

OSCILLOSCOPE

Cathode Ray Oscilloscope-Introduction, Block diagram of basic CRO, Cathode ray tube, Electron gun assembly, Screen for CRT, Time base operation, Vertical deflection system, Horizontal deflection system, Use of CRO for the measurement of voltage (DC and AC), frequency, phase difference, Different types of oscilloscopes and their uses, Digital storage Oscilloscope.

2.1 Cathode Ray Oscilloscope-Introduction, Block diagram of basic CRO

The cathode-ray oscilloscope (CRO) is a common laboratory instrument that provides accurate time and amplitude measurements of voltage signals over a wide range of frequencies. Its reliability, stability, and ease of operation makes it suitable as a general purpose laboratory instrument. Figure shows the basic block diagram of a general purpose CR oscilloscope.

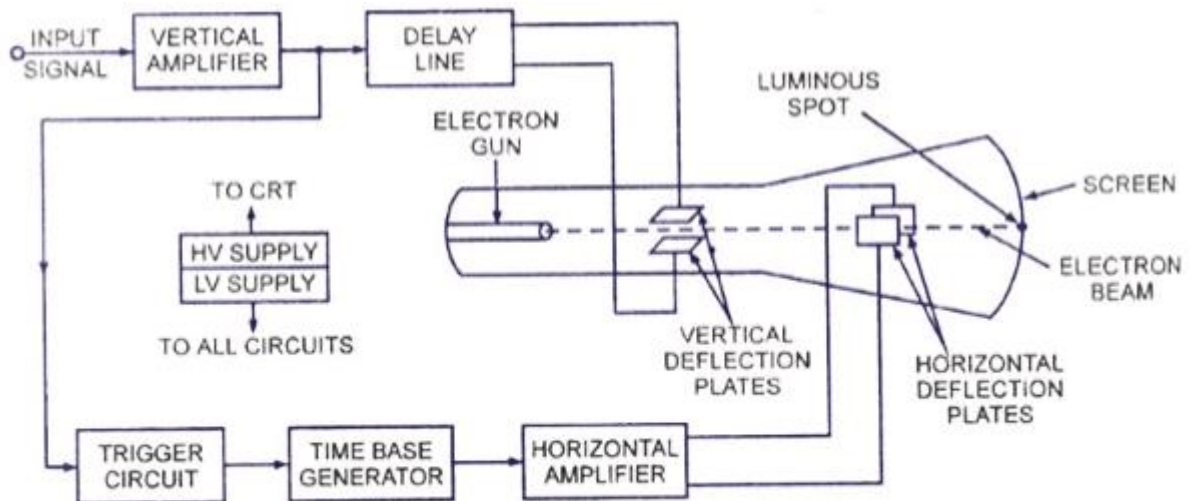


Figure - Block Diagram of General Purpose CRO

A general purpose oscilloscope consists of the following parts:

1. Cathode ray tube
2. Vertical amplifier
3. Delay line
4. Time base generator
5. Horizontal amplifier
6. Trigger circuit
7. Power supply

Cathode Ray Tube - It is the heart of the oscilloscope. When the electrons emitted by the electron gun strikes the phosphor screen, a visual signal is displayed on the CRT.

Vertical Amplifier - The input signals are amplified by the vertical amplifier. Usually, the vertical amplifier is a wide band amplifier which passes the entire band of frequencies.

Delay Line - As the name suggests, this circuit is used to delay the signal for a period of time in the vertical section of CRT. The input signal is not applied directly to the vertical plates because the part of the signal gets lost, when the delay time is not used. Therefore, the input signal is delayed by a period of time.

Time Base (Sweep) Generator - Time base circuit uses a unijunction transistor, which is used to produce the sweep. The saw tooth voltage produced by the time base circuit is required to deflect the beam in the horizontal section. The spot is deflected by the saw tooth voltage at a constant time dependent rate.

Horizontal Amplifier - The saw tooth voltage produced by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

Trigger Circuit - The signals which are used to activate the trigger circuit are converted to trigger pulses for the precision sweep operation whose amplitude is uniform. Hence input signal and the sweep frequency can be synchronized.

Power supply - The voltages required by CRT, horizontal amplifier, and vertical amplifier are provided by the power supply block. It is classified into two types -

(1) Negative high voltage supply

(2) Positive low voltage supply

The voltage of negative high voltage supply is from -1000V to -1500V. The range of positive voltage supply is from 300V to 400V.

Fluorescent Screen of CRT

In the CRT, the front face is known as the faceplate, For the CRT screen, it is flat and its size is about 100mm×100mm. The CRT screen is somewhat bent for bigger displays and the formation of faceplate can be done by pressing the molten glass into a form & after that heating it.

The inner face of the faceplate is covered by using phosphor crystal to change the energy from electrical to light. Once an electronics ray hits phosphor crystal, the energy level can be enhanced & thus light is generated throughout phosphorous crystallization, so this occurrence is known as fluorescence.

Glass Envelope

It is an extremely evacuated conical form of construction. The inside faces of the CRT along the neck as well as the display are covered through the aquadag. This is a conducting material that acts like a high-voltage electrode. The surface of the coating is connected electrically toward the accelerating anode to help the electron to be the centre.

Functioning –

The cathode ray is a beam of electrons which are emitted by the heated cathode (negative electrode) and accelerated toward the fluorescent screen. The assembly of the cathode, intensity grid, focus grid, and accelerating anode (positive electrode) is called an electron gun. Its purpose is to generate the electron beam and control its intensity and focus. Between the electron gun and the fluorescent screen are two pair of metal plates - one oriented to provide horizontal deflection of the beam and one pair oriented to give vertical deflection to the beam. These plates are thus referred to as the horizontal and vertical deflection plates

The combination of these two deflections allows the beam to reach any portion of the fluorescent screen. Wherever the electron beam hits the screen, the phosphor is excited and light is emitted from that point. This conversion of electron energy into light allows us to write with points or lines of light on an otherwise darkened screen

The linear deflection or sweep of the beam horizontally is accomplished by use of a sweep generator that is incorporated in the oscilloscope circuitry.

