INTRODUCTION

1) The cathode-ray oscilloscope (CRO) is a multipurpose display instrument used for the observation, measurement ,and analysis of waveforms.

2) A moving luminous spot over the screen displays the signal. CROs are used to study waveforms, and other time-varying phenomena from very low to very high frequencies.

3) The central unit of the oscilloscope is the Cathode-Ray Tube (CRT), and the remaining part of the CRO consists of the circuitry required to operate the cathode-ray tube.

Block diagram of a cathode-ray oscilloscope

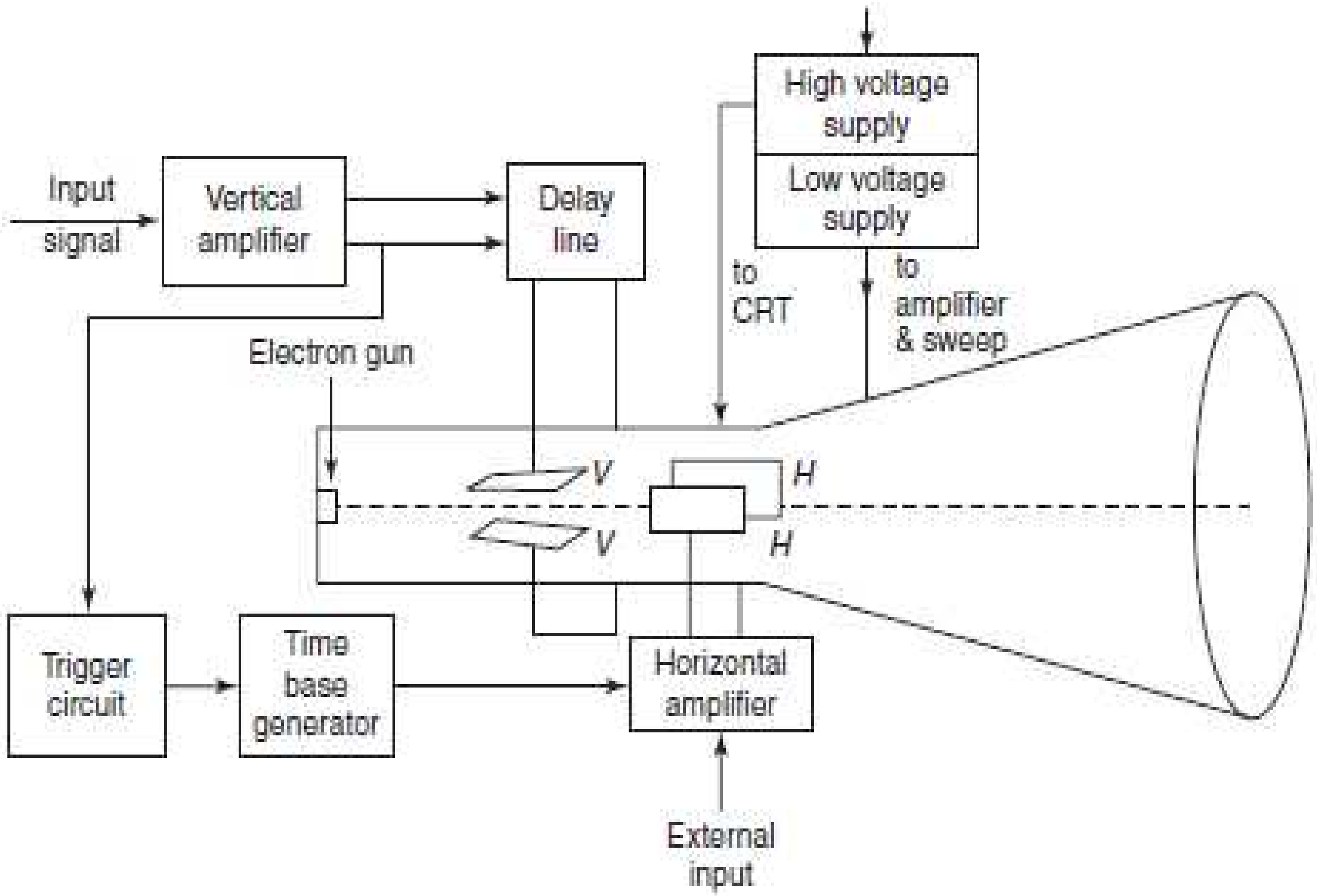


Figure 14-1 Block diagram of a cathode-ray oscilloscope

COMPONENTS OF THE CATHODE-RAY OSCILLOSCOPE

The CRO consists of the following:

- (i) CRT
- (ii) Vertical amplifier
- (iii) Horizontal amplifier
- (iv) Time-base generator
- (v) Triggering circuit
- (vi) Power supply

CATHODE-RAY TUBE

- The **electron gun or electron emitter**
- **The deflecting system and**
- **The fluorescent screen**

are the three major components of a general purpose CRT.

