

# UNIT 15

## CATHODE RAY OSCILLOSCOPE

Cathode ray oscilloscope is used to display the waveforms in various instruments used for scientific research, health monitors in medical treatment, radars used in aircraft traffic controls etc.

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### STUDY GUIDE

In the first semester Mechanics: Laboratory course (BPHCL-132) you got an opportunity to use the cathode ray oscilloscope (CRO), while studying the Lissajous figures. You must have got conversant with the main functional knobs on the CRO at that time. In this unit we will be discussing in details the construction and working of a CRO. You will also get to know the different types of CROs used in the laboratories.

You will be able to understand the mechanism used for tracing the waveform on the CRO screen, if you revise your knowledge about electron deflection in electric field from your school physics courses. You can use the knowledge gained in this unit to operate the CRO in your laboratory more effectively.

**“The oscilloscope provides the service technician with a “third eye” enabling him to see what is happening in the many electronic circuits with which he works.”**

***Paul Smith***

## 15.1 INTRODUCTION

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A Cathode Ray Oscilloscope, abbreviated as CRO and referred to as oscilloscope, in short, is now a basic, important and versatile instrument in every electronics and electrical engineering laboratory. In your laboratory courses you have learnt that voltmeters are used to measure the voltage signals. If that voltage is dc, that is not varying with time, then we get accurate measurement. If the signal is a pure sine wave, then ac voltmeter can be used to determine its root mean square value. However, we cannot measure its frequency with even the ac voltmeter. If the signals are more complicated (like a square wave, which contains many harmonics of sinusoidal signals), no voltmeter can give the proper reading of the voltage. To display and study a signal or a waveform of any simple or complicated type, we use CRO.

On a CRO, you can measure important characteristic of a signal like ac or dc voltage, period, frequency, phase relationships, indirect measurement of ac or dc current and a wide range of waveform evaluations such as rise time, fall time, ringing, and overshoot. On a CRO screen, a luminous spot enables us to study the instantaneous value of input voltage. For this reason, an oscilloscope can also be viewed as a plotter or a recorder.

In this unit we will familiarize you with CRO and functions of its various control knobs in Sec. 15.2. In Sec. 15.3 you will learn about the construction and working of the main work-horse of the oscilloscope – the Cathode Ray Tube (CRT). You will also understand how the trace of a signal is generated on the CRT screen and obtain the expression for its deflection sensitivity.

In Sec. 15.4 we describe the different subsystems of a CRO. Although most common CRO can trace a single waveform there are many advanced types of CROs that can trace two or more signals at a time of the screen. In Sec. 15.5 you will learn about some special types of CRO used in the laboratories.

In Sec. 15.6 you will learn the important applications of CRO to trace the waveform, measure the peak amplitude of the signal, measure the period and obtain the frequency of the signal. You will also learn to find the difference in phases of two sinusoidal signals.

### Expected Learning Outcomes

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After studying this unit, you should be able to:

- ❖ describe the major subsystems of a CRO;
- ❖ explain the mechanism of obtaining the trace on the CRT;
- ❖ familiarize with various controls on the front panel of the CRO;
- ❖ explain the basic functions of various controls;
- ❖ draw the block diagram of a CRO;

- ❖ explain the construction and working of a cathode ray tube (CRT);
- ❖ define the deflection sensitivity of CRT and obtain its expression;
- ❖ describe different types of laboratory oscilloscopes;
- ❖ explain the method to measure the peak-to-peak voltage and frequency of a time varying waveform; and
- ❖ measure the phase difference between two sinusoidal waveforms.

## 15.2 FAMILIARIZATION WITH CATHODE RAY OSCILLOSCOPE (CRO)

The cathode ray oscilloscope is probably the most versatile electrical measuring instrument available. To observe various signal parameters listed in the introduction, the CRO has to be properly set. There are many control knobs on the front panel of the CRO. You should get familiarized with these controls in order to make proper use of the CRO.

For proper operation of an oscilloscope, all the controls are mounted on the front panel. Fig.15.1 depicts the location of various controls on the front panel of a typical general purpose dual trace oscilloscope. In such a CRO, two signals can be viewed simultaneously on two separate channels. We may add here that the location of different controls can vary from one model of CRO to another.

