Oscilloscopes

ENEE4304

2016
N. Ismail

What is an oscilloscope?

os·cil·lo·scope (ə-sĭl'ə-skōp')

- Oscilloscopes convert electrical input signals into a visible trace on a screen - i.e. they convert electricity into light.
- Oscilloscopes dynamically graph time-varying electrical signals in two dimensions (typically voltage vs. time).
- Oscilloscopes are used by engineers and technicians to test, verify, and debug electronic designs.

Terms

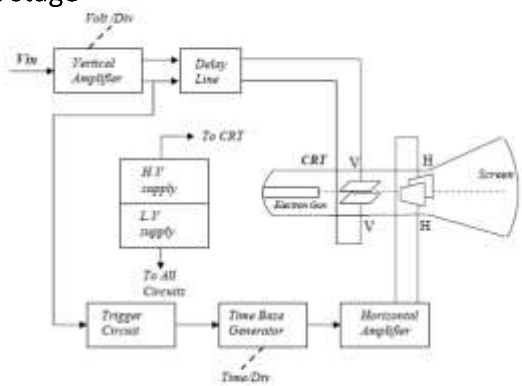
- Scope – Most commonly used terminology
- DSO – Digital Storage Oscilloscope
- Digital Scope
- Digitizing Scope
- Analog Scope – Older technology oscilloscope, but still around today.
- CRO – Cathode Ray Oscilloscope (pronounced "crow").
- Even though most scopes no longer utilize cathode ray tubes to display waveforms
- O-Scope
- MSO – Mixed Signal Oscilloscope (includes logic analyzer channels of acquisition)

CR Oscilloscope

- The ***cathode ray oscilloscope (CRO) is a device that allows the amplitude of electrical***
- signals, whether they are voltage, current; power, etc., to be displayed primarily as a function of time.
- ***The oscilloscope depends on the movement of an electron beam, which is then made visible***
- by allowing the beam to impinge on a phosphor surface, which produces a visible spot

Oscilloscope Block Diagram:

- General oscilloscope consists of the following parts:
- 1. Cathode ray tube (CRT)
- 2. Vertical deflection stage
- 3. Horizontal deflection stage
- 4. Power supply



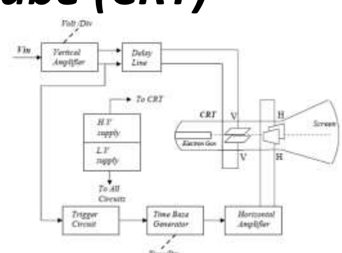
General Purpose Oscilloscope

The Cathode Ray Tube (CRT)

- Cathode ray tube is the ***heart of which generates the electron be the beam to high velocity, defle create the image, and contains*** screen where the electron beam ***become visible.***
- ***There are two standard types*** of CRT :***electromagnetic and electrostatic.***

Each CRT contains:

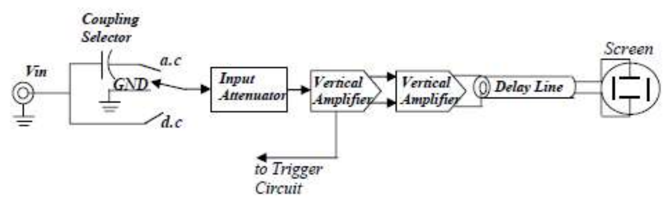
- **a) One or more electron guns.**
- **b) Electrostatic deflection plates.**
- **c) Phosphoresce screen.**



General Purpose Oscilloscope

Vertical deflection system:

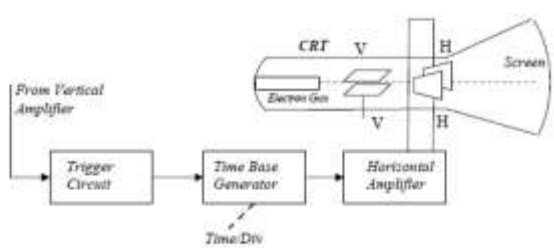
- The vertical deflection system provides an amplified signal of the proper level to drive the vertical deflection plates without introducing any appreciable distortion into the system. This system consists of the following elements:
- 1- Input coupling selector. 2- Input attenuator.
- 3- Preamplifier. 4- Main vertical amplifier.
- 5- Delay line.



Vertical Deflection System

Horizontal Deflection System:

- The horizontal deflection system of OSC consist of :
- 1- Trigger circuit.
- 2- Time base generator.
- 3- Horizontal amplifier



Horizontal Deflection System

- ***Horizontal Amplifier:***
- The horizontal amplifier is used to amplify the sweep waveform to the required level of horizontal plates operation.