In the most common use of the oscilloscope, the signal to be studied is first amplified and then applied to the vertical (deflection) plates to deflect the beam vertically, and at the same time, a voltage that increases linearly with time is applied to the horizontal (deflection) plates, thus causing the beam to be deflected horizontally at a uniform rate

The signal applied to the vertical plates is thus displayed on the screen as a function of time. The horizontal axis serves as a uniform time scale

Role of sweep in CRO –

The sweep, also known as saw tooth pulse, is required to deflect the beam in the horizontal section

To obtain steady traces on the tube face, an internal number of cycles of the unknown signal must be associated with each cycle of the sweep generator. Thus, with such a matching

of synchronization of the two deflections, the pattern on the tube face repeats itself and hence appears to remain stationary

The persistence of vision of the human eye and of the glow of the fluorescent screen aids in producing a stationary pattern

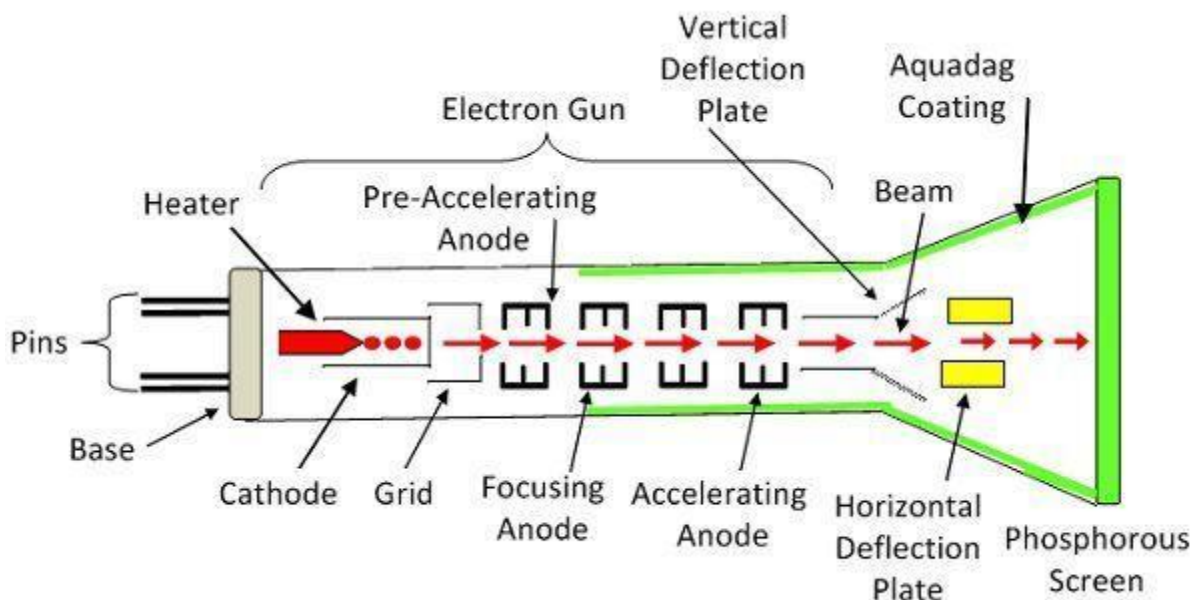
In simple words, the sweep is the horizontal speed of the cathode ray tube's spot which is used to create a trace. This ensures that the signal being tested is locked on the screen and does not drift.

2.2 Cathode Ray Tube (CRT)

Definition: The CRT is a display screen which produces images in the form of the video signal. It is a type of vacuum tube which displays images when the electron beam through electron guns strikes on the phosphorescent surface. In other words, the CRT generates the beams, accelerates it at high velocity and deflects it for creating the images on the phosphorous screen so that the beam becomes visible.

Working of CRT

The working of CRT depends on the movement of electrons beams. The electron guns generate sharply focused electrons which are accelerated at high voltage. This high-velocity electron beam when strikes on the fluorescent screen creates a luminous spot.



After exiting from the electron gun, the beam passes through the pairs of electrostatic deflection plates. These plates deflected the beams when the voltage applied across it. The one pair of plates moves the beam upward and the second pair of plates moves the beam from one side to another. The horizontal and vertical movement of the electron are independent of each other, and hence the electron beam is positioned anywhere on the screen.

The working parts of a CRT are enclosed in a vacuum glass envelope so that the emitted electron can easily move freely from one end of the tube to the other.

Construction of CRT

The Electrons Gun Assembly, Deflection Plate Assembly, Fluorescent Screen, Glass Envelope, Base are the important parts of the CRT. The electron gun emits the electron beam, and through deflecting plates, it strikes on the phosphorous screen. The detailed explanation of their parts is explained below.

Electrons Gun Assembly

The electron gun is the source of the electron beams. The electron gun has a heater, cathode, grid, pre-accelerating anode, focusing anode and accelerating anode. The electrons are emitted from the highly emitted cathode. The cathode is cylindrical in shape, and at the end of it, the layer of strontium and barium oxide is deposited which emits the high emission of electrons at the end of the tube.

The electron passes through the electron in the small grid. This control grid is made up of nickel material with a centrally located hole which is coaxial with the CRT axis. The electron which is emitted from the electron gun and passes through the control grid has high positive potential which is applied across the pre-accelerating and accelerating anodes.

The beam is focused by focusing anode. The accelerating and focusing electrodes are cylindrical in shape which has a small opening in the centre of each electrode. After exiting the focusing anode, the beams pass through the vertical and horizontal deflecting plates.

The pre-accelerating and accelerating anode are connected to the positive high voltage of about 1500V and the focusing anode are connected to the lower voltage of about 500V. There are two methods of focusing the electron beam. They are the Electrostatic Focussing Beam and the Electromagnetic Focusing.

Electrostatic Deflection Plates

The deflection plate produces the uniform electrostatic field only in the one direction. The electron beam entering into the deflection plates will accelerate only in the one direction, and hence electrons will not move in the other directions.

Screen For CRT

The front of the CRT is called the face plate. The face plate of the CRT is made up of entirely fibre optics which has special characteristics. The internal surface of the faceplate is

coated with the phosphor. The phosphorous converts the electrical energy into light energy. The energy level of the phosphorous crystal rises when the electron beams strike on it. This phenomenon is called cathodoluminescence.

The light which is emitted through phosphorous excitation is called fluorescence. When the electron beam stops, the phosphorous crystal regains its original position and releases a quantum of light energy which is called phosphorescence or persistence.

Aquadag

The Aquadag is the aqueous solution of graphite which is connected to the secondary of the anode. The Aquadag collects the secondary emitted electrons which are necessary for keeping the CRT screen in the state of electrical equilibrium.



2.3 Electron Gun

Definition: Electron gun is defined as the source of focused and accelerated electron beam. It is a device used in Cathode Ray Tube for displaying the image on the phosphorous screen of CRT. The electron gun emits electrons and forms them into a beam by the help of a heater, cathode, grid, pre-accelerating, accelerating and focusing anode.