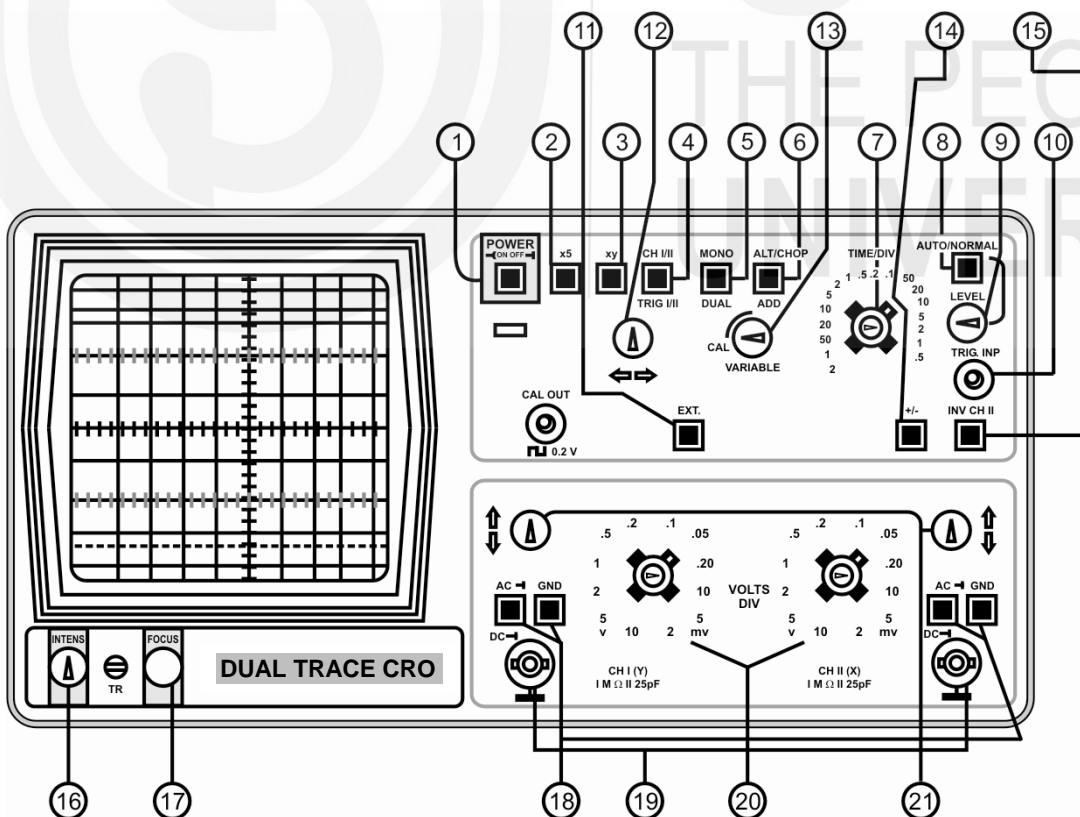


Fig.15.1: Schematic diagram of front panel of a typical general purpose CRO.

You must carefully read and understand the function of each control. Table 15.1 describes the function of each control shown in Fig. 15.1.

Table 15.1: Controls on CRO front panel

No.	CONTROL	FUNCTION
1.	Power	Turns mains power on/off.
2.	× 5	When pressed gives five times magnification of the signal.
3.	X-Y	It cuts off the time base fed to the horizontal plates when pressed and allows access to the horizontal signal fed through CH-II. It is used for X-Y display.
4.	CH-I/CH-II/Trig I/Trig II	It selects and triggers CH-I when it is out. On pressing it select and triggers CH-II.
5.	Mono/Dual	A switch to select the single/dual beam operation.
6.	Alt/Chop/Add	It selects alternate or chopped mode in DUAL trace operation. If "Add" is selected, it enables addition or subtraction of signals on two channels.
7.	Time/Div	It selects time base speeds.
8.	AUTO/NORM	AUTO mode enables trace when no signal is fed at the trigger input. In NORM position, the trigger level can be varied using LEVEL control.
9.	LEVEL	It allows setting of the trigger level between peak-to-peak amplitude of the input signal.
10.	TRIG IN	A socket that is used to feed external trigger signal in EXT mode.
11.	EXT	Switch that allows External triggering signal to be fed from the socket marked TRIG IN.
12.	X-POS	This knob controls the horizontal position of the beam trace.
13.	VAR	Controls the time base speed in between two steps of TIME/DIV switch.
14.	+/-	This switch selects the slope of triggering.
15.	INV CH.II	This switch when pressed inverts the signal at CH.II.
16.	INTENS	It controls the trace brightness.
17.	FOCUS	It controls the sharpness of the trace.
18.	DC/AC/GND	Coupling switch for each channel to choose AC or DC or ground.
19.	CH-I (Y) and CH-II (X)	BNC connectors serve as Y-input connections for CH-I and CH-II. CH-II input connector also serves as Horizontal external signal on using X-Y control.
20.	Volts/Div.	A switch to select the vertical sensitivity of each channel.
21.	Y-Pos I and II	These controls are provided for vertical deflection of trace for each channel.

## SAQ 1 – Controls on the CRO front panel

Which control will you use if

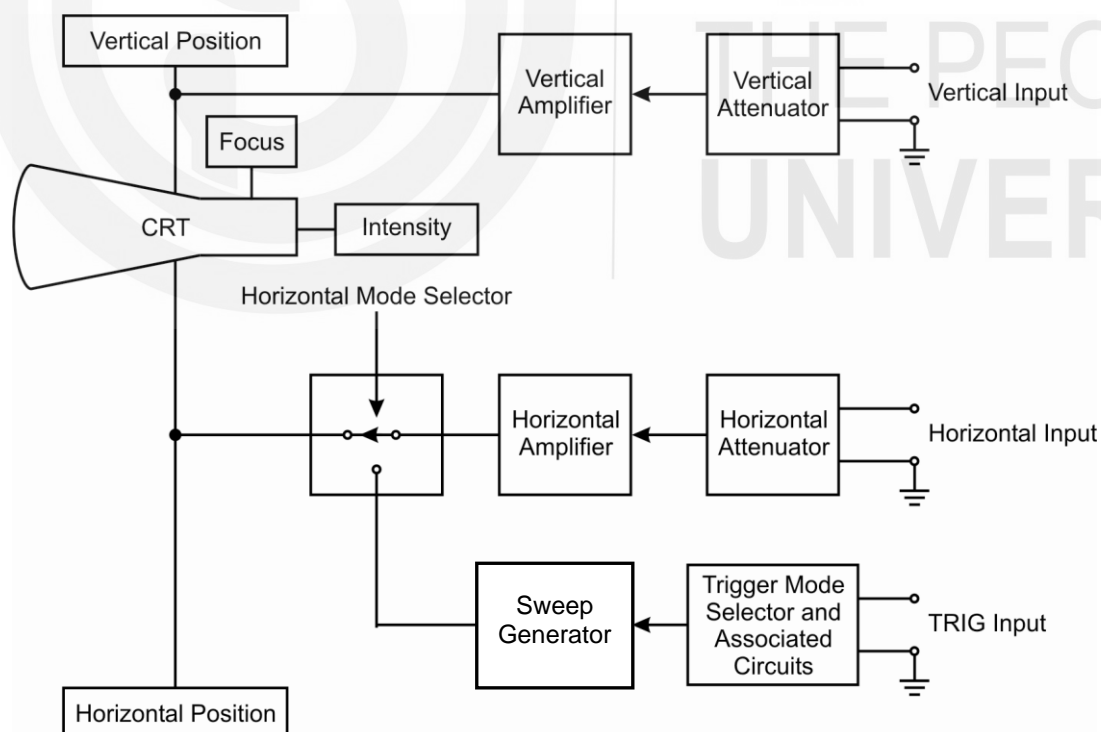
- the line being displayed on the screen is not sharp?
- the amplitude of the signal being displayed goes beyond the height of the CRO screen?
- you want to display two different signals simultaneously?

