other types, for testing, have a two-part core that permit them to be placed around a wire. Inside the probe, a coil wound around the core provides a current into an appropriate load, and the voltage across that load is proportional to current. However, this type of probe can sense AC, only.

A more-sophisticated probe (originally made by Tektronix) includes a magnetic flux sensor (Hall effect sensor) in the magnetic circuit. The probe connects to an amplifier, which feeds (low frequency) current into the coil to cancel the sensed field; the magnitude of that current provides the low-frequency part of the current waveform, right down to DC. The coil still picks up high frequencies. There is a combining network akin to a loudspeaker crossover network.

Front panel controls

Focus control

This control adjusts CRT focus to obtain the sharpest, most-detailed trace. In practice, focus needs to be adjusted slightly when observing quite-different signals, which means that it needs to be an external control. Flat-panel displays cannot be focused.

Intensity control

This adjusts trace brightness. Slow traces on CRT oscilloscopes need less, and fast ones, especially if not often repeated, require more. On flat panels, however, trace brightness is essentially independent of sweep speed, because the internal signal processing effectively synthesizes the display from the digitized data.

Astigmatism

Can also be called "Shape" or "spot shape". Adjusts the relative voltages on two of the CRT anodes such that a displayed spot changes from elliptical in one plane through a circular spot to an elipse at 90 degrees to the first. This control may be absent from simpler oscilloscope designs or may even be an internal control. It is not necessary with flat panel displays.

Beam finder

Modern oscilloscopes have direct-coupled deflection amplifiers, which means the trace could be deflected off-screen. They also might have their CRT beam blanked without the operator knowing it. In such cases, the screen is blank. To help in restoring the display quickly and without experimentation, the beam finder circuit overrides any blanking and ensures that the beam will not be deflected off-screen; it limits the deflection. With a display, it's usually very easy to restore a normal display. (While active, beam-finder circuits might temporarily distort the trace severely, however this is acceptable.)

Graticule

The graticule is a grid of squares that serve as reference marks for measuring the displayed trace. These markings, whether located directly on the screen or on a removable plastic filter, usually consist of a 1 cm grid with closer tick marks (often at 2 mm) on the centre vertical and horizontal axis. One expects to see ten major divisions across the screen; the number of vertical major divisions varies. Comparing the grid markings with the waveform permits one to measure both voltage (vertical axis) and time (horizontal axis). Frequency can also be determined by measuring the waveform period and calculating its reciprocal.

On old and lower-cost CRT oscilloscopes the graticule is a sheet of plastic, often with light-diffusing markings and concealed lamps at the edge of the graticule. The lamps had a brightness control. Higher-cost instruments have the graticule marked on the inside face of the CRT, to eliminate parallax errors; better ones also had adjustable edge illumination with diffusing markings. (Diffusing markings appear bright.) Digital oscilloscopes, however, generate the graticule markings on the display in the same way as the trace.

External graticules also protect the glass face of the CRT from accidental impact. Some CRT oscilloscopes with internal graticules have an unmarked tinted sheet plastic light filter to enhance trace contrast; this also serves to protect the faceplate of the CRT.

Accuracy and resolution of measurements using a graticule is relatively limited; better instruments sometimes have movable bright markers on the trace that permit internal circuits to make more refined measurements.

Both calibrated vertical sensitivity and calibrated horizontal time are set in 1 - 2 - 5 - 10 steps. This leads, however, to some awkward interpretations of minor divisions. At 2, each of the five minor divisions is 0.4, so one has to think 0.4, 0.8, 1.2, and 1.6, which is rather awkward. One Tektronix plug-in used a 1 - 2.5 - 5 - 10 sequence, which simplified estimating. The "2.5" didn't look as "neat", but was very welcome.

Timebase Controls

These select the horizontal speed of the CRT's spot as it creates the trace; this process is commonly referred to as the sweep. In all but the least-costly modern oscilloscopes, the **sweep speed** is selectable and calibrated in units of time per major graticule division. Quite a wide range of sweep speeds is generally provided, from seconds to as fast as picoseconds (in the fastest) per division. Usually, a **continuously-variable control** (often a knob in front of the calibrated selector knob) offers uncalibrated speeds, typically slower than calibrated. This control provides a range somewhat greater than that of consecutive calibrated steps, making any speed available between the extremes.

