



STUDY MATERIAL

VIVEKANANDA COLLEGE
THAKURPUKUR

NAAC ACCREDITED GRADE-'A'

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ELECTRONICS

(Honours and General)

Cathode Ray Oscilloscope (CRO) and **Digital Storage Oscilloscope (DSO)**

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1 Block Diagram of a CRO

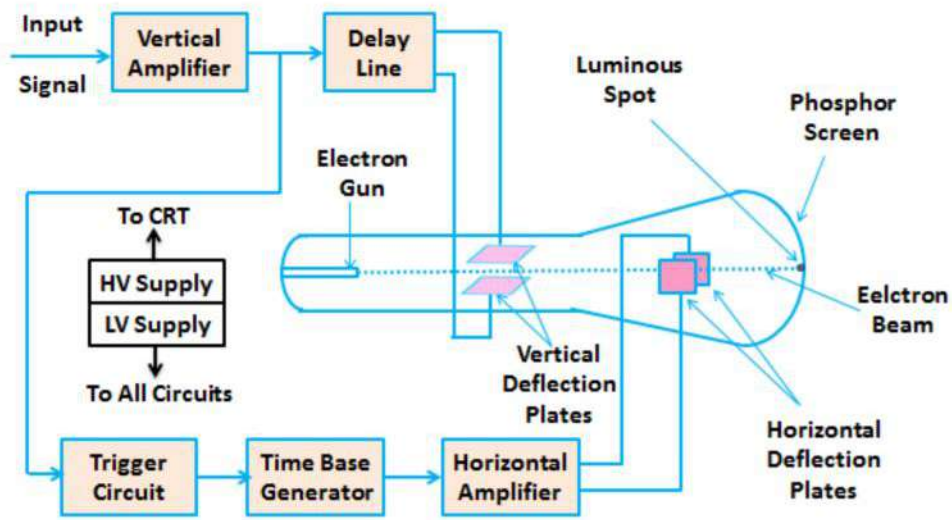


Figure 1: Block diagram of a general purpose CRO

The block diagram of general purpose cathode ray oscilloscope (CRO) is shown in Fig. 1 which consists of the following parts:

1. **Cathode Ray Tube (CRT)**- The main part of the CRO is Cathode Ray Tube (CRT). The electron gun within the CRT generates an electron beam which strikes on a fluorescent screen with high velocity. The screen produces a visible **spot** where the electron beam strikes it. Horizontal and vertical deflecting plates are fitted between the electron gun and screen to deflect the beam according to the input signal.
2. **Vertical Amplifier**- The vertical displacement of the spot is caused by the input signal. The input signal should properly be amplified by the vertical amplifier before it is applied to the vertical deflection plate to provide a measurable deflection. The vertical amplifier is a wide band amplifier which passes the entire band of frequencies contained in the input signal.
3. **Delay Line**- This circuit is used to delay the input signal for a period of time. The delay is provided to ensure that the horizontal sweep is started prior to vertical deflection so as not to cause any signal loss.
4. **Time Base Generator**- The time base generator is basically a function generator which produces sawtooth voltage (sweep voltage). This sawtooth voltage is applied to the horizontal deflecting plates to deflect the electron beam in the horizontal direction.
5. **Horizontal Amplifier**- The sawtooth voltage produced by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

6. **Trigger Circuit-** The trigger circuit is used for synchronizing two types of deflections so that horizontal deflection starts at the same point of the input vertical signal each time it sweeps.
7. **Power Supply-** The power supply required by the CRO is classified into two types:
 - i. Negative high voltage supply for CRT,
 - ii. Positive low voltage supply for electronic circuits

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

2 Cathode Ray Tube (CRT)

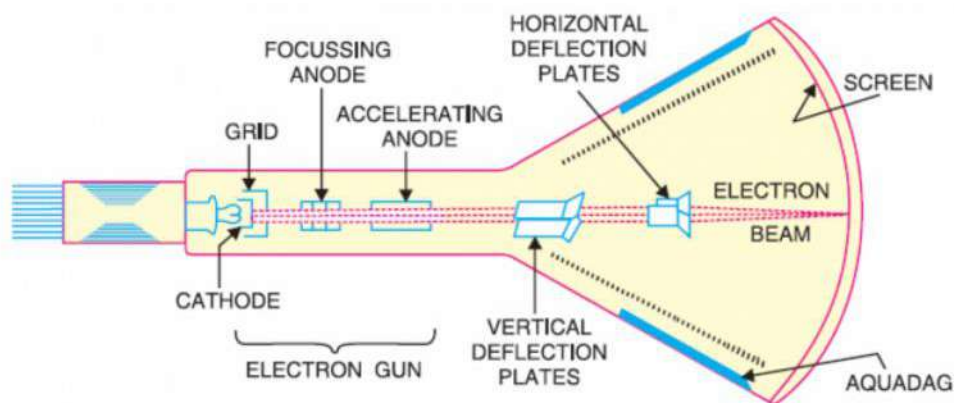


Figure 2: Cathode Ray Tube (CRT)