After getting familiarized with the functions of different controls of the CRO, we will now discuss about its construction and working.

The oscilloscope consists of the following major subsystems:

- Cathode ray tube or CRT
- Vertical amplifier
- Horizontal amplifier
- Sweep generator
- Trigger circuit
- Associated power supplies

The block diagram of a typical CRO is shown in Fig. 15.2.



**Fig.15.2: Block diagram of a general purpose CRO.**

The heart of the instrument is the cathode ray tube. The remaining subsystems are necessary for signal conditioning so that a visual representation of the input signal is done properly on the screen of the CRT.

## 15.3 CATHODE RAY TUBE (CRT)

The cathode ray tube used in an oscilloscope is very similar to the picture tube used in the old television sets. Let us first understand its components.

### 15.3.1 Construction of Cathode Ray Tube

A cross sectional representation of a CRT is shown in Fig. 15.3. The major components of a general purpose CRT are:

- Evacuated glass envelope
- Electron gun assembly
- Deflection plate assembly
- Phosphor coated fluorescent screen

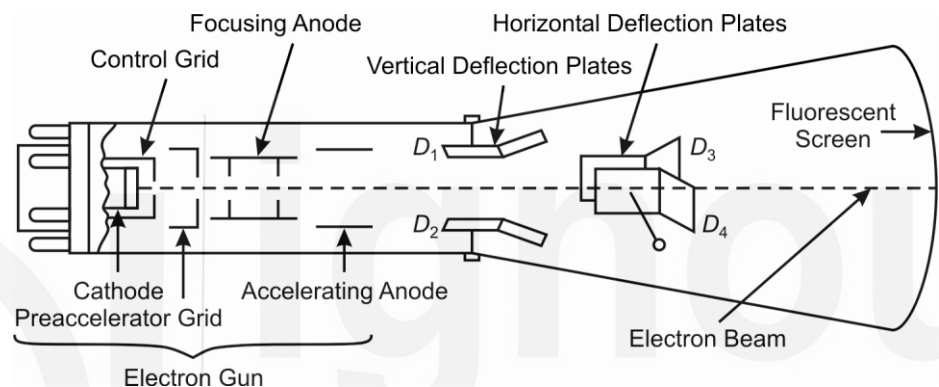


Fig. 15.3: Schematic of a cathode ray tube showing its major components.

The glass envelope is evacuated to a fairly high vacuum to permit the electron beam to traverse the tube easily. Most laboratory quality oscilloscopes use a CRT which has circular screen approximately 5 inch in diameter. All electrical connections except the high-voltage connection are made through the base of the CRT.

### 15.3.2 Generation of Electron Beam

The electron gun assembly consists of a heater to indirectly heat the cathode, a control grid, focussing anode and accelerating anode. The purpose of the electron gun assembly is to provide a source of electrons, converged and focussed into a well-defined beam, which is accelerated towards the fluorescent screen. The electrons that make up the beam are given off by thermionic emission from the heated cathode. The cathode is surrounded by a cylindrical cap that is at a negative potential. This acts as a control grid. Because the control grid is at negative potential, electrons are repelled away from the cylinder walls and, therefore, stream through the hole where they move into the electric field of the focussing and accelerating anodes. The magnitude of the accelerating field is given by

$$E = \frac{V_a}{d} \quad (15.1)$$

where,  $V_a$  is the accelerating anode voltage and  $d$  is the distance between the cathode and second anode measured in meters. When electrons enter the

electric field, which is assumed to be of uniform intensity, a force will be exerted on the electrons that will accelerate them along the axis of the tube. The magnitude of the force is given by

$$F = Eq = ma$$

$$\therefore a = \frac{Eq}{m} \quad (15.2)$$

where  $a$  is the acceleration produced due to the electric field.  $E$  is electric field intensity,  $q$  is electronic charge =  $1.6 \times 10^{-19}$  C and  $m$  is the mass of electron =  $9.1 \times 10^{-31}$  kg. Using the expression for electric field from Eq. (15.1) in Eq. (15.2) we obtain

$$a = \frac{V_a q}{dm} \quad (15.3)$$

During the period of acceleration, the electrons gain kinetic energy as they gain velocity. If  $v$  is the velocity acquired then,

$$\frac{1}{2} mv^2 = Fd = V_a q$$

which implies that,

$$v = \sqrt{\frac{2V_a q}{m}} \quad (15.4)$$

### 15.3.3 Deflection of Electrons in CRT

After the electrons leave the electron gun assembly at a speed given by Eq. (15.4), they enter and pass through a region controlled by the deflection plates. One pair of plates controls the vertical motion of the beam while the other pair controls the longitudinal components of the electron velocity. The deflection plates are described by two geometric parameters, the length ( $L$ ) of the plates and the plate separation ( $s$ ). The deflection action of the plates depends on the intensity of the electric field ( $E_d$ ) between the deflection plates given by

$$E_d = \frac{V_d}{s}$$

where  $V_d$  is the magnitude of the deflecting voltage. This field will exert a force  $F_d = E_d q$  on the electrons, deviating the beam from a straight line trajectory.

$$F_d = E_d q = \frac{V_d}{s} q = ma_y$$

$$\Rightarrow \text{Acceleration along } y\text{-axis, } a_y = \frac{V_d q}{ms} \quad (15.5)$$

It can be shown (refer to the margin remark) that the vertical distance travelled by electron is given by

$$h = \frac{V_d q t^2}{2sm} \quad (15.6)$$

where  $t$  is the time required for electron to pass through the plates, given by

$$t = \frac{L}{v}$$

We use the identity: distance travelled in time  $t$ ,

$$x = \frac{1}{2} at^2$$

where  $a$  is the acceleration.