Holdoff control

Found on some better analog oscilloscopes, this varies the time (holdoff) during which the sweep circuit ignores triggers. It provides a stable display of some repetitive events in which some triggers would create confusing displays. It is usually set to minimum, because a longer time decreases the number of sweeps per second, resulting in a dimmer trace. See trigger holdoff for a more detailed description.

Vertical sensitivity, coupling, and polarity controls

To accommodate a wide range of input amplitudes, a switch selects **calibrated sensitivity** of the vertical deflection. Another control, often in front of the calibrated-selector knob, offers a **continuously-variable sensitivity** over a limited range from calibrated to less-sensitive settings.

Often the observed signal is offset by a steady component, and only the changes are of interest. A switch (**AC** position) connects a capacitor in series with the input that passes only the changes (provided that they are not too slow -- "slow" would mean visible). However, when the signal has a fixed offset of interest, or changes quite slowly, the input is connected directly (**DC** switch position). Most oscilloscopes offer the DC input option. For convenience, to see where zero volts input currently shows on the screen, many oscilloscopes have a third switch position (**GND**) that disconnects the input and grounds it. Often, in this case, the user centers the trace with the Vertical Position control.

Better oscilloscopes have a **polarity selector**. Normally, a positive input moves the trace upward, but this permits inverting—positive deflects the trace downward.

Horizontal sensitivity control

This control is found only on more elaborate oscilloscopes; it offers adjustable sensitivity for external horizontal inputs.

Vertical position control

The vertical position control moves the whole displayed trace up and down. It is used to set the no-input trace exactly on the center line of the graticule, but also permits offsetting vertically by a limited amount. With direct coupling, adjustment of this control can compensate for a limited DC component of an input.

Horizontal position control

The horizontal position control moves the display sidewise. It usually sets the left end of the trace at the left edge of the graticule, but it can displace the whole trace when desired. This control also moves the X-Y mode traces sidewise in some instruments, and can compensate for a limited DC component as for vertical position.

Dual-trace controls

** (Please see Dual and Multiple-trace Oscilloscopes, below.)*

Each input channel usually has its own set of sensitivity, coupling, and position controls, although some four-trace oscilloscopes have only minimal controls for their third and fourth channels.

Dual-trace oscilloscopes have a **mode switch** to select either channel alone, both channels, or (in some) an X-Y display, which uses the second channel for X deflection. When both channels are displayed, the type of **channel switching** can be selected on some oscilloscopes; on others, the type depends upon timebase setting. If manually selectable, channel switching can be free-running (asynchronous), or between consecutive sweeps. Some Philips dual-trace analog oscilloscopes had a fast analog multiplier, and provided a display of the product of the input channels.

Multiple-trace oscilloscopes have a switch for each channel to enable or disable display of that trace's signal.

Delayed-sweep controls

** (Please see Delayed Sweep, below.)*

These include controls for the **delayed-sweep timebase**, which is calibrated, and often also variable. The slowest speed is several steps faster than the slowest main sweep speed, although the fastest is generally the same. A calibrated multiturn **delay time control** offers wide range, high resolution delay settings; it spans the full duration of the main sweep, and its reading corresponds to graticule divisions (but with much finer precision). Its accuracy is also superior to that of the display.

A switch selects **display modes**: Main sweep only, with a brightened region showing when the delayed sweep is advancing, delayed sweep only, or (on some) a combination mode.

Good CRT oscilloscopes include a **delayed-sweep intensity control**, to allow for the dimmer trace of a much-faster delayed sweep that nevertheless occurs only once per main sweep. Such oscilloscopes also are likely to have a trace separation control for multiplexed display of both the main and delayed sweeps together.

Sweep trigger controls

** (Please see Triggered Sweep, below.)*

A switch selects the **Trigger Source**. It can be an external input, one of the vertical channels of a dual or multiple-trace oscilloscope, or the AC line (mains) frequency. Another switch enables or disables **Auto** trigger mode, or selects single sweep, if provided in the oscilloscope. Either a spring-return switch position or a pushbutton arms single sweeps.

A **Level** control varies the voltage on the waveform which generates a trigger, and the **Slope** switch selects positive-going or negative-going polarity at the selected trigger level.

Basic types of sweeps

Triggered sweeps

To display events with unchanging or slowly (visibly) changing waveforms, but occurring at times that may not be evenly spaced, modern oscilloscopes have triggered sweeps. Compared to simpler oscilloscopes with sweep oscillators that are always running, triggered-sweep oscilloscopes are markedly more versatile.