The main part of the CRO is Cathode Ray Tube (CRT). A basic CRT consists of following major components:

1. **Glass Tube:** The glass tube (also known as the bulb) encloses and holds the components of the CRT. Vacuum is maintained inside the bulb to avoid collisions between electrons and gas molecules of the air, which would attenuate the beam.
2. **Electron Gun:** The electron gun is placed at the base of the CRT which produces a narrow, collimated electron beam which is accelerated towards the phosphor screen. It consists of five major parts: heater, cathode, control grid, focussing anode, and accelerating anode. The *heater*, a rod of metal, is supplied an electric current which converts it into heat. The *cathode* is a nickel cylinder which emits plenty of electrons, when heated. The cathode serves as the source of the electron beam and is held at a negative voltage potential. The rate of emission of electrons or the intensity of electron beam is controlled by the *control grid*. The *focussing anode* controls the width of the electron beam and the *accelerating anode* creates the electric field needed to accelerate the electrons from the cathode to the screen.
3. **Deflection Plates:** The deflection plates are simply pairs of oppositely charged metal plates which are placed at the neck of the tube. There are two sets of deflection plates: vertical and horizontal. The *vertical* deflection plates are used to control the vertical position of the beam spot on screen while the *horizontal* plates are used to control the horizontal position of the beam spot.

4. **Fluorescent Screen:** The fluorescent screen is the display on the CRT. The inner surface of the display is painted with *phosphor*. When an electron hits the phosphor coating, the phosphor absorbs the kinetic energy of the electron and reemits energy as photons of visible light. This results in a spot of light on the display, with brightness proportional to the intensity of the beam. Even after the electron beam is cut off, the emission of light persists for a short period of time. This is known as the *phosphorescence*.

The bombarding electrons striking the phosphor release secondary-emission electrons which may accumulate on the screen and thus preventing the electron beam to reach the screen. To overcome this problem, a conductive coating, known as *aquadag*, is applied on the inside surface of the glass tube to collect the secondary-emission electrons, which is electrically connected to the accelerating anode so that the circuit is complete.

3 Electrostatic Deflection

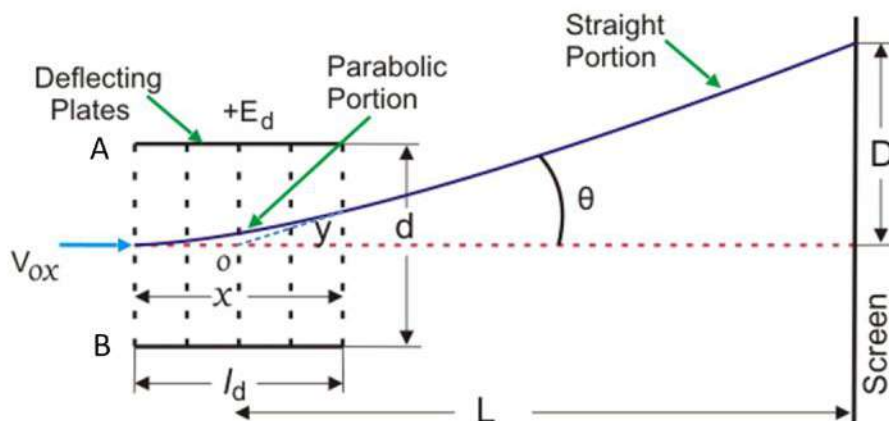


Figure 3: Electrostatic deflection

In electrostatic deflection system, we have two deflection plates A and B which are at potential $+E_d$ and 0 respectively (see Fig. 3). The field produced by these plates is in the direction of negative y -axis and there is no force along the x -axis. Now let us consider a beam of electrons coming along the x -axis as shown in Fig. 3. The beam deflects by angle θ toward the positive y -direction, due to the presence of electric field as shown in the figure.

Let e and m indicates the charge and mass of the electron respectively. The electric field along the y -axis is $\frac{E_d}{d}$; therefore force acting on electron along the y -axis is given by $F = \frac{eE_d}{d}$ where d is the separation between the deflection plates. Due to this force F the electron will undergo an acceleration $\frac{eE_d}{dm}$ along y -axis and the electron will be deflected along y -axis. Let the deflection of the electron along y -axis be equal to D . We can write the expression of displacement along y -axis as,

$$y = \frac{1}{2} \left(\frac{eE_d}{dm} \right) t^2 \quad (1)$$

As the velocity along the x-direction is constant therefore we can write displacement along x-axis as,

$$x = v_{0x}t \quad (2)$$

where, v_{0x} is velocity of the electron along x-axis. From equations (1) and (2) we have,

$$y = \frac{1}{2} \left(\frac{eE_d}{dmv_{0x}^2} \right) x^2 \quad (3)$$

This is the equation of the trajectory of electron. The slope of the trajectory at the end of the plate of length l_d is calculated as

$$\tan \theta = \left. \frac{dy}{dx} \right|_{x=l_d} = \frac{eE_d l_d}{dmv_{0x}^2} \quad (4)$$