Digital Storage Oscilloscope (DSO)

- The digital oscilloscope or digital storage oscilloscope (DSO) differs from its analog counterpart in that the input signal is converted to digital data and therefore it can be managed by an embedded microprocessor.
- The waveform data can have correction factors applied to remove errors in the scope's acquisition system and can then be stored, measured, and/or displayed.
- That the input signal is converted from analog to digital and manipulations are performed on it by a microprocessor results in people not having a good mental model of the digital oscilloscope's operation.

- This would not be a problem except for the fact that the waveform digitizing process is not totally free from errors, and a lack of a correct mental model of the scope's operation on the part of its user can increase the odds of a measurement error.
- To make matters worse, various manufacturers of these products make conflicting claims, making it easy to propagate incorrect mental models of the digital scope's operation.
- It is the intention of this presentation to give the information needed to create a mental model of the operation of these devices that will enable the user to perform error-free measurements with ease.

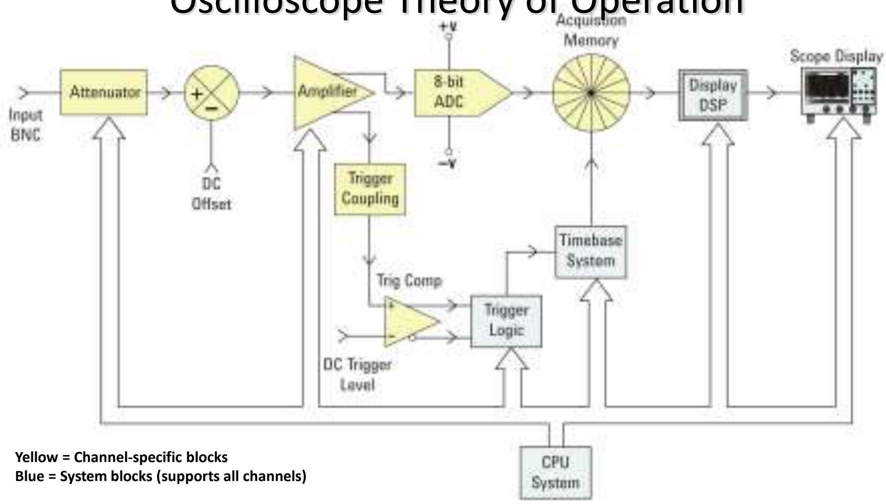
Analog Vs Digital

TABLE 37.2 A Comparison of Analog and Digital Oscilloscopes

	Analog Oscilloscope	Digital Oscilloscope
Operation	Simple	Complex
Front panel controls	Direct access knobs	Knobs and menus
Display	Real-time vector	Digital raster scan
Gray scales	>16	>4
Horizontal resolution	>1000 lines	500 lines
Dead-time	Short	Can be long
Aliasing	No	Yes
Voltage accuracy	±3% of full scale	±3% of full scale
Timing accuracy	±3% of full scale	±0.01% of full scale
Single shot capture	None	Yes
Glitch capture	Limited	Yes
Waveform storage	None	Yes
Pretrigger viewing	None	Yes
Data out to a computer	No	Yes

- One of the driving forces making scope manufacturers believe that the future of the digital oscilloscope is bright is that modern electronic systems are becoming ever more digital in nature.
- Digital systems place additional demands on the oscilloscope that exceed the capabilities of the analog scope.
- For example, often in digital electronic systems, there is a need to view fast events that occur at very slow or infrequent rates..
- Another common problem with digital systems is the location of trigger events. Often the only usable trigger is available at the end of the event being viewed. Analog scopes can only display events that occur after a trigger event.

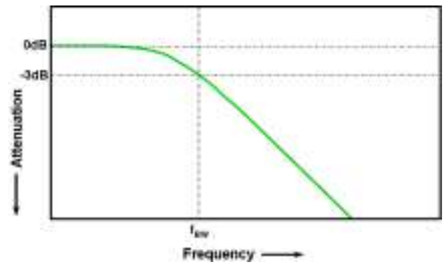
Oscilloscope Theory of Operation



DSO Block Diagram
(for info only)