A triggered sweep starts at a selected point on the signal, providing a stable display. In this way, triggering allows the display of periodic signals such as sine waves and square waves, as well as nonperiodic signals such as single pulses, or pulses that don't recur at a fixed rate.

Type 465 Tektronix oscilloscope. This was a very popular analog oscilloscope, portable, and is an excellent representative example.

With triggered sweeps, the scope will blank the beam and start to reset the sweep circuit each time the beam reaches the extreme right side of the screen. For a period of time, called *holdoff*, (extendable by a front-panel control on some better oscilloscopes), the sweep circuit resets completely and ignores triggers. Once holdoff expires, the next trigger starts a sweep. The trigger event is usually the input waveform reaching some user-specified threshold voltage (trigger level) in the specified direction (going positive or going negative—trigger polarity).

In some cases, variable holdoff time can be really useful to make the sweep ignore interfering triggers that occur before the events one wants to observe. In the case of repetitive, but quite-complex waveforms, variable holdoff can create a stable display that can't otherwise practically be obtained.

Automatic sweep mode

Triggered sweeps can display a blank screen if there are no triggers. To avoid this, these sweeps include a timing circuit that generates free-running triggers so a trace is always visible. Once triggers arrive, the timer stops providing pseudo-triggers. Automatic sweep mode can be de-selected when observing low repetition rates.

Recurrent sweeps

If the input signal is periodic, the sweep repetition rate can be adjusted to display a few cycles of the waveform. Early (tube) oscilloscopes and lowest-cost oscilloscopes have sweep oscillators that run continuously, and are uncalibrated. Such oscilloscopes are very simple, comparatively inexpensive, and were useful in radio servicing and some TV servicing. Measuring voltage or time is possible, but only with extra equipment, and is quite inconvenient. They are primarily qualitative instruments.

They have a few (widely spaced) frequency ranges, and relatively wide-range continuous frequency control within a given range. In use, the sweep frequency is set to slightly lower than some submultiple of the input frequency, to display typically at least two cycles of the input signal (so all details are visible). A very simple control feeds an adjustable amount of the vertical signal (or possibly, a related external signal) to the sweep oscillator. The signal triggers beam blanking and a sweep retrace sooner than it would occur free-running, and the display becomes stable.

Single sweeps

Some oscilloscopes offer these—the sweep circuit is manually armed (typically by a pushbutton or equivalent) "Armed" means it's ready to respond to a trigger. Once the sweep is complete, it resets, and will not sweep until re-armed. This mode, combined with a oscilloscope camera, captures single-shot events.

Types of trigger include:

- *external trigger*, a pulse from an external source connected to a dedicated input on the scope.
- *edge trigger*, an edge-detector that generates a pulse when the input signal crosses a specified threshold voltage in a specified direction. These are the most-common types of triggers; the level control sets the threshold voltage, and the slope control selects the direction (negative or positive-going). (The first sentence of the description also applies to the inputs to some digital logic circuits; those inputs have fixed threshold and polarity response.)

threshold and polarity response.)
- *video trigger*, a circuit that extracts synchronizing pulses from video formats such as PAL and NTSC and triggers the timebase on every line, a specified line, every field, or every frame. This circuit is typically found in a waveform monitor device, although some better oscilloscopes include this function.
- *delayed trigger*, which waits a specified time after an edge trigger before starting the sweep. As described under delayed sweeps, a trigger delay circuit (typically the main sweep) extends this delay to a known and adjustable interval. In this way, the operator can examine a particular pulse in a long train of pulses.

Some recent designs of oscilloscopes include more sophisticated triggering schemes; these are described toward the end of this article.

Delayed sweeps

These are found on more-sophisticated oscilloscopes, which contain a second set of timebase circuits for a delayed sweep. A delayed sweep provides a very-detailed look at some small selected portion of the main timebase. The main timebase serves as a controllable delay, after which the delayed timebase starts. This can start when the delay expires, or can be triggered (only) after the delay expires. Ordinarily, the delayed timebase is set for a faster sweep, sometimes much faster, such as 1000:1. At extreme ratios, jitter in the delays on consecutive main sweeps degrades the display, but delayed-sweep triggers can overcome that.