The tangent of the trajectory at the end of the plate intersect the x-axis at point O' . The point O' is located exactly at the middle at $x = \frac{l_d}{2}$ as

$$\frac{y}{\tan \theta} = \frac{\frac{1}{2} \left(\frac{eE_d}{dmv_{0x}^2} \right) x^2}{\frac{eE_d l_d}{dmv_{0x}^2}} = \frac{l_d}{2}$$

The deflection on the screen can be calculated as,

$$D = L \times \frac{dy}{dx} = L \frac{eE_d l_d}{dmv_{0x}^2} \quad (5)$$

The kinetic energy of the electron entering the area between the deflecting plates with an initial velocity v_{0x} is

$$\frac{1}{2} m v_{0x}^2 = eE_a \quad (6)$$

where E_a is the accelerating voltage in the electron gun. Thus we obtain

$$v_{0x}^2 = \frac{2eE_a}{m} \quad (7)$$

From equation (5) and (7) we can write

$$D = \frac{L l_d E_d}{2d E_a} \quad (8)$$

The *deflection sensitivity* S of a CRT is defined as the deflection in the screen (meters) per volt of deflection voltage.

$$S = \frac{D}{E_d} = \frac{L l_d}{2d E_a} \text{ (m/V)} \quad (9)$$

The *deflection factor* G of a CRT is defined as the reciprocal of the sensitivity S .

$$G = \frac{1}{S} = \frac{2d E_a}{L l_d} \text{ (V/m)} \quad (10)$$

4 Displaying a Voltage Waveform in CRO

For the visual display of voltage waveform on the CRT screen, a time-base generator is used. This time-base generator produces a saw-tooth voltage waveform. Each cycle of the saw-tooth voltage waveform consists of a slow linearly increasing voltage followed by a fast linearly decreasing voltage as shown in the Fig. 4. The time interval during which the voltage increases is referred to as the *sweep time* and the time interval during which the voltage decreases is referred to as the *flyback time* or *return time*.

The sawtooth voltage waveform is applied to the horizontal deflecting plates of the CRT.

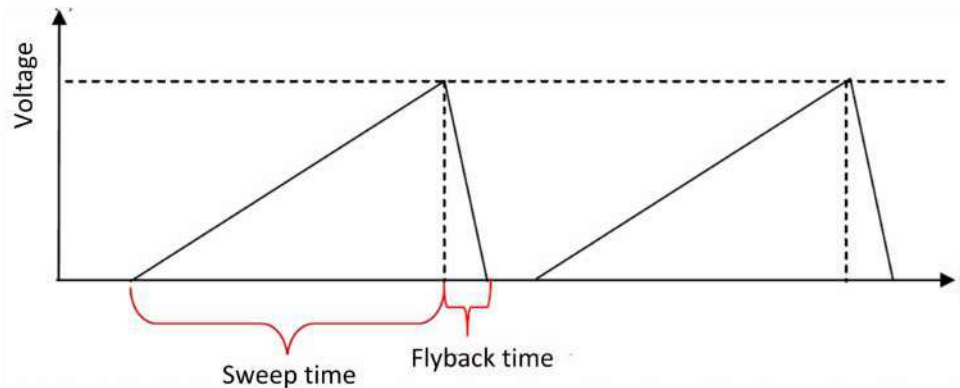


Figure 4: Sawtooth voltage waveform

As the sweep voltage increases linearly, the beam spot on the screen moves horizontally from left to right at a constant speed. During flyback time the beam spot quickly returns to the starting left position and the cycle is repeated.

The voltage to be displayed on the CRT screen is applied to the vertical deflection plates of the CRT. The vertical deflection of the beam spot is therefore proportional to this applied voltage. For example, the display of a sinusoidal voltage waveform is shown in Fig. 5. In order to obtain a stable waveform display on the CRT screen, the sawtooth signal should be applied to the horizontal deflection plates, in synchronism with the sinusoidal waveform being displayed. This is achieved by triggering each sweep at the exact point of the signal waveform. That's why a triggering circuit is used which generates a triggering pulse at the selected point of the input waveform which starts the sweep generator.

5 Applications of CRO

5.1 Measurement of voltage

The CRO has nearly infinite resistance (between the two-plates). Therefore it draws very little amount of current and shows the correct value of the voltages on the CRT screen. The CRO can be used to measure both dc and ac voltages.

5.2 Measurement of Frequency

To measure the frequency of a periodic waveform one need to estimate the time-period. The time periods T for sinusoidal, triangular and square voltage waveforms are shown in

Fig. 6. To determine the frequency f , calculate the reciprocal of the time period i.e.