Here  $v$  is the velocity of electron when it comes out of electron gun assembly given by Eq. (15.4) and  $L$  is the length of the deflection plate.

Combining Eqs. (15.6) and (15.4), we get

$$h = \frac{L^2 V_d}{4V_a s} \quad (15.7)$$

Fig. 15.4 shows the deflection geometry of the CRT.

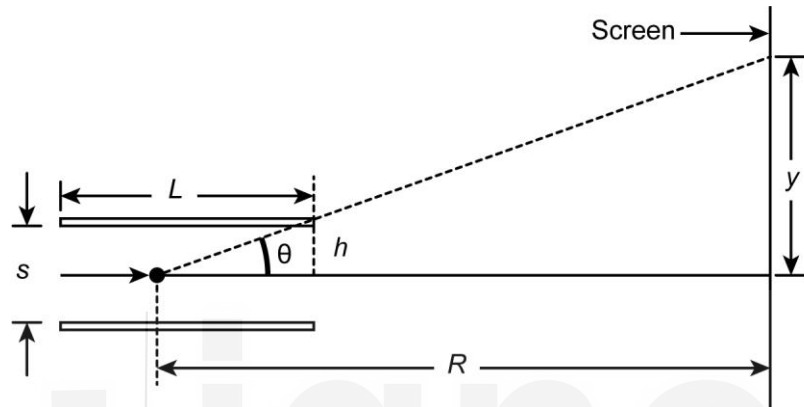


Fig. 15.4: Deflection of electron beam in CRT.

Using small angle approximation ( $\sin \theta \approx \theta$ ) from Fig. 15.4 we can write,

$$\begin{aligned} \theta &= \frac{h}{L/2} = \frac{2h}{L} = \frac{y}{R} \\ \Rightarrow y &= \frac{2hR}{L} \\ &= \frac{RLV_d}{2V_a s} \\ \Rightarrow \frac{V_d}{y} &= \frac{2V_a s}{RL} \quad (15.8) \end{aligned}$$

The term  $\frac{V_d}{y}$  is referred to as **deflection sensitivity** and is defined as voltage required per unit deflection.

The deflection of the beam in CRT is obtained electrostatically. You should note that the potential applied across the horizontal plates  $D_1$  and  $D_2$  in Fig. 15.3 would deflect the beam vertically, whereas a potential applied to vertical plates  $D_3$  and  $D_4$  would deflect the beam horizontally. Further, you learnt that the magnitude of the deflection is proportional to the voltage applied across the horizontal/vertical plates. In a CRT, with display screen of about 10 cm, under ordinary conditions, a deflection of about 2.5 cm could be obtained for a potential of about 100V. Since the signals are well below 100V in a real situation, we need to amplify signals. Therefore, deflection amplifiers are provided for each pair of deflection plates.

When the electron beam strikes the phosphor-coated face of the CRT, a spot of light is produced due to “fluorescence” as phosphor is a fluorescent material such as ZnS. The high velocity electrons that strike the phosphor coated face of the CRT are either repelled by the collision or cause secondary emission of electrons to maintain electrical equilibrium of the screen. To provide return path to ground for these electrons, the inside surface of the CRT is coated with graphite called “aquadag”.

To understand the relationship between the applied deflection potential and resultant deflection of the beam, solve the following SAQ.

### SAQ 2 – Deflection of beam in CRT

In a CRT, the separation between the deflection plates is 6 mm, length of the plates is 3 cm, distance between the screen and the centre point of the deflection plates is 10 cm. If accelerating potential applied to anode is 1000V, the beam is deflected by 2 cm on the screen. What is the applied deflection voltage? Calculate the deflection sensitivity of the CRT.

#### 15.3.4 Obtaining a Trace on the CRT Screen

You may now like to understand, how a waveform is displayed on the CRO screen. Refer again to Fig. 15.4. For a dc-voltage applied to plates  $D_3$  and  $D_4$  (horizontal deflection plates), the spot on CRO screen will move either to the left or to the right, depending on whether  $D_3$  is at a lower or higher potential than  $D_4$ . In order to generate a straight line on CRO display screen, a linearly increasing voltage with time (called ramp waveform) is applied between  $D_3$  and  $D_4$ . This shifts the spot from extreme left to extreme right of the screen. If the voltage is brought to zero and again applied, the motion of electron beam (spot on the screen) may be repeated from left to right. Such a waveform is called a saw-tooth waveform, as shown in Fig. 15.5. If this process is repeated at a faster rate, you will see a straight line formed by the moving spot due to persistence of vision. An oscillator which generates such a voltage is called a saw-tooth oscillator or a sweep generator.

When a dc-voltage is applied to plates  $D_1$  and  $D_2$  (vertical deflection plates), you may see the spot moving up or down on the screen depending on the potential of  $D_1$  relative to  $D_2$ . If we apply a time varying waveform like sinusoidal, square, triangular etc. across the vertical deflection plates, it will also appear as a spot moving up and down on the screen. However, application of a saw-tooth waveform to the horizontal deflection plates gives rise to display along the time axis. Let us now understand how display evolves on time scale.

The time period of a saw-tooth wave of frequency 50 Hz, applied to the horizontal deflection plate (Fig. 15.5) is 20 ms. Suppose that it traces a line of length  $AB = 10$  cm on CRO screen, as shown in Fig. 15.6. Then at  $t = 0$ , the spot will be located at the point A. After 10 ms, it will be at the point C as the saw-tooth voltage increases to half of its peak value. After 15 ms, the spot will reach the point D such that AD is three fourth of the line AB. In this way, you



Fig. 15.5: Saw-tooth Waveform.