The display shows the vertical signal in one of several modes—the main timebase, or the delayed timebase only, or a combination. When the delayed sweep is active, the main sweep trace brightens while the delayed sweep is advancing. In one combination mode, provided only on some oscilloscopes, the trace changes from the main sweep to the delayed sweep once the delayed sweep starts, although less of the delayed fast sweep is visible for longer delays. Another combination mode multiplexes (alternates) the main and delayed sweeps so that both appear at once; a trace separation control displaces them.

Dual and multiple-trace oscilloscopes

Oscilloscopes with two vertical inputs, referred to as dual-trace oscilloscopes, are extremely useful and commonplace. Using a single-beam CRT, they multiplex the inputs, usually switching between them fast enough to display two traces apparently at once. Less common are oscilloscopes with more traces; four inputs are common among these, but a few (Kikusui, for one) offered a display of the sweep trigger signal if desired. Some multi-trace oscilloscopes use the external trigger input as an optional vertical input, and some have third and fourth channels with only minimal controls. In all cases, the inputs, when independently displayed, are time-multiplexed, but dual-trace oscilloscopes often can add their inputs to display a real-time analog sum. (Inverting one channel provides a difference, provided that neither channel is overloaded. This difference mode can provide a moderate-performance differential input.)

Switching channels can be asynchronous, that is, free-running, with trace blanking while switching, or after each horizontal sweep is complete. Asynchronous switching is usually designated "Chopped", while sweep-synchronized is designated "Alt[ernate]". A given channel is alternately connected and disconnected, leading to the term "chopped". Multi-trace oscilloscopes also switch channels either in chopped or alternate modes.

In general, chopped mode is better for slower sweeps. It is possible for the internal chopping rate to be a multiple of the sweep repetition rate, creating blanks in the traces, but in practice this is rarely a problem; the gaps in one trace are overwritten by traces of the following sweep. A few oscilloscopes had a modulated chopping rate to avoid this occasional problem. Alternate mode, however, is better for faster sweeps.

avoid this occasional problem. Alternate mode, however, is better for faster sweeps.

True dual-beam CRT oscilloscopes did exist, but were not common. One type (Cossor, U.K.) had a beam-splitter plate in its CRT, and single-ended deflection following the splitter. (More details are near the end of this article; see "CRT Invention". Others had two complete electron guns, requiring tight control of axial (rotational) mechanical alignment in manufacturing the CRT. Beam-splitter types had horizontal deflection common to both vertical channels, but dual-gun oscilloscopes could have separate time bases, or use one time base for both channels. Multiple-gun CRTs (up to ten guns) were made in past decades. With ten guns, the envelope (bulb) was cylindrical throughout its length.

The vertical amplifier

In an analog oscilloscope, the vertical amplifier acquires the signal[s] to be displayed. In better oscilloscopes, it delays them by a fraction of a microsecond, and provides a signal large enough to deflect the CRT's beam. That deflection is at least somewhat beyond the edges of the graticule, and more typically some distance off-screen. The amplifier has to have low distortion to display its input accurately (it must be linear), and it has to recover quickly from overloads. As well, its time-domain response has to represent transients accurately—minimal overshoot, rounding, and tilt of a flat pulse top.

A vertical input goes to a frequency-compensated step attenuator to reduce large signals to prevent overload. The attenuator feeds a low-level stage (or a few), which in turn feed gain stages (and a delay-line driver if there is a delay). Following are more gain stages, up to the final output stage which develops a large signal swing (tens of volts, sometimes over 100 volts) for CRT electrostatic deflection.

In dual and multiple-trace oscilloscopes, an internal electronic switch selects the relatively low-level output of one channel's amplifiers and sends it to the following stages of the vertical amplifier, which is only a single channel, so to speak, from that point on.

In free-running ("chopped") mode, the oscillator (which may be simply a different operating mode of the switch driver) blanks the beam before switching, and unblanks it only after the switching transients have settled.

Part way through the amplifier is a feed to the sweep trigger circuits, for internal triggering from the signal. This feed would be from an individual channel's amplifier in a dual or multi-trace oscilloscope, the channel depending upon the setting of the trigger source selector.

This feed precedes the delay (if there is one), which allows the sweep circuit to unblank the CRT and start the forward sweep, so the CRT can show the triggering event. High-quality analog delays add a modest cost to a oscilloscope, and are omitted in oscilloscopes that are cost-sensitive.