$$f = \frac{1}{T} \tag{11}$$

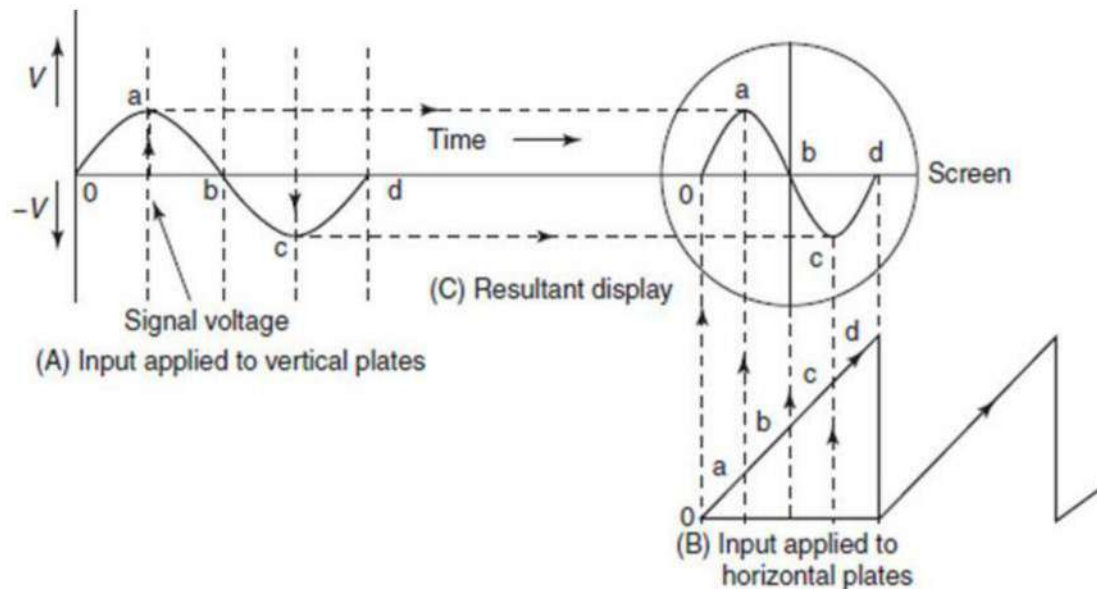


Figure 5: Display of sinusoidal waveform

There is an alternative way to measure the frequency in a CRO using **Lissajous figure**. Lissajous figure is the pattern produced in the CRT screen when two sinusoidal voltages are applied to the vertical and horizontal plates respectively. Let f_v and f_h be the frequencies of those two voltages respectively. The frequency f_h is generally known and f_v is the unknown frequency. The pattern in the CRT stands still whenever the ratio of f_v and f_h are a rational number. The fractional relationship between the two frequencies is determined by counting the number of tangencies in the vertical and horizontal direction of the Lissajous pattern.

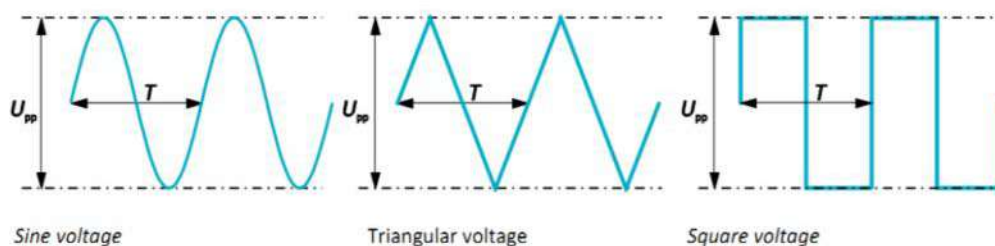


Figure 6: Time period for different waveform

$$\frac{f_v}{f_h} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}} \tag{12}$$

The frequency f_h can be adjusted to a suitable value so that the Lissajous pattern is stable. Then the frequency f_v can be calculated using equation (12). The Lissajous figures for different frequencies f_v and f_h are depicted in Fig. 7