Oscilloscope Performance Specifications

"Bandwidth" is the most important oscilloscope specification

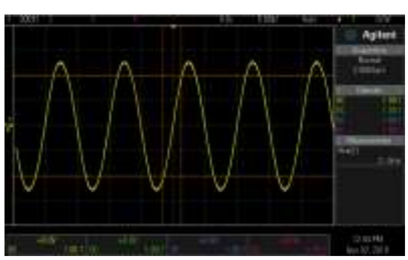


Oscilloscope Frequency Response

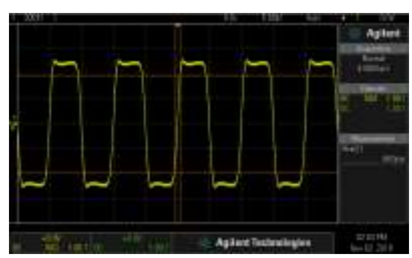
- All oscilloscopes exhibit a low-pass frequency response.
- The frequency where an input sine wave is attenuated by 3 dB defines the scope's bandwidth.
- -3 dB equates to ~ -30% amplitude error (-3 dB = 20 Log $\frac{Vo}{Vi}$).

Selecting the Right Bandwidth

Assume an Input = 100-MHz Digital Clock



Response using a 100-MHz BW scope



Response using a 500-MHz BW scope

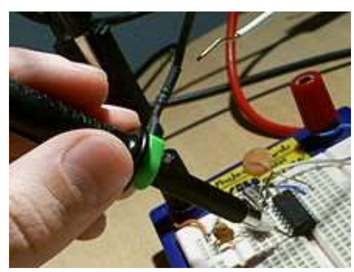
- Required BW for analog applications: ≥ 3X highest sine wave frequency.
- Required BW for digital applications: ≥ 5X highest digital clock rate.

Other Important Oscilloscope Specifications

- Sample Rate (in samples/sec) – Should be ≥ 4X BW
- Memory Depth – Determines the longest waveforms that can be captured while still sampling at the scope's maximum sample rate.
- Number of Channels – Typically 2 or 4 channels. MSO models add 8 to 32 channels of digital acquisition with 1-bit resolution (high or low).

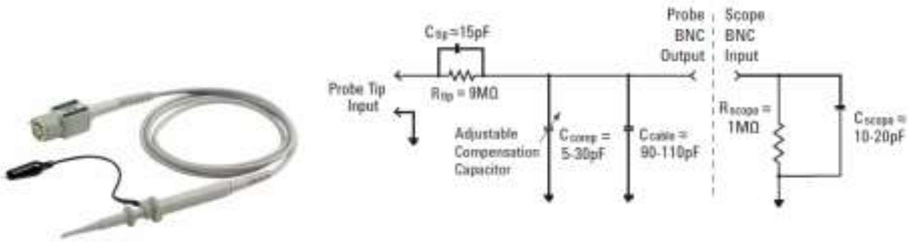
- Waveform Update Rate – Faster update rates enhance probability of capturing infrequently occurring circuit problems.
- Display Quality – Size, resolution, number of levels of intensity gradation.
- Advanced Triggering Modes – Time-qualified pulse widths, Pattern, Video, Serial, Pulse Violation (edge speed, Setup/Hold time, Runt), etc.

Probing Basics



- **Probes are used to transfer the signal from the device-under-test to the oscilloscope's BNC inputs.**
- **There are many different kinds of probes used for different and special purposes (high frequency applications, high voltage applications, current, etc.).**
- **The most common type of probe used is called a "Passive 10:1 Voltage Divider Probe".**

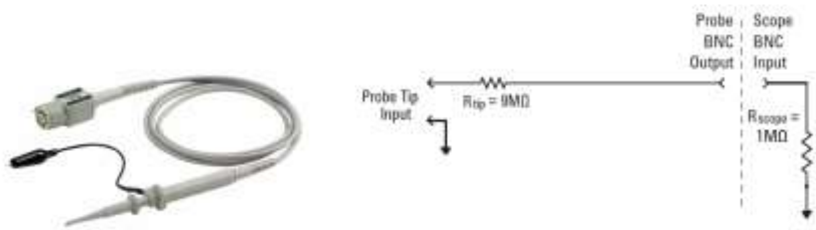
Passive 10:1 Voltage Divider Probe



Passive 10:1 Probe Model

- Passive: Includes no active elements such as transistors or amplifiers.
- 10-to-1: Reduces the amplitude of the signal delivered to the scope's BNC input by a factor of 10. Also increases input impedance by 10X.
- ***Note: All measurements must be performed relative to ground!***

Low-frequency/DC Model



Passive 10:1 Probe Model

- Low-frequency/DC Model: Simplifies to a 9-MΩ resistor in series with the scope's 1-MΩ input termination.
- Probe Attenuation Factor:
  - ✓ Some scopes such as Agilent's 3000 X-Series automatically detect 10:1 probes and adjust all vertica settings and voltage measurements relative to the probe tip.
  - ✓ Some scopes such as Agilent's 2000 X-Series require manual entry of a 10:1 probe attenuation factor.
- Dynamic/AC Model: Covered later.