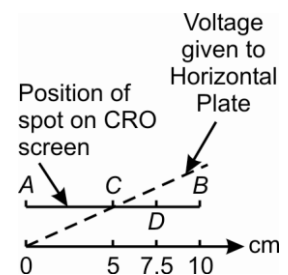
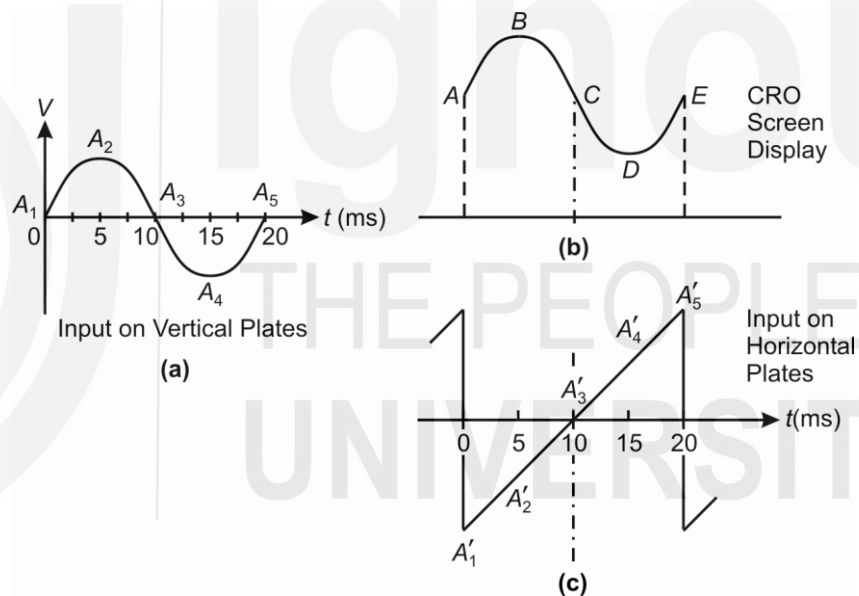


Fig. 15.6: Horizontal time base of CRO.

can calibrate line  $AB$  in time, i.e., half of it to 10 ms; quarter of it to 5 ms and so on.

Consider that a sinusoidal signal of frequency 50 Hz shown in Fig. 15.7a is applied to vertical deflection plates. At the same time we apply internally generated saw-tooth voltage of the same frequency across the horizontal deflection plates (Fig. 15.7c). The trace obtained on the CRO screen is shown in Fig. 15.7b. Note that at  $A_1$ , the sinusoidal wave has zero voltage and so there will be no deflection in the vertical direction. The horizontal input corresponds to the lowest voltage at  $A'_1$  and thus the spot moves to the extreme left point  $A$  on the screen. After 5 ms, the vertical input will correspond to  $A_2$ . This will move the spot upward. Since at the same time the horizontal input is less negative at  $A'_2$ , the spot moves rightwards as well. This results in the position  $B$  of the spot on the CRO screen. After 10 ms, the vertical and the horizontal inputs will correspond to points  $A_3$  and  $A'_3$ , respectively; the voltage will be zero. This leads the spot to move to point  $C$  on the screen. Continuing in the same way, we finally obtain the points  $A, B, C, D$  and  $E$  on the CRO screen corresponding to points  $A_1, A_2, A_3, A_4$  and  $A_5$  on the vertical input and  $A'_1, A'_2, A'_3, A'_4$  and  $A'_5$  on the horizontal input.



**Fig. 15.7: Display of 50 Hz sinusoidal wave on CRO: a) input to vertical deflection plates; b) trace on the CRO screen; c) input on the horizontal deflection plates.**

From the above discussion, you can conclude that for **an oscilloscope to display the variation of an electrical signal in the vertical direction as a function of time, a voltage varying linearly with time such as a saw-tooth wave will have to be applied on the horizontal deflection plates. The frequency of internally generated saw-tooth waveform can be selected by using the time base (time/div) control.**

To provide a stable trace, an additional feature in the form of a *trigger* is provided in the oscilloscopes. While using a trigger, the CRO pauses in each cycle when the sweep reaches extreme right side of the screen and retraces back to the left hand side of the screen. Then it waits for a specified event before starting the next trace. The trigger event is usually the input waveform

reaching some user-specified threshold voltage in a specified direction (going positive or negative).

Before proceeding further, solve an SAQ.

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### SAQ 3 – Choice of time base

If you wish to display a single cycle of 1 kHz sine wave signal on the entire 10cm width of CRO screen, plot the saw-tooth waveform given to the horizontal deflection plates (similar to Fig. 15.7c) with proper scale on the time axis.

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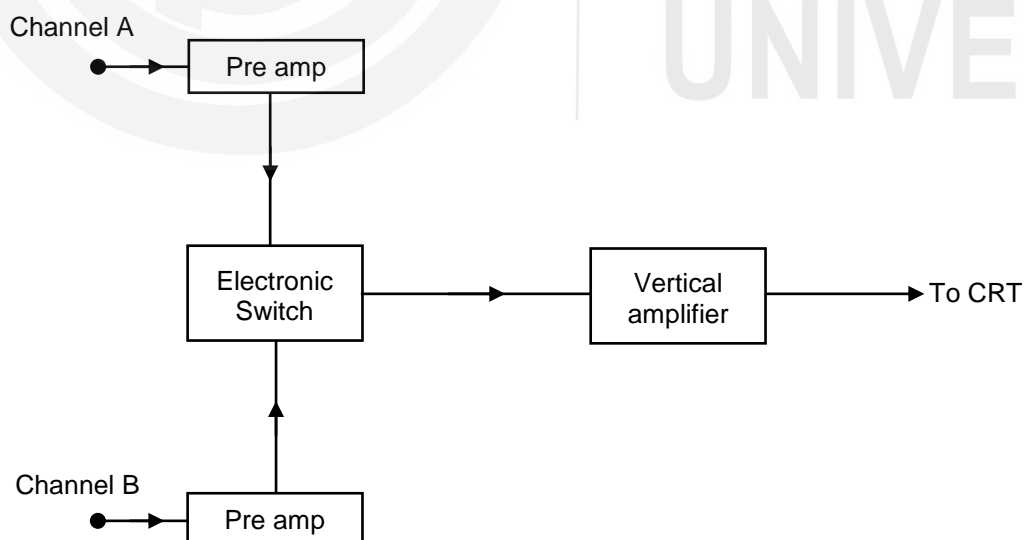
After getting acquainted with working of a typical CRO, we will now discuss about the types of CRO commonly used in the laboratories.