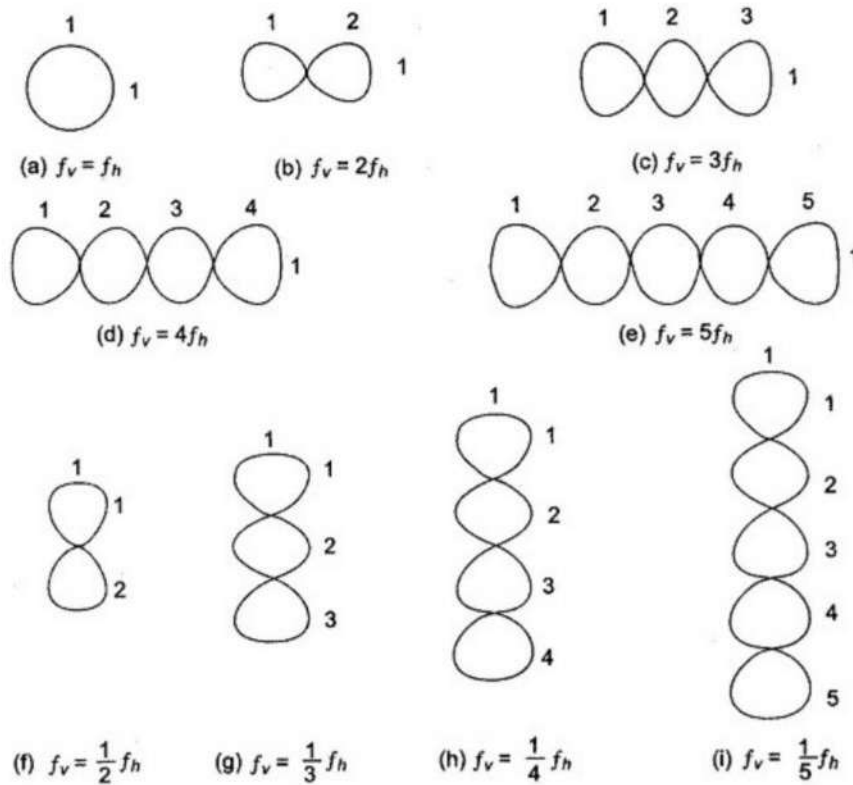


Figure 7: Lissajous figure for different frequencies f_v and f_h

5.3 Measurement of Phase

A dual-trace CRO is generally used to determine the phase shift between two sinusoidal signals of same frequency. Both of the signals will appear in proper time perspective and the amount of time difference between the waveforms can be measured from the time scale of the CRT screen. If Δt is the time difference between the two waveforms and T is the time period for both the signals, then the phase difference between the waveforms can be measured as

$$\Delta\theta = \frac{2\pi}{T} \Delta t \quad (13)$$

There is also an alternative method for measuring the phase using **Lissajous figure**. Let V_x and V_y be the two sinusoidal voltages of same frequency f (but with a phase difference θ) applied to the vertical and horizontal deflecting plates of the CRO respectively.

$$V_x = A \sin(2\pi ft) \quad (14)$$

$$V_y = A \sin(2\pi ft + \theta) \quad (15)$$

From equation (15) we can write

$$\begin{aligned} V_y &= A \sin(2\pi ft) \cos \theta + A \cos(2\pi ft) \sin \theta \\ &= A \sin(2\pi ft) \cos \theta + A \sqrt{1 - \sin^2(2\pi ft)} \sin \theta \\ &= V_x \cos \theta + \left(\sqrt{A^2 - V_x^2} \right) \sin \theta \end{aligned}$$

$$V_y - V_x \cos \theta = \left(\sqrt{A^2 - V_x^2} \right) \sin \theta$$

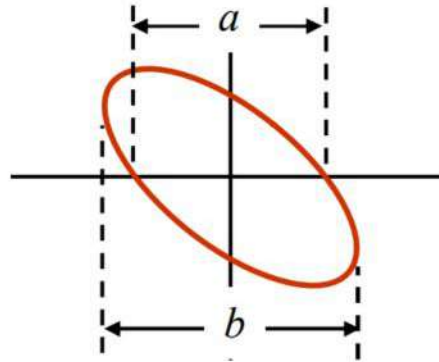


Figure 8: Ellipse represented by equation (16)

Taknig the square on both sides

$$V_x^2 + V_y^2 - 2V_x V_y \cos \theta = A^2 \sin^2 \theta \quad (16)$$

The equation (16) describes an ellipse as shown in the Fig. (8). After measuring the value of a and b as shown in the Figure (8), the phase difference can be calculated as

$$\theta = \sin^{-1} \left(\frac{a}{b} \right) \quad (17)$$

Depending on the value of the phase difference θ , the Lissajous figure can take different types of pattern.

1. If $\theta = 0^\circ$, $V_x = V_y$. In this case, the Lissajous figure is just a straight line with a slope angle of 45° .
2. If $\theta = 90^\circ$, equation (16) yields

$$V_x^2 + V_y^2 = A^2$$

Thus in this case, the Lissajous figure is a circle of radius A .

3. If $\theta = 180^\circ$, $V_x = -V_y$. In this case, the Lissajous figure is a straight line with a slope angle of -45° .

6 Digital Storage Oscilloscope

In digital storage oscilloscope, the waveform to be displayed is first digitized and then stored in a digital memory. The digitized signal can be retrieved from the memory at any convenient time and can be displayed in the cathode ray tube by repeatedly scanning the stored waveform. The stored display can be displayed indefinitely as long as power is applied to the memory.

The block diagram of digital storage oscilloscope is shown in the Fig. 9. The input signal is applied to an attenuator and then to an amplifier known as vertical amplifier. The input signal, after passing through the vertical amplifier, is digitized by first passing it through a sample and hold circuit and then passing the sampled version of the signal to an analog-to-digital (A/D) converter. In order to ensure that no information is lost, the