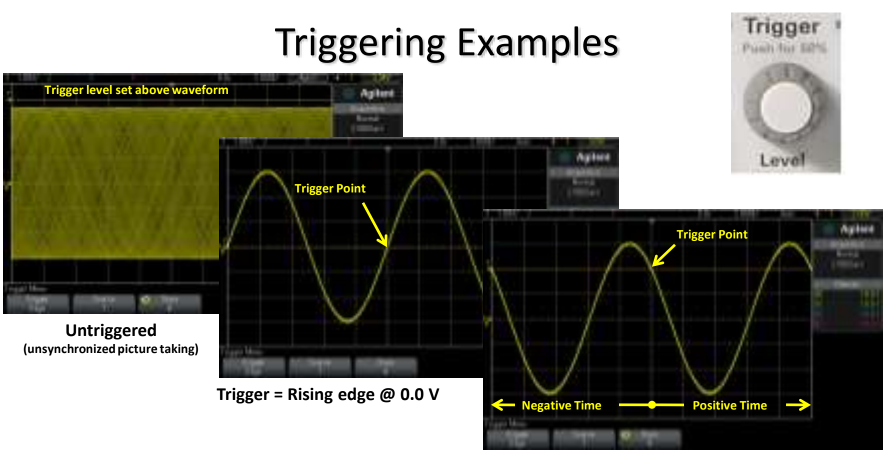
Properly Scaling the Waveform

Initial Setup Condition (example) **Optimum Setup Condition**

- Adjust **V/div** knob until waveform fills most of the screen vertically.
- Adjust vertical **Position** knob until waveform is centered vertically.
- Adjust **s/div** knob until just a few cycles are displayed horizontally.
- Adjust **Trigger Level** knob until level set near middle of waveform vertically.

Setting up the scope's waveform scaling is an iterative process of making front panel adjustments until the desired "picture" is displayed on-screen.

Triggering Examples



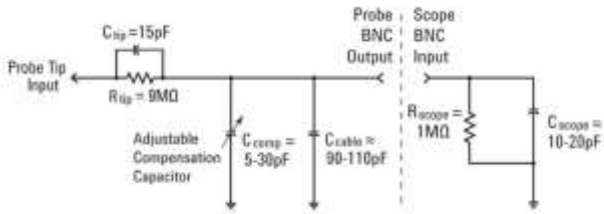
Untriggered
(unsynchronized picture taking)

Trigger = Rising edge @ 0.0 V

Trigger = Falling edge @ +2.0 V

- **Default trigger location (time zero) on DSOs = center-screen (horizontally)**
- **Only trigger location on older analog scopes = left side of screen**

Probing Revisited - Dynamic/AC Probe Model



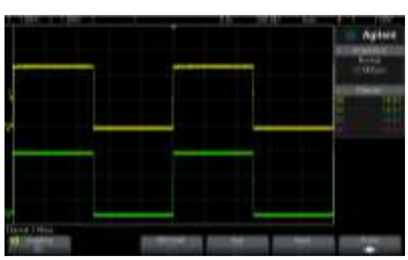
Passive 10:1 Probe Model

- $\boldsymbol{C_{scope}}$ and $\boldsymbol{C_{cable}}$ are inherent/parasitic capacitances (not intentionally designed-in)
- $\boldsymbol{C_{tip}}$ and $\boldsymbol{C_{comp}}$ are intentionally designed-in to compensate for $\boldsymbol{C_{scope}}$ and $\boldsymbol{C_{cable}}$.
- With properly adjusted probe compensation, the dynamic/AC attenuation due to frequency-dependant capacitive reactances should match the designed-in resistive voltage-divider attenuation (10:1).

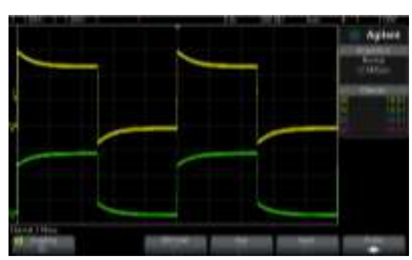
$$\frac{1}{2\pi f C_{tip}} = \frac{9}{2\pi f C_{parallel}}$$

Where $C_{parallel}$ is the parallel combination of C_{comp} + C_{cable} + C_{scope}

Compensating the Probes



Proper Compensation



Channel-1 (yellow) = Over compensated
Channel-2 (green) = Under compensated

- Connect Channel-1 and Channel-2 probes to the “Probe Comp” terminal
- Adjust V/div and s/div knobs to display both waveforms on-screen.
- Using a small flat-blade screw driver, adjust the variable probe compensation capacitor ($\boldsymbol{C_{comp}}$) on both probes for a flat (square) response.