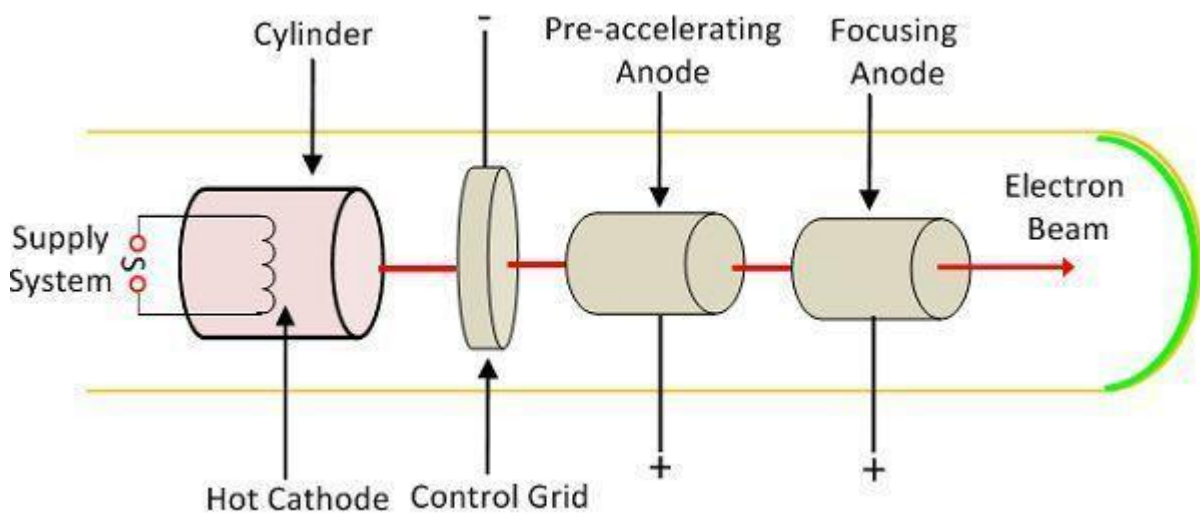
Emission of Electrons

The electrons are emitted through the indirectly heated cathode. Indirectly heated cathode means the cathode electrode are surrounded by the filament, and the electrodes emit electrons when the power is applied across it.

For getting the high emission of electrons at the moderate temperature, the layer of barium and strontium oxide is applied at the end of the cathode. The current and voltage required by the indirectly heated cathode are approximately equal to the 600 mA and 6.3V.

Working of Electron Gun

After exiting from the cathode, the electron passes through the control grid. The control grid is made up of nickel material. It is centrally hole and co-axial with the CRT axis. The intensity of the control beams depends on the number of electrons emitted from the cathode. The grid has negative biasing which controls the flow of electrons.



The electron which passes from the control grid is accelerated by the high positive potential which is applied across the pre-accelerating and accelerating grids. The electron

beam is focused by the focusing anode. The beam after passing through the focusing anode passes through the deflection plates and goes to the fluorescent screen.

Construction of Electron Gun

The main function of the electron gun is to produce and accelerate the beam of an electron inside the vacuum tube of the CRT. For generating and accelerating the gun requires the heater, cathode electrodes, grid, and different types of anodes. The detailed explanation of their parts is shown below.

1. Heater – The heater converts the electric energy in the form of heat. It has a resistor which obstructs the flow of current and converts it into thermal energy. The heater heats the cathode electrodes and emits the electrons.
2. Control Grid – The control grid is a nickel cylinder. It is the metallic cup which has lower permeability steel. It is about 15 mm long and has a diameter of 15 mm. The hole of about 0.25 mm is drilled in the cap of the grid for the flow of the electron. The intensity of an electron beam passing through the grid depends upon the emission of electrons. The control grid is negative biasing due to which it controls the flow of electrons.
3. Pre-Accelerating & Accelerating Anode – The pre-accelerating and accelerating anode accelerated the beams passing through the gun. These anodes are connected to the high potential for accelerating the electrons.
4. Focussing Anode – After passing through the pre-accelerating and accelerating electrodes, the electrons are passing through the focusing beam. The focusing anode produces the beams of sharply focused electrons.
5. The electron gun is placed inside the glass tube so that the electron beam did not interact with the air molecules.

2.4 Screen For CRT

The light produced by the screen does not disappear immediately when bombardment by electrons ceases, i.e., when the signal becomes zero. The time period for which the trace remains on the screen after the signal becomes zero is known as persistence. The persistence may be as short as a few microseconds, or as long as tens of seconds or even minutes.

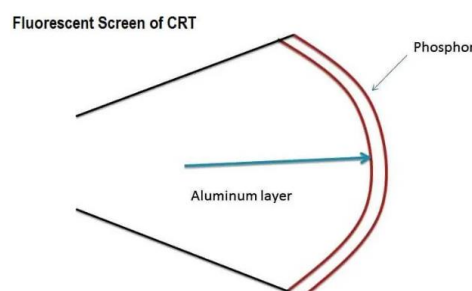
1. Medium persistence traces are mostly used for general purpose applications.
2. Long persistence traces are used in the study of transients. Long persistence helps in the study of transients since the trace is still seen on the screen after the transient has disappeared.
3. Short persistence is needed for extremely high-speed phenomena.

The screen is coated with fluorescent material called phosphor which emits light when bombarded by electrons. There are various phosphors available which differ in color, persistence and efficiency.

One of the common phosphors is willemite, which is zinc, orthosilicate, $ZnO+SiO_2$, with traces of manganese. This produces the familiar greenish trace. Other useful screen materials include compounds of zinc, cadmium, magnesium and silicon.

The kinetic energy of the electron beam is converted into both light and heat energy when it hits the screen. The heat so produced gives rise in phosphor burn which is damaging and sometimes destructive. This degrades the light output of phosphor and sometimes may cause complete phosphor destruction. Thus, the phosphor must have high burn resistance to avoid accidental damage.

Similarly, the phosphor screen is provided with an aluminium layer called aluminizing the cathode ray tube. This is shown in the image below.



These Aluminizing layers serve three functions:

1. To avoid buildup of charges on the phosphor which tend to slow down the electrons and limit the brightness.
2. It serves as a light scatter. When the beam strikes the phosphor with an aluminized layer, the light emitted back into the tube is reflected back towards the viewer which increases the brightness.
3. The aluminium layer acts as a heat sink for the phosphor and thus reduces the chances of the phosphor burning.

Phosphor screen characteristics

1. Many phosphor materials having different excitation times and colors as well as different phosphorescence times are available.
2. The type P1, P2, P11 or P31 are the short persistence phosphors and are used for the general-purpose oscilloscopes.
3. Medical oscilloscopes require longer phosphor decay and hence phosphors like P7 and P39 are preferred for such applications
4. Very slow displays like radar require long persistence phosphors to maintain sufficient flicker free picture. Such phosphors are P19, P26 and P33.
5. The phosphors P19, P26, P33 have low burn resistance. The phosphors P1, P2, P4, P7, P11 have medium burn resistance while P15, P31 have high burn resistance.

Why P31 is commonly used?

Out of these varieties, the materials P31 is used commonly for general purpose oscilloscopes due to following characteristics:

1. It gives color to which human eye response is maximum.
2. It gives short persistence required to avoid multiple image displays.
3. It has high burn resistance to avoid accidental damage.
4. Its illumination level is high.
5. It provides high writing speed.

Note: the light output of a fluorescent screen is proportional to the number of bombarding electrons, i.e., to the beam current.

2.5 Time base operation

Definition: The circuit that produces a linearly varying voltage or current with time is known as Time-Base Generator. It is basically a function generator that generates a sawtooth waveform of high frequency. These circuits are also known as sweep circuits. This is so because they are used to sweep the beam of electrons across the screen in a horizontal direction in CRO.