The delay, itself, comes from a special cable with a pair of conductors wound around a flexible magnetically-soft core. The coiling provides distributed inductance, while a conductive layer close to the wires provides distributed capacitance. The combination is a wideband transmission line with considerable delay per unit length. Both ends of the delay cable require matched impedances to avoid reflections.

X-Y mode

Most modern oscilloscopes have several inputs for voltages, and thus can be used to plot one varying voltage versus another. This is especially useful for graphing I-V curves (current versus voltage characteristics) for components such as diodes, as well as Lissajous patterns. Lissajous figures are an example of how an oscilloscope can be used to track phase differences between multiple input signals. This is very frequently used in broadcast engineering to plot the left and right stereophonic channels, to ensure that the stereo generator is calibrated properly. Historically, stable Lissajous figures were used to show that two sine waves had a relatively simple frequency relationship, a numerically-small ratio. They also indicated phase difference between two sine waves of the same frequency.

Complete loss of signal in an X-Y display means that the CRT's beam strikes a small spot, which risks burning the phosphor. Older phosphors burned more easily. Some dedicated X-Y displays reduce beam current greatly, or blank the display entirely, if there are no inputs present.

Bandwidth

Bandwidth is a measure of the range of frequencies that can be displayed; it refers primarily to the vertical amplifier, although the horizontal deflection amplifier has to be fast enough to handle the fastest sweeps. The bandwidth of the oscilloscope is limited by the vertical amplifiers and the CRT (in analog instruments) or by the sampling rate of the analog to digital converter in digital instruments. The bandwidth is defined as the frequency at which the sensitivity is 0.707 of the sensitivity at lower frequency (a drop of 3 dB). The rise time of the fastest pulse that can be resolved by the scope is related to its bandwidth approximately:

Bandwidth in Hz x rise time in seconds = 0.35 [8]

For example, a oscilloscope intended to resolve pulses with a rise time of 1 nanosecond would have a bandwidth of 350 MHz.

For a digital oscilloscope, a rule of thumb is that the continuous sampling rate should be ten times the highest frequency desired to resolve; for example a 20 megasample/second rate would be applicable for measuring signals up to about 2 megahertz.

Other features

Some oscilloscopes have *cursors*, which are lines that can be moved about the screen to measure the time interval between two points, or the difference between two voltages. A few older oscilloscopes simply brightened the trace at movable locations. These cursors are more accurate than visual estimates referring to graticule lines.

Better quality general purpose oscilloscopes include a calibration signal for setting up the compensation of test probes; this is (often) a 1 kHz square-wave signal of a definite peak-to-peak voltage available at a test terminal on the front panel. Some better oscilloscopes also have a squared-off loop for checking and adjusting current probes.

Sometimes the event that the user wants to see may only happen occasionally. To catch these events, some oscilloscopes, known as "storage scopes", preserve the most recent sweep on the screen. This was originally achieved by using a special CRT, a "storage tube", which would retain the image of even a very brief event for a long time.

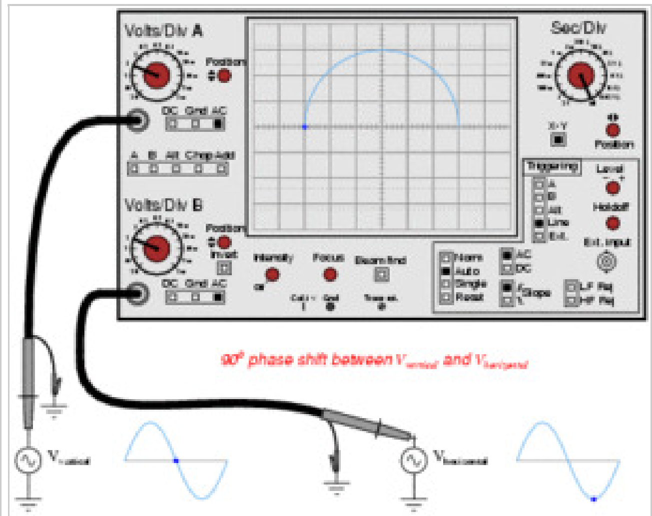
Some digital oscilloscopes can sweep at speeds as slow as once per hour, emulating a strip chart recorder. That is, the signal scrolls across the screen from right to left. Most oscilloscopes with this facility switch from a sweep to a strip-chart mode at about one sweep per ten seconds. This is because otherwise, the scope looks broken: it's collecting data, but the dot cannot be seen.