## 15.4 LABORATORY OSCILLOSCOPES

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### 15.4.1 Dual Trace Oscilloscope

A dual trace is obtained by electronically switching the single electron beam between two channels. Fig. 15.8 shows a block diagram of the two vertical input channels and the electronic switch that alternately connects the two input channels to the vertical amplifier. There are generally at least four modes of operation with dual trace oscilloscopes; they are labelled A, B, alternate (ALT), and chopped (CHOP). When set to A or B, only the input of that channel is displayed. In the alternate mode the inputs are displayed on alternate traces. Since the switching rate is synchronised with the sweep generator, switching occurs at the same rate as the output of the sweep generator. The “alternate mode” of operation is generally preferred when displaying relatively high-frequency signals.



**Fig. 15.8: Block diagram of the input channels of a dual trace oscilloscope.**

In the “chopped mode”, electronic switching occurs at a rate completely independent of the sweep rate, and therefore, each display has portions missing during which time the other signal is being displayed. The chopped mode is normally used at low sweep rates when the alternate mode would provide a display with appreciable flicker.

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### **15.4.2 Storage Oscilloscope**

There are many oscilloscope applications where the limited persistence of the CRT phosphor makes real time observation of one-time events nearly impossible. Although such events can be recorded photographically, this may prove to be fairly expensive and time consuming. The storage oscilloscope makes it possible to retain a CRT display for an extended period of time. The storage CRT uses two electron guns – the usual electron gun called a writing gun and a flood gun which uniformly bombards the entire CRT screen with low-energy electrons.

The storage is achieved due to secondary emission phenomenon. When the writing gun bombards electrons on the phosphor screen, alongwith causing a short duration illumination of the phosphor, the kinetic energy of the electrons knocks out some electrons from the screen, where the beam strikes. So this region of the screen has some net positive charge, in comparison with the other parts of the screen, where writing beam has not fallen.

Now, the low energy electrons coming from the flood gun are supposed to be uniformly covering the entire screen area. But, due to net positive charge left on the trace area of the screen by the writing gun, these low energy electrons get strongly attracted to this region, illuminating it further.

By properly tuning the energy of the flood gun electrons, it is possible to make every low energy electron falling on the positively charged region to eject one secondary electron. So this preserves the positive charge on the illuminated area, and the next low energy electron from the flood gun can keep the illumination process going on in the similar way for a longer time. Finally, the screen is erased by grounding the phosphor screen, which removes the excess charge.

### **15.4.3 Digital Oscilloscope**

The storage oscilloscopes described above are quite expensive and are now being replaced by digital oscilloscopes. In these oscilloscopes the signal being displayed is sampled and digitized. The amplitude and time base per cm are displayed in numbers at a corner of the screen. The digitized signal can be stored in a memory (like computer memory) and recalled (with the help of a digital-to-analog converter-DAC) to display whenever required. Thus, they also serve as storage oscilloscope.

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### ***SAQ 4* – Dual trace CRO**

Which mode of dual trace oscilloscope is preferred at high frequencies? Why?

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Now we will explain the procedures to measure various signal parameters using a CRO.

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## **15.5 APPLICATIONS OF CRO**

The range of applications of oscilloscope varies from basic voltage, time, frequency measurements and waveform observations to highly specialised applications in all areas of science, engineering and technology.

We now describe some basic measurements carried out with a CRO.

### 15.5.1 Measurement of Peak Voltage

You can use an oscilloscope to measure both dc and ac voltage. To measure dc voltage, you should first keep the DC/AC/GND switch in the ground (GND) position to establish the ground (0 V) level on the screen. Next you change the DC/AC/GND selector switch to DC position to measure the dc voltage level. When the dc voltage to be measured is applied to the channel input using the probes of the CRO, the horizontal trace line shifts in vertical direction. This deflection of the trace can be used to measure the dc voltage by using the relation

$$\text{dc voltage} = \text{vertical deflection of the trace (cm)} \times \text{vertical sensitivity (V/cm)}$$

To measure ac voltage, the DC/AC/GND switch is kept in the AC mode. On the screen the waveform corresponding to the input signal is observed. Now we measure the vertical distance between the maximum and minimum levels of the signal using the graduated scale on the screen, as shown in Fig. 15.9.

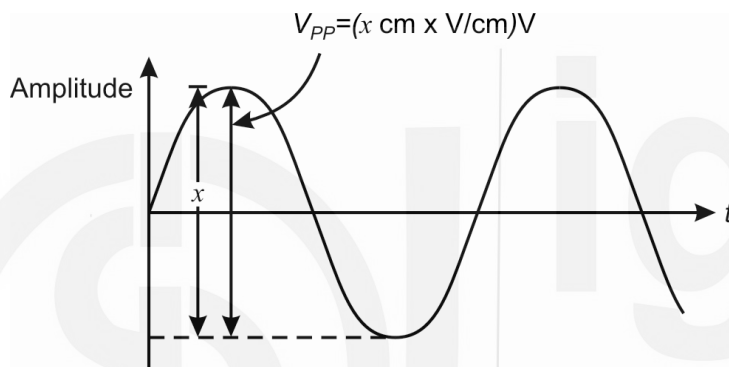


Fig. 15.9: Peak-to-peak voltage measurement for ac-signal using CRO.