Types of Time-Base Generator

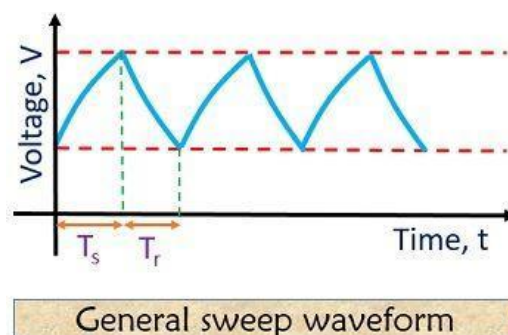
These are basically of two types:

1. Voltage time-base generator: It generates a voltage that varies linearly according to time and finds its application in electrostatic deflection.
2. Current time-base generator: It generates linearly varying current with respect to time at the output. This current is then allowed to flow through inductor or deflection coils and used in the field of electromagnetic deflection.

Time-Base signal

A CRO basically measures or displays a quantity that varies according to the time. This needs a CRT spot to move with a constant velocity that resultantly requires a linearly varying voltage to be applied at the set of a deflection plate.

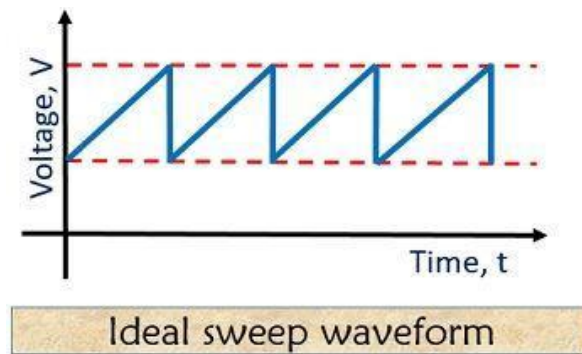
Now, let us have a look at the Time-base voltage waveform shown below. It is sometimes known as the sweep voltage waveform.



Here, we can see that the linearly varying voltage starts from a point, it can be 0 and returns to the same point after reaching the peak value.

The duration of time at which there is a linear increase in the voltage of the waveform is known as Sweep time and denoted by T_s . On the other side, the time duration required by the signal to return to its initial value is known as Restoration time or retrace time T_r .

Normally the output generated by a sweep circuit is shown above i.e., sweep voltage waveform. However, an idealised output is a sawtooth waveform that results when T_r is very small or negative with respect to T_s . That particular ideal sawtooth or ramp voltage waveform is shown below.



In the case of an idealised waveform, the sweep produced voltage becomes exactly linear and the retrace time is 0 that is shown in the figure above

Errors of sweep waveform in Time-Base Generator

Practically it is not possible for a time-base generator to provide exactly linear sweep voltage. However, if we still consider that an exactly linear sweep voltage is generated, it will definitely get distorted during transmission. So there are commonly 3 different ways to express deviation from linearity.

Slope or sweep speed error:

In a sweep generator, there is a need to keep sweep speed constant with time. The variation in sweep speed results in non-linearity of the slope of sweep voltage. This error is known as sweep speed error and is given as

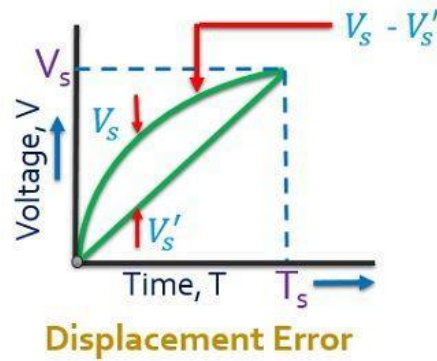
$$e_s = \frac{\text{difference in slope at the beginning and end of slope}}{\text{initial value of slope}}$$

Displacement error:

It is the ratio of the maximum difference between actual and linear sweep voltage to the peak value of sweep voltage. It is given as

$$e_d = \frac{(V_s - V_s')_{max}}{V_s}$$

The figure below shows the graphical representation of the displacement error:

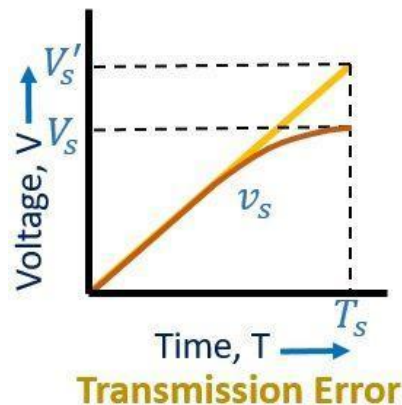


It holds significance in timing application and defines non-linearity of a signal.

Transmission error: It is a result of passing sweep voltage through a high pass R-C network because the maximum amplitude of output deviates from the input. It is given as

$$e_t = \frac{(V_s' - V_s)}{V_s'}$$

The figure below shows the transmission error in a sweep waveform:



For smaller deviation sweep voltage can be considered as the summation of linear and quadratic terms then

$$e_d = \frac{1}{8} e_s = \frac{1}{8} e_t$$

Methods of sweep voltage generation

It is practically not possible to obtain exact linearity in sweep voltages, thus, different methods are developed to achieve it. The methods are discussed below:

1. **Exponential charging:** In this method, a capacitor is charged through a resistor exponentially from a voltage source up to a value which is somewhat smaller as compared to source voltage.

2. **Constant current charging:** Here, a constant current source is used to charge the capacitor linearly.
3. **Miller circuit:** In this method, a step is converted into a ramp waveform using an operational integrator.
4. **Bootstrap circuit:** In this circuit, basically, a constant voltage is used across the resistor in series with a capacitor in order to maintain a constant current.
5. **Phantatron circuit:** This circuit is a modified version of the miller circuit where pulse input is needed rather than step waveform.
6. **Compensating network:** These are the circuits that improve the linearity of the signal but are used along with bootstrap and miller time base generator.
7. **Inductor circuit:** Here, linear charging of the capacitor is done by using a series RLC circuit.

The most commonly used methods of sweep voltage generation among all the above is exponential charging and miller sweep and bootstrap time-base generators.

Applications of Time-base generator

- It is used in CRO for measuring and displaying time-varying quantities.
- Time base generators are used in radar systems in order to obtain target range.
- These circuits are used in computer monitors and television indicators.
- Automatic controlling systems and analogue to digital converters use these circuits for controlling and converting applications by time variation.
- For accurate time measurement and time modulation techniques time-base circuits find their uses.

In a time-base generator, the displacement error is less ascendant as compared to the sweep speed error.

2.6 Vertical deflection system

Definition: 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:

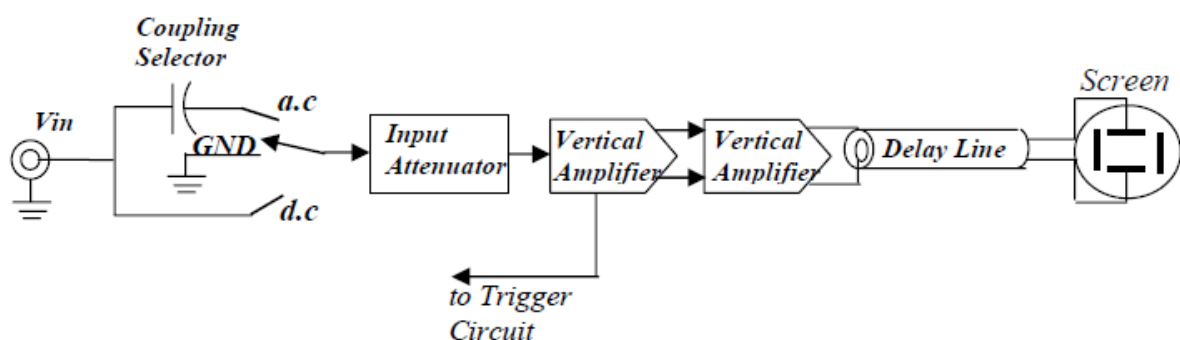
1. Input coupling selector.
2. Input attenuator.
3. Preamplifier.
4. Main vertical amplifier.
5. Delay line.