In current oscilloscopes, digital signal sampling is more often used for all but the simplest models. Samples feed fast analog-to-digital converters, following which all signal processing (and storage) is digital.

Many oscilloscopes have different plug-in modules for different purposes, e.g., high-sensitivity amplifiers of relatively narrow bandwidth, differential amplifiers, amplifiers with four or more channels, sampling plugins for repetitive signals of very high frequency, and special-purpose plugins, including audio/ultrasonic spectrum analyzers, and stable-offset-voltage direct-coupled channels with relatively high gain.

Examples of use

One of the most frequent uses of scopes is troubleshooting malfunctioning electronic equipment. One of the advantages of a scope is that it can graphically show signals: where a voltmeter may show a totally unexpected voltage, a scope may reveal that the circuit is oscillating. In other cases the precise shape or timing of a pulse is important.



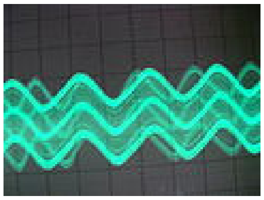
Lissajous figures on an oscilloscope, with 90 degrees phase difference between x and y inputs.

In a piece of electronic equipment, for example, the connections between stages (e.g. electronic mixers, electronic oscillators, amplifiers) may be 'probed' for the expected signal, using the scope as a simple signal tracer. If the expected signal is absent or incorrect, some preceding stage of the electronics is not operating correctly. Since most failures occur because of a single faulty component, each measurement can prove that half of the stages of a complex piece of equipment either work, or probably did not cause the fault.

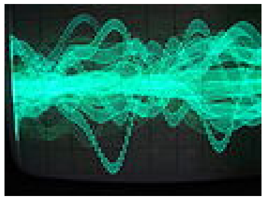
Once the faulty stage is found, further probing can usually tell a skilled technician exactly which component has failed. Once the component is replaced, the unit can be restored to service, or at least the next fault can be isolated. This sort of troubleshooting is typical of radio and TV receivers, as well as audio amplifiers, but can apply to quite-different devices such as electronic motor drives.

Another use is to check newly designed circuitry. Very often a newly designed circuit will misbehave because of design errors, bad voltage levels, electrical noise etc. Digital electronics usually operate from a clock, so a dual-trace scope which shows both the clock signal and a test signal dependent upon the clock is useful. **Storage scopes** are helpful for "capturing" rare electronic events that cause defective operation.

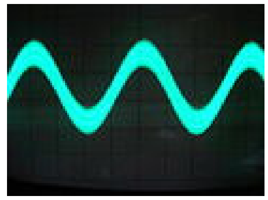
Pictures of use



Heterodyne

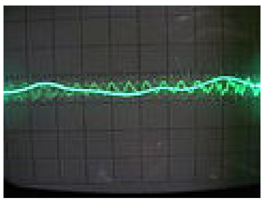


AC hum on sound.



Sum of a low-frequency and a high-frequency signal.

Bad filter on sine.



Dual trace, showing different time bases on each trace.

Selection

Oscilloscopes generally have a checklist of some set of the above features. The basic measure of virtue is the bandwidth of its vertical amplifiers. Typical scopes for general purpose use should have a bandwidth of at least 100 MHz, although much lower bandwidths are acceptable for audio-frequency applications. A useful sweep range is from one second to 100 nanoseconds, with triggering and delayed sweep.

The chief benefit of a quality oscilloscope is the quality of the trigger circuit. If the trigger is unstable, the display will always be fuzzy. The quality improves roughly as the frequency response and voltage stability of the trigger increase.

Analog oscilloscopes have been almost totally displaced by digital storage scopes except for the low bandwidth (< 60 MHz) segment of the market. Greatly increased sample rates have eliminated the display of incorrect signals, known as "aliasing", that was sometimes present in the first generation of digital scopes. The used test equipment market, particularly on-line auction venues, typically have a wide selection of older analog scopes available. However it is becoming more difficult to obtain replacement parts for these instruments and repair services are generally unavailable from the original manufacturer.