By multiplying this distance (in cm) with the selected sensitivity (V/cm), we get the magnitude of peak-to-peak amplitude of the applied ac voltage ( $V_{PP}$ ). You can calculate the root mean square (rms) value of the voltage by dividing  $V_{PP}$  by  $\sqrt{2}$ .

This can be easily explained with the following Example.

#### **EXAMPLE 15.1: VOLTAGE MEASUREMENT USING CRO**

For the waveform shown in Fig. 15.9, the peak of the trace is at 1.5 cm on the oscilloscope screen. If the vertical sensitivity is set to 0.5 volts/div, find the peak-to-peak and rms amplitude of the signal.

#### **SOLUTION ■**

$$V_{PP} = \frac{\text{volts}}{\text{div}} \times \text{no. of div}$$

The peak-to-peak amplitude of the signal is 2 times the height of the maximum.

$$\begin{aligned} \text{Hence, } V_{PP} &= \frac{0.5 \text{ V}}{\text{div}} \times 3 \text{ div} \\ &= 1.5 \text{ V} \end{aligned}$$

$$V_{rms} = \frac{1.5 \text{ V}}{\sqrt{2}} = 1.06 \text{ V}$$

We now discuss how CRO can be used to measure frequency of an input signal obtained from an oscillator or a function generator.

### 15.5.2 Measurement of Frequency

To measure an unknown frequency, we have to essentially measure the period of the signal on the CRO screen. The period of the signal is the length of one cycle of signal on time (horizontal) axis in cm multiplied by the (time/div) setting. The frequency is given by the inverse of the period.

#### ***E*XAMPLE 15.2: FREQUENCY MEASUREMENT USING CRO**

Determine the frequency of the signal displayed on the CRO screen as shown in Fig.15.10.

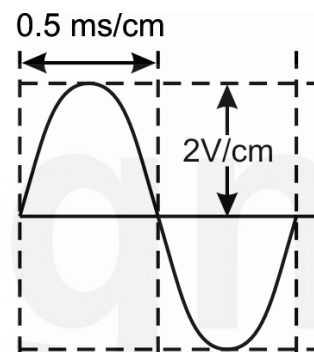


Fig. 15.10: Frequency of trace displayed on CRO screen.

#### **SOLUTION ■**

$$\text{Period} = \frac{\text{time}}{\text{div}} \times \text{no. of div}$$

The selected time/div is 0.5 ms/cm. One cycle of waveform is displayed over 2 divisions on the CRO screen.

$$\text{Hence, Period} = \frac{0.5 \text{ ms}}{\text{div}} \times 2 \text{ div} = 1 \text{ ms}$$

$$\begin{aligned} \text{Frequency} &= \frac{1}{\text{Period}} \\ &= \frac{1}{1 \text{ ms}} = 1 \text{ kHz} \end{aligned}$$

### 15.5.3 Measurement of Phase Difference

We can use an oscilloscope to determine the phase difference between two signals of same frequency by two methods:

- Direct measurement by comparing the two waveforms displayed simultaneously using a dual trace CRO; and
- Lissajous pattern method.

The first method is quite simple, and we will explain it now. You have already learnt (and used) the second method while doing the experiment on Lissajous Patterns in the first semester laboratory course entitled Mechanics: Laboratory (BPHCL-132).

### Dual Trace Method

This method of determining phase difference between two waveforms of same frequency and equal or different amplitudes is quite accurate. It involves displaying both the signals on the CRO screen simultaneously. The distances (in time scale divisions) between two identical points on two traces (Fig.15.11) are measured. Here we choose one signal as a reference, that is, with zero-phase angle. Therefore, the signal being compared is said to be leading by an angle  $\theta$  if it is to the left of the reference signal and lagging if it is to the right of the reference signal. The lead indicates positive value of phase while lag indicates negative value of phase.

To begin with, we obtain traces of both waveforms on the CRO screen, as shown in Fig. 15.11. For setting both patterns in the vertical centre of the display screen use AC switch.

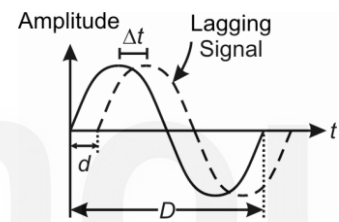
Then we calculate the scale factor that correlates the distance on the CRO time axis (horizontal axis) with the phase angle in degree. For this we measure the horizontal distance  $D$  (cm) required for one full cycle of either waveform and calculate the scale factor ( $S$ ) by using the relation

$$S = 360^\circ/D \quad (15.9)$$

Next, we measure the horizontal distance  $d$  (cm) between corresponding positive slopes of the two waveforms. The phase angle  $\theta$  between the two waveforms is therefore obtained by:

$$\theta = S \cdot d = \left(\frac{d}{D}\right) 360^\circ \quad (15.10)$$

For these measurements, you may select the mode of operation-ALT or CHOP depending on the frequency of the signals. If the frequency of the input signal is less than 50 kHz, use CHOP mode. ALT mode is selected for frequencies greater than 50 kHz.



**Fig.15.11: Phase difference measured on dual trace CRO.**

### SAQ 5 – Phase difference between waves

In Fig. 15.11, if  $D = 6$  cm and  $d = 3$  mm, calculate the phase difference between the waves.

Now, we will summarize the points discussed in this unit.