Input Coupling Selector:

Its purpose is to allow the oscilloscope more flexibility in the display of certain types of signals. For example, an input signal may be a d.c signal, an a.c signal, or a.c component superimposed on a d.c component.

There are three position switches in the coupling selector (d.c, a.c, and GND). If an a.c position is chosen, the capacitor appears as an open circuit to the d.c components and hence blocks them from entering.

While the GND position grounds the internal circuitry of the amplifier to remove any stored charge and recenter the electron beam.



Input Attenuators and Amplifiers:

The combined operation of the attenuator, preamplifier and main amplifier together make up the amplifying portion of the system.

The function of the attenuator is to reduce the amplitude of the input signal by a selected factor and reverse varies amplifier function.

Delay Line:

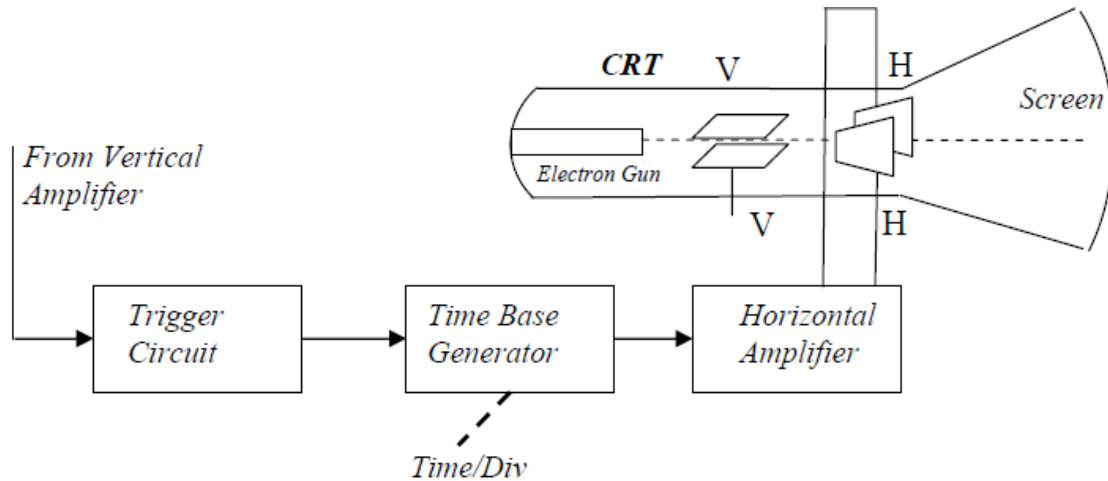
Since part of the input signal is picked off and fed to the horizontal deflection system to initiate a sweep waveform that is synchronized with the leading edge of the input signal.

So the purpose of delay is to delay the vertical amplified signal from reaching the vertical plates until the horizontal signal reaches the horizontal plates to begin together at the same time on the CRT screen.

2.7 Horizontal deflection system

The horizontal deflection system of OSC consist of :

- 1- Trigger circuit.
- 2- Time base generator.
- 3- Horizontal amplifier.



Horizontal Deflection System

Trigger and Time Base Generator:

- The most common application of an oscilloscope is the display of voltage variation versus time.
- To generate this type of display a saw tooth waveform is applied to horizontal plates.
- The electron beam is bent towards the more positive plate and deflected the luminous spot from left to right of the screen at constant velocity whilst the return or fly back is at a speed in excess of the maximum writing speed and hence invisible.
- The saw tooth or time base signal must be repetitively applied to the horizontal plates so that; the beam can retrace the same path rapidly enough to make the moving spot of light appear to be a solid line.
- To synchronize the time base signal applied to (X-plates) with input voltage to be measured which is applied to vertical or (Y-plates) a triggering circuit is used.
- This circuit is sensitive to the level of voltage applied to it, so that when a predetermined level of voltage is reached a pulse is passed from the trigger circuit to initiate one sweep of the time base.
- In a practical oscilloscope the time base will be adjustable from the front panel control of scope.

Horizontal Amplifier:

The horizontal amplifier is used to amplify the sweep waveform to the required level of horizontal plates operation.

2.8 Use of CRO for the measurement of voltage (AC and DC)

Both d.c and a.c can be measured on CRO. The CRO will be switched on and a horizontal line is obtained using the internal sweep. The unknown d.c voltage is applied to the vertical input terminals placing the input switch to d.c mode. On application of the voltage the horizontal line shifts. This displacement is measured using the scale marking on the graticule. The magnitude of the unknown voltage can be calculated, by multiplying the displacement obtained in meters with a deflection factor.

$$\text{Unknown voltage} = \text{deflection factor} \times \text{displacement in m.}$$

To measure the magnitude of alternating voltage, the CRO is switched on and the horizontal line is obtained. The unknown voltage is applied to the vertical deflecting plates. Now the sweep is withdrawn. A vertical line is displayed by the CRO. The length of this line is measured using the scale marking on the graticule. This length l multiplied by the deflection factor gives the peak to peak voltage of the applied voltage. $1/2$ deflection factor gives the peak amplitude of the unknown voltage.

2.9 Frequency

A CRO can be used in a number of ways to measure frequency when two sources of identical frequencies are available. The frequencies may also have harmonic relationships with each other. The CRO establishes the harmonic relationship without the necessity of generating the harmonic. The three methods commonly used for measurement of frequency using CRO are listed below.

1. Lissajous figures.
2. Spot wheel pattern.
3. Gear wheel pattern.

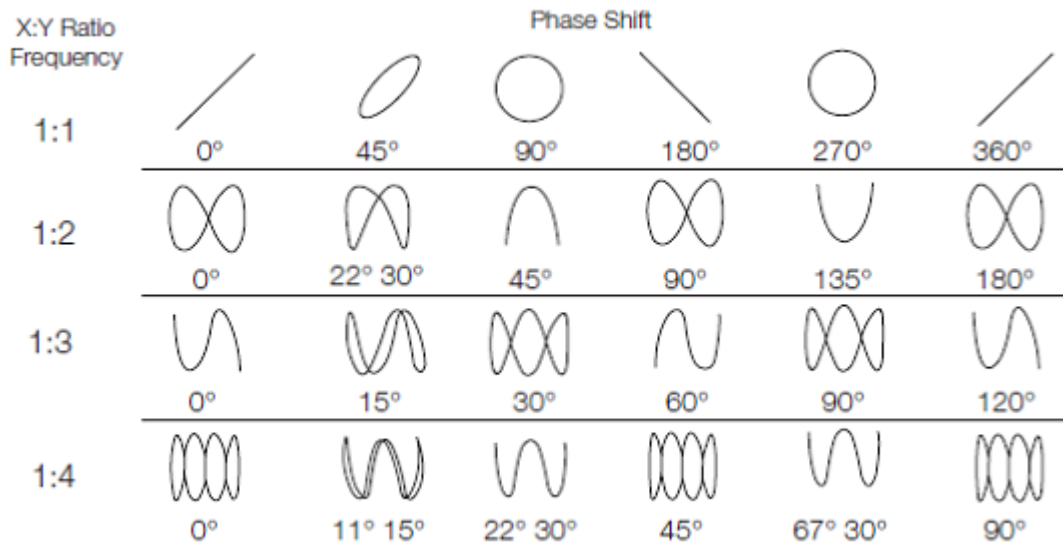
1. Lissajous Figures Method :