As of 2007, a 350 MHz bandwidth (BW), 2.5 giga-samples per second (GS/s), dual-channel digital storage scope costs about US$7000 new. The current true real-time analog bandwidth record, as of June 2011, is held by the LeCroy Wavemaster 8 ZI series of oscilloscopes with a 45 GHz BW and a sample rate of

LeCroy WaveMaster 8 Zi series of oscilloscopes with a 45 GHz BW and a sample rate of 120 GSa/s.[citation needed] The current equivalent time sampling bandwidth record for sampling digital storage oscilloscopes, as of June 2006, is held by the LeCroy WaveExpert series with a 100 GHz bandwidth.[citation needed]

On the lowest end, an inexpensive hobby-grade single-channel DSO can now be purchased for under $90 as of June 2011. These often have limited bandwidth but fulfill the basic functions of an oscilloscope.

Software

Many oscilloscopes today provide one or more external interfaces to allow remote instrument control by external software. These interfaces (or buses) include GPIB, Ethernet, serial port, and USB.

Types and models

Main article: Oscilloscope types

The following section is a brief summary of various types and models available. For a detailed discussion, refer to the other article.

Cathode-ray oscilloscope (CRO)

The earliest and simplest type of oscilloscope consisted of a cathode ray tube, a vertical amplifier, a timebase, a horizontal amplifier and a power supply. These are now called 'analog' scopes to distinguish them from the 'digital' scopes that became common in the 1990s and 2000s.

Dual-beam oscilloscope

The dual-beam analog oscilloscope can display two signals simultaneously. A special dual-beam CRT generates and deflects two separate beams. Although multi-trace analog oscilloscopes can simulate a dual-beam display with **chop** and **alternate** sweeps, those features do not provide simultaneous displays. (Real time digital oscilloscopes offer the same benefits of a dual-beam oscilloscope, but they do not require a dual-beam display.)

Analog storage oscilloscope

Trace storage is an extra feature available on some analog scopes; they used direct-view storage CRTs. Storage allows the trace pattern that normally decays in a fraction of a second to remain on the screen for several minutes or longer. An electrical circuit can then be deliberately activated to store and erase the trace on the screen.

Digital oscilloscopes

While analog devices make use of continually varying voltages, digital devices employ binary numbers which correspond to samples of the voltage. In the case of digital oscilloscopes, an analog-to-digital converter (ADC) is used to change the measured voltages into digital information..

Digital storage oscilloscope

The digital storage oscilloscope, or DSO for short, is now the preferred type for most industrial applications, although simple analog CROs are still used by hobbyists. It replaces the unreliable storage method used in analog storage scopes with digital memory, which can store data as long as required without degradation. It also allows complex processing of the signal by high-speed digital signal processing circuits.[1]

Digital sampling oscilloscopes

Digital sampling oscilloscopes operate on the same principle as analog sampling oscilloscopes and like their analog partners, are of great use when analyzing high frequency signals. That is, signals whose frequencies are higher than the oscilloscope's sampling rate.

Digital phosphor oscilloscopes

A digital phosphor Oscilloscope (DPO) is a digital oscilloscope but instead of a CRT, it uses a digital flat panel display, usually a liquid crystal panel. These are becoming the de facto digital oscillosope system. With the relentless march of technological progress: DPOs can offer significant enhancements over traditional oscilloscopes, such as different colour traces for different inputs or signal types or even parts of the displayed signal. Also a DPO can emulate long persistence phosphors in traditional CRT systems. Many designs can also provide near real time information on the displayed waveform such as amplitude (including average; peak; peak to peak; and RMS), repetition rate and even more complex functions such as fourier transforms.

Mixed-signal oscilloscopes

A mixed-signal oscilloscope (or MSO) has two kinds of inputs, a small number (typically two or four) of analog channels, and a larger number (typically sixteen) of digital channels.

Handheld oscilloscopes

Handheld oscilloscopes (also called scopemeters) are useful for many test and field service applications. Today, a hand held oscilloscope is usually a digital sampling oscilloscope, using a liquid crystal display.

PC-based oscilloscopes (PCO)

A new type of "oscilloscope" is emerging that consists of a specialized signal acquisition board (which can be an external USB or Parallel port device, or an internal add-on PCI or ISA card).

Related instruments

A large number of instruments used in a variety of technical fields are really oscilloscopes with inputs, calibration, controls, display calibration, etc., specialized and optimized for a particular application. Examples of such oscilloscope-based instruments include waveform monitors for analyzing video levels in television productions and medical devices such as vital function monitors and electrocardiogram and electroencephalogram instruments. In automobile repair, an ignition analyzer is used to show the spark waveforms for each cylinder. All of these are essentially oscilloscopes, performing the basic task of showing the changes in one or more input signals over time in an X-Y display.