SUMMARY

1. Analog oscilloscopes use a cathode ray tube to display voltage patterns.
2. The waveforms shown on an analog oscilloscope cannot be stored for later viewing.
3. A digital storage oscilloscope (DSO) creates an image or waveform on the display by connecting thousands of dots captured by the scope leads.
4. An oscilloscope display grid is called a graticule. Each of the 8 x 10 or 10 x 10 dividing boxes is called a division.

SUMMARY

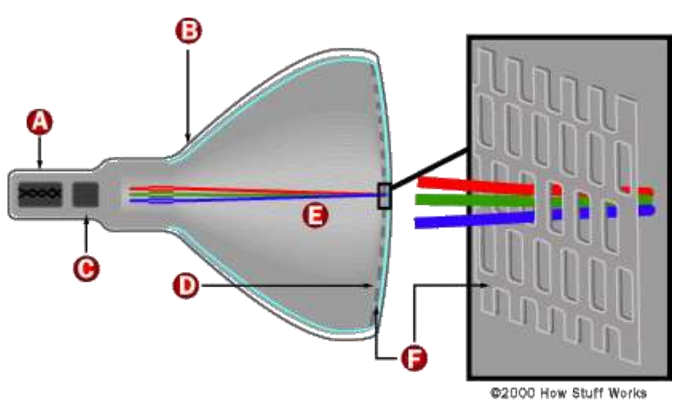
5. Setting the time base means establishing the amount of time each division represents.
6. Setting the volts per division allows the technician to view either the entire waveform or just part of it.
7. DC coupling and AC coupling are two selections that can be made to observe different types of waveforms.
8. A graphing multimeter is not capable of capturing short duration faults but can display usable waveforms.
9. Oscilloscopes display voltage over time. A DSO can capture and store a waveform for viewing later.

Display Technology

- Often referred to as a **monitor** when packaged in a separate case, the display is the most-used output device on a computer.
- The display provides instant feedback by showing you text and graphic images as you work or play.
- Most desktop displays use liquid crystal display (LCD) or cathode ray tube (CRT) technology, while nearly all portable computing devices such as laptops incorporate LCD technology.
- Because of their slimmer design and lower energy consumption, monitors using LCD technology (also called **flat panel** or **flat screen** displays) are replacing the venerable CRT on most desktops.

47

The Cathode Ray Tube



A Cathode
B Conductive coating
C Anode
D Phosphor-coated screen
E Electron beams
F Shadow mask

48

CRT

53

Advantages of LCD Monitors

- **Require less power** - Power consumption varies greatly with different technologies. CRT displays are somewhat power-hungry, at about 100 watts for a typical 19-inch display. The average is about 45 watts for a 19-inch LCD display. LCDs also produce less heat.
- **Smaller and weigh less** - An LCD monitor is significantly thinner and lighter than a CRT monitor, typically weighing less than half as much. In addition, you can mount an LCD on an arm or a wall, which also takes up less desktop space.
- **More adjustable** - LCD displays are much more adjustable than CRT displays. With LCDs, you can adjust the tilt, height, swivel, and orientation from horizontal to vertical mode. As noted previously, you can also mount them on the wall or on an arm.
- **Less eye strain** - Because LCD displays turn each pixel off individually, they do not produce a flicker like CRT displays do. In addition, LCD displays do a better job of displaying text compared with CRT displays.

68

Advantages of CRT Monitors

- **Less expensive** - Although LCD monitor prices have decreased, comparable CRT displays still cost less.
- **Better color representation** - CRT displays have historically represented colors and different gradations of color more accurately than LCD displays. However, LCD displays are gaining ground in this area, especially with higher-end models that include color-calibration technology.
- **More responsive** - Historically, CRT monitors have had fewer problems with ghosting and blurring because they redrew the screen image faster than LCD monitors. Again, LCD manufacturers are improving on this with displays that have faster response times than they did in the past.
- **Multiple resolutions** - If you need to change your display's resolution for different applications, you are better off with a CRT monitor because LCD monitors don't handle multiple resolutions as well.
- **More rugged** - Although they are bigger and heavier than LCD displays, CRT displays are also less fragile and harder to damage.

69