This is the simplest method to determine the frequency relation of two sine wave voltages. One voltage is used to produce vertical deflection, while the second is used to give the horizontal deflection. If the ratio of the two frequencies involved can be expressed by an integer, or by a ratio of integers the pattern obtained on the CRO is dependent on the relative phase of the two signals. (Phase measurement can also be made in this way).

The pattern will be stationary when the ratio of the two frequencies is correctly a ratio of integers. The ratio of horizontal to vertical frequency is given by the number of times the figure (pattern) is tangent to the horizontal line divided by the number of times its end is tangential to the vertical line. This rule is valid when the forward and return traces do not coincide. When the phase difference is 0° and 180° they do coincide, and the rule is not applicable in those conditions.

When the frequency ratio of the two signals is not exactly equal then the pattern will rotate or barrel or wave about as if the relative phase of the two deflecting signals is continuously changing. If the frequencies differ very much we see only a luminous rectangle on the screen.

Lissajous figures for different frequency ratios and phase angles are shown below in Figure.



It can be observed from the figures that when the phase difference is π , the patterns observed are interesting. When the frequency ratio is 1 we get a circle, for a ratio of 1:2 we get a figure of eight and so on. The patterns observed for ratios 2:3 and 3:4 are slightly complicated. To determine the frequency ratio of such complicated patterns the following procedure is used. If a tangent is drawn against the top edge of the pattern for 2:3 pattern it will make contact with the pattern at two places.

Similarly drawing a vertical tangent along the vertical side will contact at three places. So it is evident that the horizontal tangencies correspond to the vertical frequency in their number and the vertical tangencies correspond to the horizontal frequency, hence the ratio 2:3. The same rule can be applied to patterns of 3:4 frequency ratio, or in general any pattern of this type. It is to be noted here that the pattern not only depends on the frequency of the voltage applied to the deflecting plates but also on their phase. So the circle can be obtained only if the ratio is 1 and the phase difference is 90° . If the ratio is 1 and the phase is not specified a straight line inclined to right or left, an ellipse inclined to right or left, or a circle can appear.

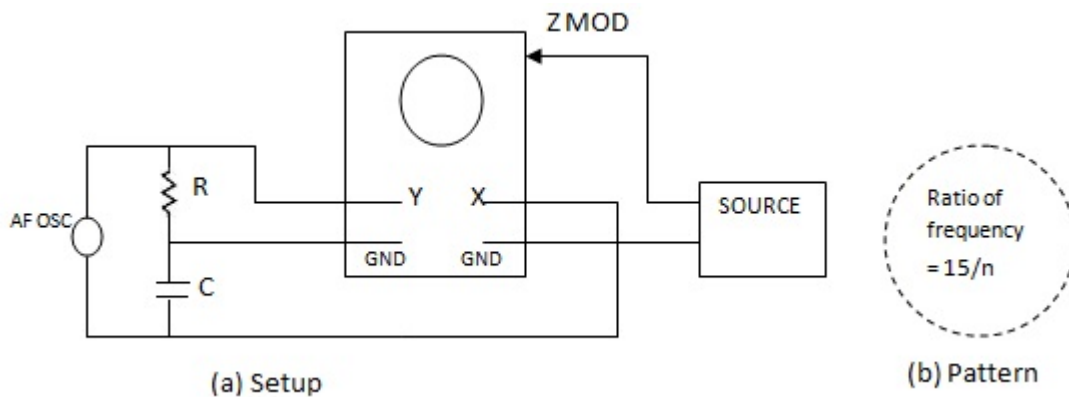
Lissajous figures become difficult to interpret if the frequency ratio is large as complicated patterns will result. Alternate methods are available as described here under.

(b) Spot Wheel Method :

In this method a circular sweep is produced using the low frequency source and a R.C. combination in series. When the midpoint of the series combination is taken as reference the voltages out of the other two terminals will have a phase difference of 90° . This is called the

phase splitting network. The resistance is so chosen that its value is equal to the capacitive reactance at the working frequency. Then the magnitudes of the voltages produced across the two will be equal. This R.C. series phase splitting network satisfactorily works only at one frequency.

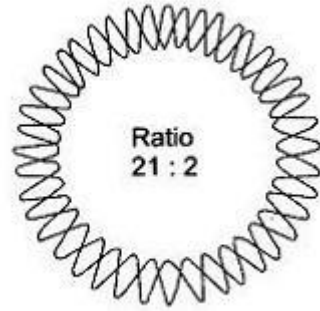
The arrangement for the split circle or spot wheel method of measurement is shown below along with the typical pattern in Figure.



The low frequency is used with the phase splitter to get the circular sweep. The high frequency signal is used to modulate the intensity of the electron beam. This can easily be done by applying the high frequency voltage to the Z-modulation terminal of the oscilloscope. This terminal is made available usually on the rear side of the instrument and is accessible through an opening. The resultant pattern consists of a circle of spots in which the ratio of the high frequency to the low frequency is equal to the number of spots divided by a suitable integer 'n' that is less than the number of spots. The pattern will be the same for different values of 'n' so that the proper value of this integer must be determined from other information such as prior knowledge for approximate frequency.

(c) Gear Wheel Method :

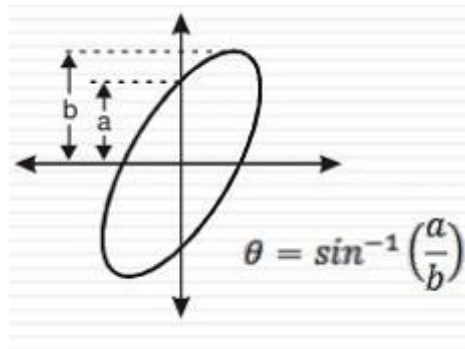
An R.C. a series phase splitting unit is used in this method to produce a circular sweep supplied by the low frequency signal. The high frequency signal is given to the radial deflecting electrode. This causes the beam to move regularly in and out in accordance with the amplitude and frequency of the high frequency wave. The number of teeth in the wheel pattern that results, divided by the number of times a radial line from center outwards that intersect the pattern, gives the frequency ratio. The Gear wheel pattern is shown below Figure.