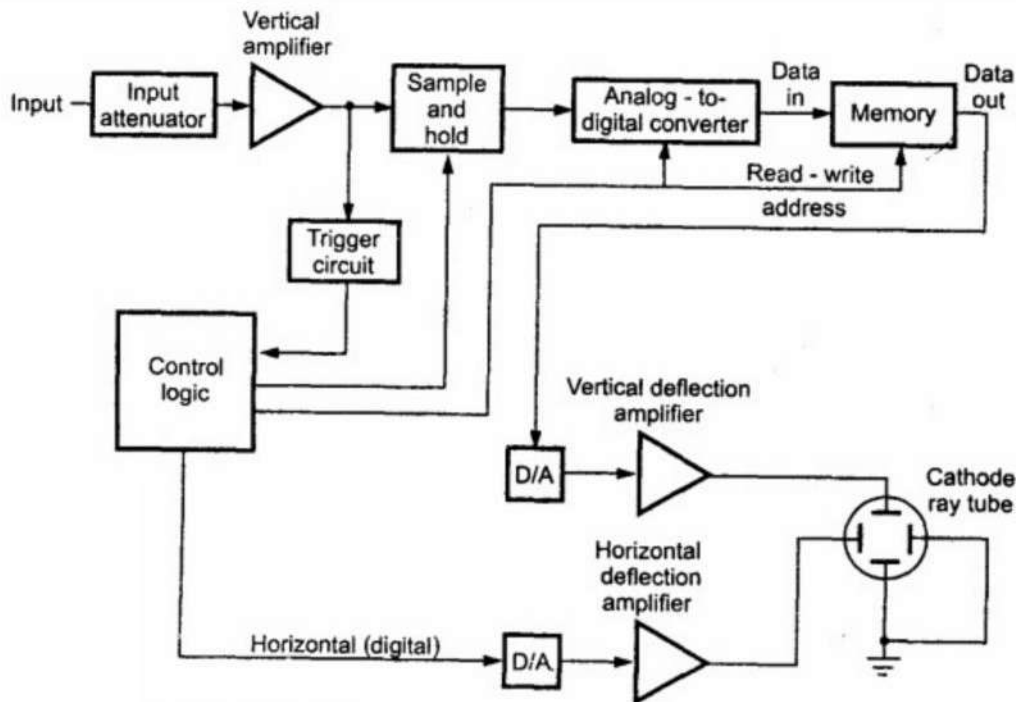


Figure 9: Block diagram of a digital storage oscilloscope

sampling rate must be at least twice as fast as the highest frequency in input signal. If this is not done then aliasing will result. The A/D converter outputs a digital data set for the corresponding signal which is then stored in a memory. In the storage oscilloscope application, the main requirement of the converter is speed. The ramp converter or dual-slope converter are too slow for the use in digital storage oscilloscope. The flash A/D converter is very useful in this case for its very fast speed. The digital data set is retrieved at a later time using a microprocessor which is first converted to analog signal by means of a digital-to-analog (D/A) converter and then sent to the vertical deflection plates of a CRT for display after proper amplification. A sawtooth waveform is applied to horizontal deflection plates of the CRT in synchronism with the input signal which is also retrieved from its digitized version stored in the memory.

FAQ

- **What is storage oscilloscope? What is its use?**

The conventional CRO can display the input signal in real time but cannot retain it much longer. Storage oscilloscope, on the other hand, can retain the display the input signal waveform much longer.

Storage oscilloscopes are used when it is necessary to store waveforms for visualization later. Storage oscilloscopes also provide the capability for display of a signal that would normally persist only for a very small fraction of a second and then disappear.

- **State briefly the principle of focusing of the electron beam in a CRO.**

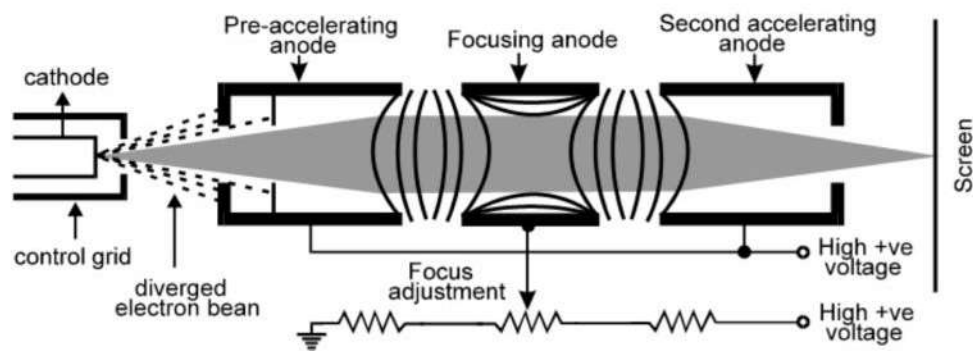


Figure 10: Electrostatic focusing system of a CRT

An electrostatic focusing system is shown in figure. If the accelerated electrons are allowed to simply travel towards the screen, they would simply diverge due to their mutual repulsion and produce a broad ill-defined spot on the screen. Therefore the electron beam is focused using an electrostatic lens so that the electron beam converges at the phosphor screen. In electrostatic focusing, electron lens consists of three cylindrical anodes: *pre-accelerating anode*, *focusing anode* and *second accelerating anode*. The focusing anode is at lower potential than the other two anodes.

Because of the potential difference between the any two consecutive electrodes, an electric field is generated between them. Spreading of electric field is caused because of repulsion between electric lines. If equipotential lines are drawn, as shown in Fig. 11, they would bulge at the centre of the two anodes. As we know that electrons move in a direction opposite to that of electric field lines and equipotential surfaces are perpendicular to the electric field lines; so force on the electrons is exerted in the direction normal to the equipotential surface. Electrons entering at the centre line of the two anodes experience no force but electrons displaced from the centre line experience a force normal to the direction of equipotential surface and get deflected (see Fig. 12).