## 15.6 SUMMARY

CONCEPT	DESCRIPTION
<b>Cathode ray oscilloscope</b>	<ul style="list-style-type: none"> <li>■ Cathode ray oscilloscope comprises a cathode ray tube and allied electronic subsystems. On the screen of CRT waveform of input signal is displayed.</li> </ul>

- Time base** ■ Saw-tooth generator provides the horizontal sweep. Frequency of sweep generator sets the time/div (time base) scale.
- Types of CRO** ■ Laboratory oscilloscope can be classified into three categories: i) Dual trace oscilloscope, ii) Storage oscilloscope; iii) Digital oscilloscope.
- Applications** ■ Cathode ray oscilloscope is used for measurement of electrical parameters like, ac and dc voltage, time-phase relationship, frequency and for observing the shapes of various waveforms.

## 15.7 TERMINAL QUESTIONS

1. Explain the functions of main subsystems of a general purpose CRO.
2. Explain the two modes of operation of a dual trace CRO.
3. If the time/div control is set to  $2 \mu\text{s}/\text{div}$  and a single cycle of displayed signal covers 4 div on the horizontal scale of the CRT screen, determine the frequency of the signal.
4. Determine the peak-to-peak amplitude and frequency of the signal shown in Fig. 15.12. The screen width is 10 cm and height is 8 cm. The voltage sensitivity is  $2 \text{ V}/\text{cm}$  and time base is  $2 \text{ ms}/\text{cm}$ .

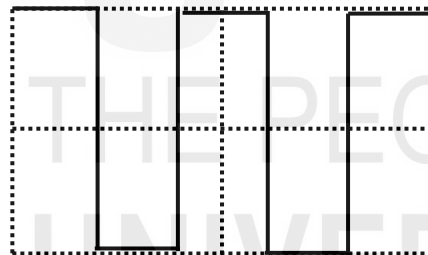


Fig. 15.12: Signal trace on a CRO screen.

## 15.8 SOLUTIONS AND ANSWERS

### Self-Assessment Questions

1. a) Focus                                      b) Volts / Div                                      c) Mono / Dual
2. We use Eq. (15.8). It is given that

$$V_a = 1000 \text{ V}, \quad s = 6 \text{ mm} = 0.6 \text{ cm}$$

$$R = 10 \text{ cm}, \quad L = 3 \text{ cm}, \quad y = 2 \text{ cm}$$

$$\therefore V_d = \frac{2V_a s y}{RL}$$

$$= \frac{2 \times 1000 \text{ V} \times 0.6 \text{ cm} \times 2 \text{ cm}}{10 \text{ cm} \times 3 \text{ cm}} = \frac{2400 \text{ V cm}^2}{30 \text{ cm}^2} = 80 \text{ V}$$

$$\text{Deflection sensitivity} = \frac{V_d}{y} = \frac{80 \text{ V}}{2 \text{ cm}} = 40 \text{ V cm}^{-1}$$

3. The saw-tooth waveform given to horizontal deflection plates is shown in Fig. 15.13.

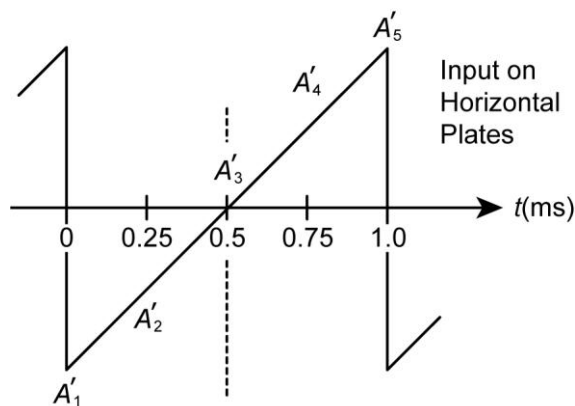


Fig. 15.13: Saw-tooth waveform for 1 kHz signal.

4. At high frequencies, the “alternate mode” of dual trace CRO is used. Since the sweep rates are higher, even when the two traces are traced alternately, due to persistence of vision of our eyes, both the channels can be seen simultaneously without any disturbance.
5.  $D = 6 \text{ cm}$ ,  $d = 3 \text{ mm} = 0.3 \text{ cm}$

Using Eq. (15.10), the phase difference is

$$\theta = \left( \frac{0.3}{6} \right) 360^\circ = 18^\circ$$

### Terminal Questions

1. The main subsystems of oscilloscope and their functions are as follows:
- **Cathode ray tube or CRT** – generates a beam of electrons and display the input waveform on the screen after necessary deflections.
  - **Vertical amplifier** – amplifies the input signal to be given to vertical deflection plates to an adequate level so that the beam can be deflected in vertical direction (representing the amplitude of the signal).
  - **Horizontal amplifier** – amplifies the signal from the sweep generator to be provided to the horizontal deflection plates.
  - **Sweep generator** – provides the saw-tooth waveform of selected frequency (by time/div time base control) to the horizontal deflection plates.
  - **Trigger circuit** – provides the starting signal for every horizontal sweep.

2. Refer to Sec.15.4.1.

$$3. \quad T = \frac{2\mu\text{s}}{\text{div}} \times \frac{4 \text{ div}}{\text{cycle}} = \frac{8\mu\text{s}}{\text{cycle}}$$

$$\therefore f = \frac{1}{T} = \frac{1}{8\mu\text{s}} = 125 \text{ kHz}$$

4. The amplitude of the waveform is covering entire 8 cm height of the screen. The sensitivity on vertical scale is 2 V/cm. Hence peak-to-peak amplitude of the signal is

$$V_{PP} = (2 \text{ V/cm}) \times 8 \text{ cm} = 16 \text{ V.}$$

The screen width is 10 cm. In this length, there are 2.5 cycles of the signal. Hence each cycle covers 4 cm length on the time axis. The selected time base is 2 ms/cm.

Hence, Period of the signal = (2 ms/cm) × 4 cm = 8 ms.

$$\text{Frequency} = \frac{1}{\text{Period}} = \frac{1}{8\text{ms}} = 125 \text{ Hz.}$$



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