Gear Wheel Method

2.10 Phase difference

Cathode ray oscilloscope is used to determine the phase difference between two signals of the same frequency. The procedure is to apply one of the signals to the horizontal deflecting plates and the other to the vertical deflecting plates. The result is a pattern that reflects the character of the phase difference. Typical pattern for a phase angle is shown below in Figure.



The phase difference θ between the two signals is given by

$$\sin \theta = \pm B/A$$

Where A is the maximum vertical deflection produced and B is Y intercept.

Irrespective of the relative amplitudes of the applied signal voltages the ellipse provides a simple means of finding the phase difference between the signals. The gains of vertical and horizontal amplifiers can be adjusted to get the ellipse in a square marked by the coordinate lines on the graticule. If the major axis is in the first and third quadrants the phase angle is between 0° and 90° or 270° and 360° . If the major axis passes through the second and fourth quadrants the phase angle is between 90° and 180° or between 180° and 270° .

Measurement of Time Interval using CRO:

Time intervals of short duration can be measured using CRO. The sweep is triggered by the pulse that serves as a time reference. The length or duration of this driven sweep is adjusted so that both the pulses are visible on the screen. If the approximate sweep speed is known, a rough measurement of the time interval separating the two pulses can be determined from the linear distance separating the pulses on the screen.

Greater accuracy can be had by markers (or indexes or cursor). Markers can be superimposed upon the cathode ray trace. These markers have their origin in a sine wave

oscillator of accurately known frequency. The waveform from this oscillator is then modified by amplification, clamping and differentiating until a series of sharp pulses are obtained.

The operator or user has to adjust the position of the marker until it coincides with the observed pulse, the time interval is given by the setting of the position control.

2.11 Different types of oscilloscopes and their uses

Types of Oscilloscopes

Several types of oscilloscopes are available, both analog and digital, for a range of prices. Since digital oscilloscopes can miss some transient signals, analog oscilloscopes are still prized for transient troubleshooting applications. However, high-end digital phosphor oscilloscopes can provide similar capabilities.

Analog Oscilloscopes

An analog oscilloscope displays the signal picked up by a probe and traces it on the screen. Storage capabilities allow the waveform to display for extended periods of time rather than decay immediately.

Where analog oscilloscopes come into their own is in dealing with analog signals and transient effects. In analog oscilloscopes, phosphors on a CRT monitor glow for a period of time before going dark, allowing high-speed signals to build up a more intense glow. This process allows transients to stand out as well.

Analog oscilloscopes offer a better dynamic range than digital oscilloscopes. These don't suffer from aliasing problems, which can cause false readings. Analog oscilloscopes are generally more affordable than digital oscilloscopes and are a great option for beginners and hobbyists. Analog oscilloscopes that can also handle low-speed digital signals are especially ideal for audio and analog video work.

Digital Oscilloscopes

Digital oscilloscopes are available in many types. Two key factors determine the performance of a digital oscilloscope: sampling rate and bandwidth. An oscilloscope's sampling rate limits its ability to capture transient, one-time events. The bandwidth of an oscilloscope limits the frequency of repetitive signals that can be displayed.

Digital Storage Oscilloscopes

Most digital oscilloscopes are digital storage oscilloscopes. Digital storage oscilloscopes can capture transient events and store those events for analysis, archival,

printing, or other processing. These have permanent storage for recording signals and can be offloaded to other media for storage and analysis.

Digital storage oscilloscopes are the workhorses of real-world digital design where four or more signals are analyzed simultaneously. However, unlike an analog oscilloscope, digital storage oscilloscopes cannot display the level of intensity of a real-time signal. Single-shot events can be captured through the use of triggers, which can be set manually or automatically depending on the device.

Digital Phosphor Oscilloscopes

Digital phosphor oscilloscopes allow for faster signal capture and analysis than standard digital storage oscilloscopes. Digital phosphor oscilloscopes use a parallel processing ADC solution that delivers higher sampling rates, enabling a signal visualization performance level that has the appearance of real-time.

Digital phosphor oscilloscopes are similar to analog oscilloscopes in displaying the intensity of a signal. These oscilloscopes duplicate the effect of phosphorus by storing a database of the values of the repeating waveforms and increasing the intensity on the display where the waveforms overlap.

Like an analog oscilloscope, a digital phosphor scope can reveal transients by displaying the intensity level. However, it can miss transients that happen outside of the data capture window and its update rate.

Digital phosphor oscilloscopes combine the features of digital storage oscilloscopes and analog oscilloscope technology. These qualities are great for general purpose design, digital timing, advanced analysis, communication testing, and troubleshooting.

Mixed Domain Oscilloscopes

A mixed domain oscilloscope combines the functionality of a digital oscilloscope, an RF spectrum analyzer, and a logic analyzer into one device. When designing or working with systems that include digital signals, digital logic, and radiofrequency communication, mixed domain oscilloscopes are an essential tool.

The main benefit of a mixed domain oscilloscope is seeing signals from each domain time-correlated to each other, which helps with troubleshooting, debugging, and design testing.

Mixed Signal Oscilloscopes

Engineers often use digital oscilloscopes and logic analyzers together, which is why the mixed signal oscilloscope was developed. These devices combine the capabilities of a digital storage oscilloscope (or a digital phosphor oscilloscope) with a multi-channel logic analyzer.

The digital triggering capability of the mixed signal oscilloscope aids the analysis of analog events that can trigger digital logic transitions. Typically, mixed signal oscilloscopes have two or four analog input channels and around 16 digital input channels.

Digital Sampling Oscilloscopes

Digital sampling oscilloscopes have a slightly different input technique that trades a higher bandwidth for a lower dynamic range. The input is not attenuated or amplified, so the oscilloscope must handle the full range of the input signal, which is generally limited to about 1-volt peak-to-peak.

Digital sampling oscilloscopes only work on repetitive signals and will not help capture transients beyond the normal sampling rate. On the other hand, digital sampling oscilloscopes can capture signals that are an order of magnitude faster than other types of oscilloscopes with bandwidths exceeding 80 [GHz](#).

Handheld Oscilloscopes

Small handheld oscilloscopes are available for field and test applications where bulkier oscilloscopes are unwieldy or power outlets are unavailable. These typically contain two inputs and have limited sampling rates and bandwidth.

Computer-Based Oscilloscopes

Computer-based oscilloscopes are small, external devices that connect to a computer through [USB](#). These types of oscilloscopes have seen significant improvements in sampling rates and bandwidth over the years.

Some computer-based oscilloscopes have the same capabilities as low-end digital storage oscilloscopes for only a few hundred dollars. These are a great option for hobbyists looking for an oscilloscope.