Each junction between two cylinders contains equipotential lines which act as a converging lens in geometrical optics. The electron beam from the cathode passing

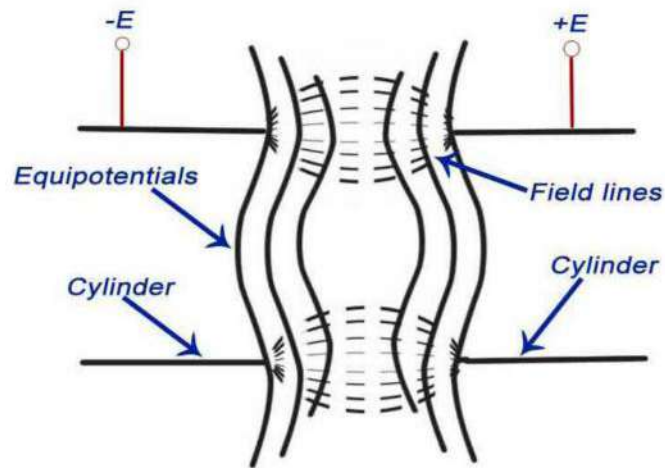


Figure 11: Equipotential surfaces for two cylindrical electrodes

through the first electrostatic lens tends to become more aligned towards the axis and after passing through the second lens will become more focused at the screen.

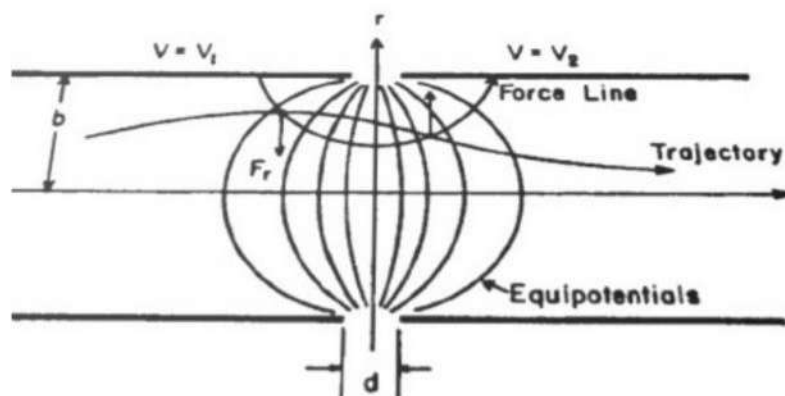


Figure 12: Trajectory of electron beam through electrostatic lens

- Determine how many cycles of a 2 kHz sinusoidal signal are viewed on the screen if the sweep frequency is 1 kHz.

Here the frequency of the sinusoidal signal waveform is twice the frequency of the sawtooth waveform. Hence the number of cycles of the sinusoidal signal that can be viewed on the CRO screen is 2.

- A Lissajous figure is produced on the screen of a CRO when sinusoidal voltages are applied to both the vertical and horizontal deflecting plates. The figure makes three tangencies with the horizontal and four tangencies with the vertical. If the frequency of the horizontal signal is 2 kHz, what is the frequency of the vertical signal?

Here,

$$\frac{f_v}{f_h} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}}$$

$$\Rightarrow \frac{f_v}{2 \text{ kHz}} = \frac{3}{4} \Rightarrow f_v = \frac{3}{4} \times 2 = 1.5 \text{ kHz}$$

- **A uniform electric field \vec{E} and a uniform magnetic field \vec{B} are produced simultaneously in the region between the plates of a CRO. An electron having the velocity \vec{v} enters the region. Write down the total force experienced by the electron. What must be the direction of \vec{v} , \vec{E} and \vec{B} so that the electron is not deflected by the field. Find the relation between \vec{v} , \vec{E} and \vec{B} under such situation.**

Consider the electron has a charge $-e$ moving with a velocity \vec{v} in the uniform electric and magnetic fields, \vec{E} and \vec{B} . The total force acting on the electron is given by the *Lorentz law*:

$$\vec{F} = -e \left(\vec{E} + \vec{v} \times \vec{B} \right) \quad (18)$$

If the motion of the electron should not deflect from its original direction then the direction of the magnetic field \vec{B} should be parallel or anti-parallel to the velocity vector \vec{v} and the direction of electric field \vec{E} should be anti-parallel to the velocity vector \vec{v} .

The relation between \vec{v} , \vec{E} and \vec{B} under such situation is given by

$$\vec{E} = -\vec{v}$$

$$\vec{v} \times \vec{B} = 0$$

- **Mention the advantages of an active probe over a passive probe.**

There are two main categories of oscilloscope probes: passive and active probes.