Other instruments convert the results of their measurements to a repetitive electrical signal, and incorporate an oscilloscope as a display element. Such complex measurement systems include spectrum analyzers, transistor oscilloscope as a display element. Such complex measurement systems include spectrum analyzers, transistor analyzers, and time domain reflectometers (TDRs). Unlike an oscilloscope, these instruments automatically generate stimulus or sweep a measurement parameter.

History

Main article: Oscilloscope history

The Braun tube was known in 1897, and in 1899 Jonathan Zenneck equipped it with beam-forming plates and a magnetic field for sweeping the trace.[*citation needed*] Early cathode ray tubes had been applied experimentally to laboratory measurements as early as the 1920s,but suffered from poor stability of the vacuum and the cathode emitters. V. K. Zworykin described a permanently sealed, high-vacuum cathode ray tube with a thermionic emitter in 1931. This stable and reproducible component allowed General Radio to manufacture an oscilloscope that was usable outside a laboratory setting.[1]

Use as props

In the 1950s and 1960s, oscilloscopes were frequently used in movies and television programs to represent generic scientific and technical equipment. The 1963–65 U.S. TV show *The Outer Limits* famously used an image of fluctuating sine waves on an oscilloscope as the background to its opening credits ("*There is nothing wrong with your television set....*").

Television legend Ernie Kovacs utilized an oscilloscope display as a visual transition piece between his comedy "blackouts" video segments. It was most notably used with the synchronized playback of a German language version of the song "Mack the Knife". They were televised during his monthly ABC Television Network specials during the late 1950s until his death in 1962.

See also

- Eye pattern
- Phonodeik
- Tennis for Two - Oscilloscope game
- Time-domain reflectometry
- Vectorscope
- Waveform monitor

References

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2. ^ The 20 picofarad value is typical for scope bandwidths around 100 MHz; for example, a 200 MHz Tektronix 7A26 input impedance is 1M and 22 pF. (Tektronix (1983, p. 271); see also Tektronix (1998, p. 503), "typical high Z 10X passive probe model".) Lower bandwidth scopes used higher capacitances; the 1 MHz Tektronix 7A22 input impedance is 1M and 47 pF. (Tektronix 1983, p. 272–273) Higher bandwidth scopes use smaller capacitances. The 500 MHz Tektronix TDS510A input impedance is 1M and 10 pF. (Tektronix 1998, p. 78)
3. ^ Probes are designed for a specific input impedance. They have compensation adjustments with a limited range, so they often cannot be used on different input impedances.

4. ^ Wedlock & Roberge (1969)
5. ^ Kobbe & Polits (1959)
6. ^ Tektronix (1983, p. 426); Tek claims 300 MHz resistive coax at 30 pF per meter; schematic has 5 adjustments.
7. ^ Zeidlhack & White (1970)
8. ^ Spitzer, Frank; Howarth, Barry (1972), *Principles of modern Instrumentation*, New York: Holt, Rinehart and Winston, p. 119, ISBN 0-03-080208-3

- US 2883619 (http://v3.espacenet.com/textdoc?DB=EPODOC&IDX=US2883619) , Kobbe, John R. & William J. Polits, "Electrical Probe", issued April 21, 1959
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External links

- Oscilloscope Tutorial Videos in HD (http://www.afrotechmods.com/groovy/oscilloscope_tutorial/oscilloscope_tutorial.htm)
- The Cathode Ray Tube site (http://www.crtsite.com/page3.html)
- XYZ of Oscilloscopes 64 page Tutorial (http://www.tek.com/learning/oscilloscopes/)
- Digital Storage Oscilloscope Measurement Basics (http://www.tiepie.com/uk/classroom/Measurement_basics/Digital_Data_Acquisition.html)
- Using an Oscilloscope (http://www.doctronics.co.uk/scope.htm)
- Oscilloscope Measurement Fundamentals (http://www.ztecinstruments.com/oscilloscope-measurement-fundamentals)
- Oscilloscope Development, 1943-1957 (http://www.syscompdesign.com/AppNotes/scope-history.pdf)
- Oscilloscope basic guide (http://www.bbaba.altervista.org/tecnica/oscilloscope.php)