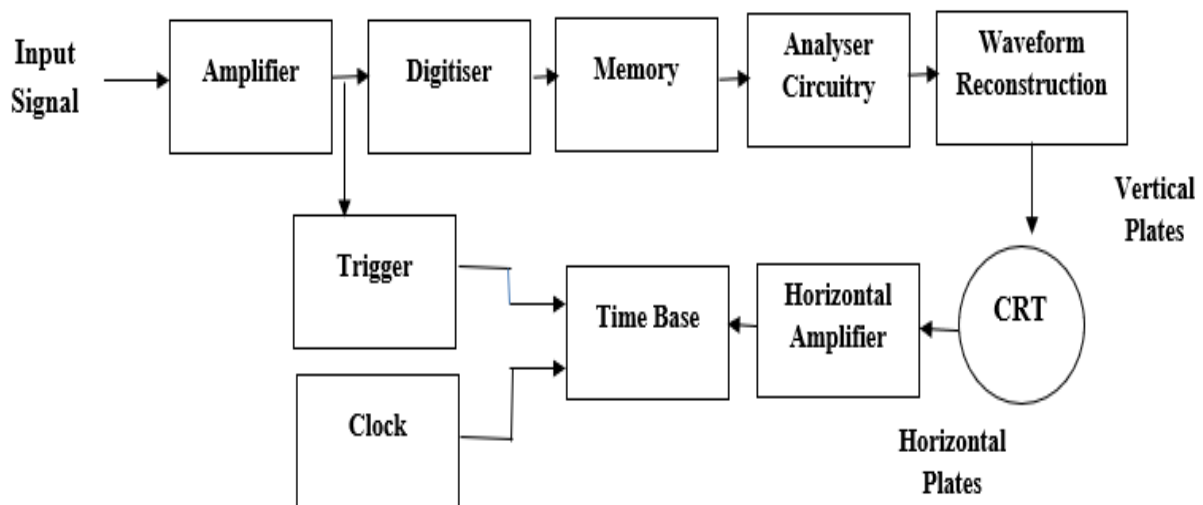
2.12. Digital Storage Oscilloscope

In 1897, Karl Ferdinand Braun invented an oscilloscope.

Definition: The digital storage oscilloscope is an instrument which gives the storage of a digital waveform or the digital copy of the waveform. It allows us to store the signal or the waveform in the digital format, and in the digital memory also it allows us to do the digital signal processing techniques over that signal. The maximum frequency measured on the digital signal oscilloscope depends upon two things: the sampling rate of the scope and the nature of the converter. The traces in DSO are bright, highly defined, and displayed within seconds.

Block Diagram of Digital Storage Oscilloscope

The block diagram of the digital storage oscilloscope consists of an amplifier, digitizer, memory, analyzer circuitry, waveform reconstruction, vertical plates, horizontal plates, cathode ray tube (CRT), horizontal amplifier, time base circuitry, trigger, and clock. The block diagram of the digital storage oscilloscope is shown in the figure.



At first digital storage oscilloscopes digitizes the analog input signal, then the analog input signal is amplified by the amplifier if it has any weak signal. After amplification, the signal is digitized by the digitizer and that digitized signal is stored in memory. The analyzer circuit processes the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).

The cathode ray tube has two inputs they are vertical input and horizontal input. The vertical input signal is the 'Y' axis and the horizontal input signal is the 'X' axis. The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal. Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate. On the CRT screen, we will get the waveform of the input signal versus time.

The digitizing occurs by taking a sample of the input waveform at periodic intervals. At the periodic time interval, when half of the time cycle is completed then we are taking the samples of the signal. The process of digitizing or sampling should follow the sampling theorem. The sampling theorem says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal. When the analog signal is not properly converted into digital then there occurs an aliasing effect.

When the analog signal is properly converted into digital then the resolution of the A/D converter will be decreased. When the input signals stored in analog store registers can be read out at a much slower rate by the A/D converter, then the digital output of the A/D converter is stored in the digital store, and it allows operation up to 100 mega samples per second. This is the working principle of a digital storage oscilloscope.

DSO Operation Modes

The digital storage oscilloscope works in three modes of operation: roll mode, store mode, and hold or save mode.

Roll Mode: In roll mode, very fast varying signals are displayed on the display screen.

Store Mode: In the store mode the signals are stored in memory.

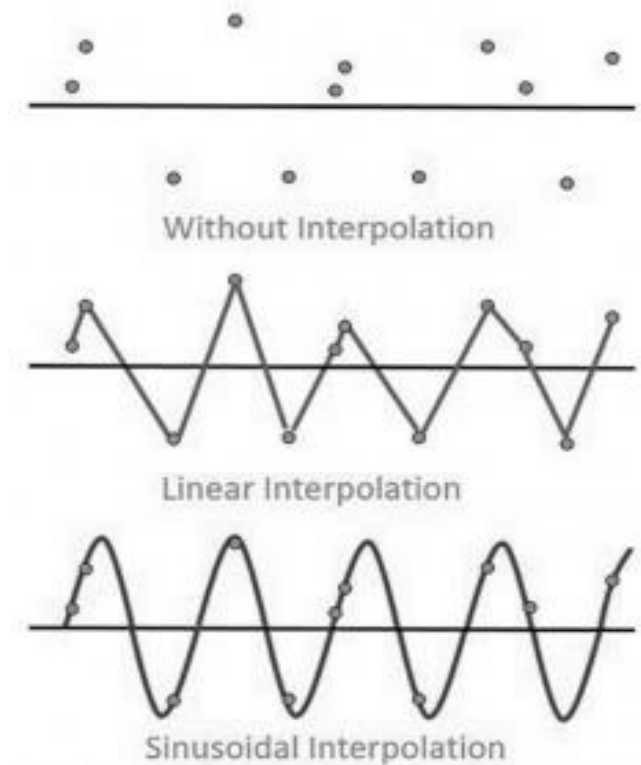
Hold or Save Mode: In hold or save mode, some part of the signal will hold for some time and then they will be stored in memory.

Waveform Reconstruction

There are two types of waveform reconstructions they are linear interpolation and sinusoidal interpolation.

Linear Interpolation: In linear interpolation, the dots are joined by a straight line.

Sinusoidal Interpolation: In sinusoidal interpolation, the dots are joined by a sine wave.



Applications

The applications of the DSO are

- It checks faulty components in circuits
- Used in the medical field
- Used to measure capacitor, inductance, time interval between signals, frequency and time period
- Used to observe transistors and diodes V-I characteristics.
- Used to analyze TV waveforms.
- Used in video and audio recording equipment.
- Used in designing
- Used in the research field
- For comparison purpose, it displays 3D figure or multiple waveforms
- It is widely used an oscilloscope

Advantages

The advantages of the DSO are

- Portable
- Have the highest bandwidth
- The user interface is simple
- Speed is high

Disadvantages

The disadvantages of the DSO are

- Complex
- High cost

Difference Between Digital Storage Oscilloscope and Conventional Storage Oscilloscope

The difference between DSO and the conventional storage oscilloscope or analog storage oscilloscope (ASO) is shown in the below table.

S.No.	Digital Storage Oscilloscope	Conventional Storage Oscilloscope
1	DSO collects data always	After triggering only, ASO collects data.
2.	The cost of the tube is cheap	The cost of the tube is costlier
3.	For higher frequency signals the DSO produce bright images	For higher frequency signals the ASO cannot produce bright images.
4.	The resolution is higher	The resolution is lower
5.	Operating speed is less	Operating speed is less