Passive probes are constructed of wires and connectors and when needed for compensation or attenuation, resistors and capacitors. There are no active components like transistors or amplifiers in the probe and thus no need to supply power to the probe. Passive voltage probes are available with various attenuation factors 1X, 10X, and 100X for different voltage ranges. Of these, the 10X passive voltage probe is the most commonly used probe. At higher frequencies, the standard passive probes become less effective. The effect of the capacitance rises and the bandwidth is limited (below 500 MHz).

Active probes contain active components such as transistors for their operation. Most often, the active device is a field-effect transistor (FET). The advantage of a FET input is that it provides a very low input capacitance, typically about 1 pF. Such low capacitance results in a high input impedance over a broader band of frequencies. As a result, active FET probes will typically have specified bandwidths ranging from 500 MHz to several GHz. In addition to higher bandwidth, the high input impedance of active FET probes allows measurements at test points of unknown impedance with much less risk of loading effects.

- **What is a dual beam and dual trace CRO?**

Sometimes it is necessary to view the behavior of two voltages simultaneously. This can be accomplished by using two oscilloscopes. However it is difficult to trigger the sweep of the two different oscilloscope exactly at the same time. Also two traces on two different oscilloscope makes the comparison difficult. The *dual beam CRO* provides an elegant solution to this problem, which contains a special cathode ray tube that has two separate electron guns generating two separate beams. Each

electron beam has its own vertical deflection plates, but the two beams are deflected horizontally by a common set of horizontal plate.

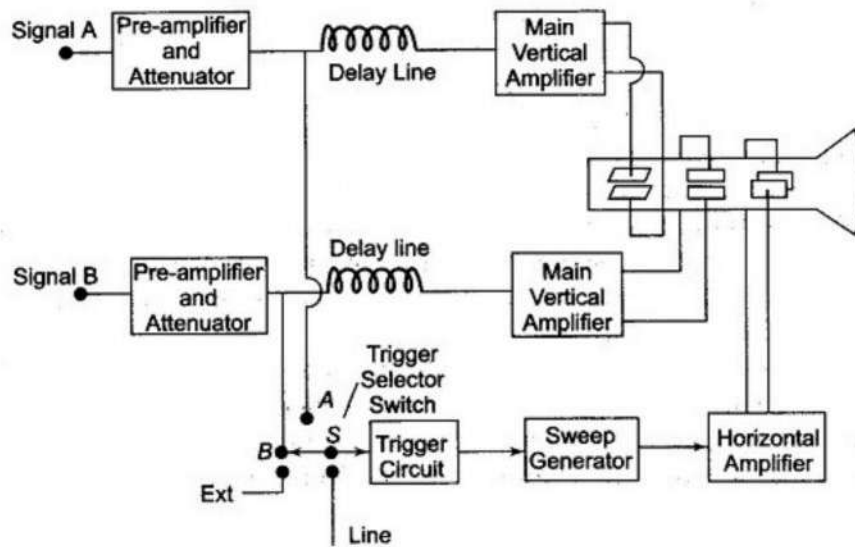


Figure 13: Block diagram of a dual beam CRO

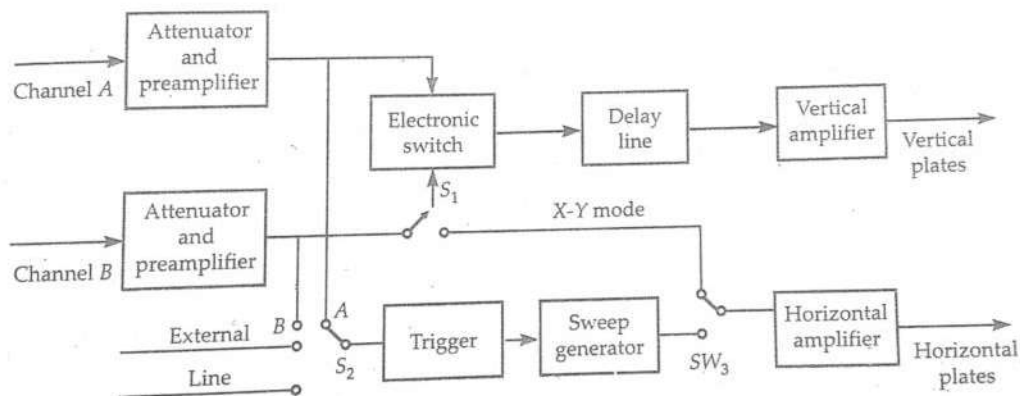


Figure 14: Block diagram of a dual trace CRO

As opposed to dual beam CRO, a more common and less costly method is to use a *dual trace oscilloscope*. In dual trace CRO, the same electron beam is used to generate the two traces that can be deflected from two independent vertical sources. An electronic switch is used which allow only one vertical channel signal to pass to the vertical amplifier and then to the vertical deflection plates at a time. This switching frequency should be much greater than the input signals so as to prevent the display being unrecognizable.

(Note: In X-Y mode of operation the input signal from channel A goes to the vertical deflection plates and input signal from channel B goes to the horizontal deflection plates, giving very accurate X-Y measurement.)

Reference

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2. <http://electronicspost.com/cathode-ray-oscilloscope-cro/>
3. <http://studytronics.weebly.com/cro.html>
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