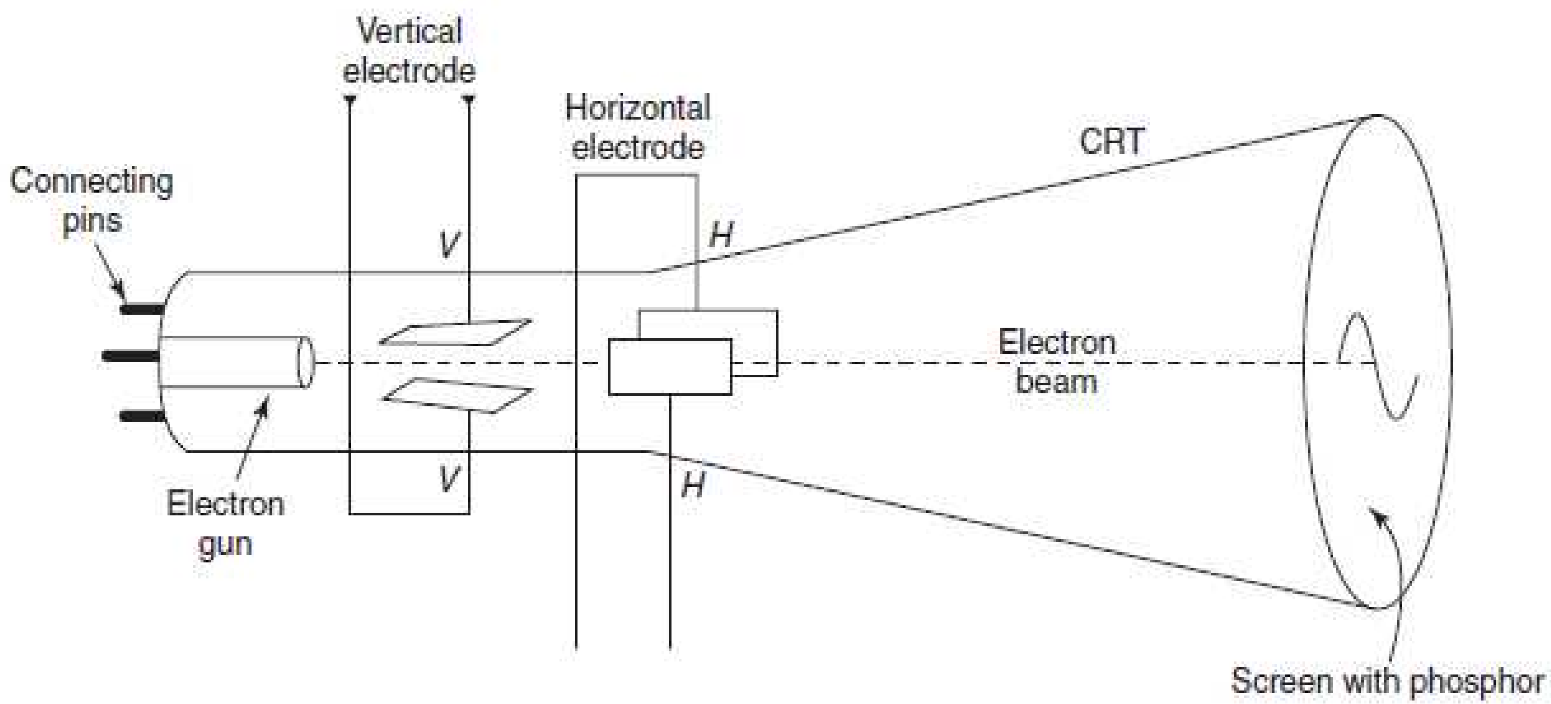
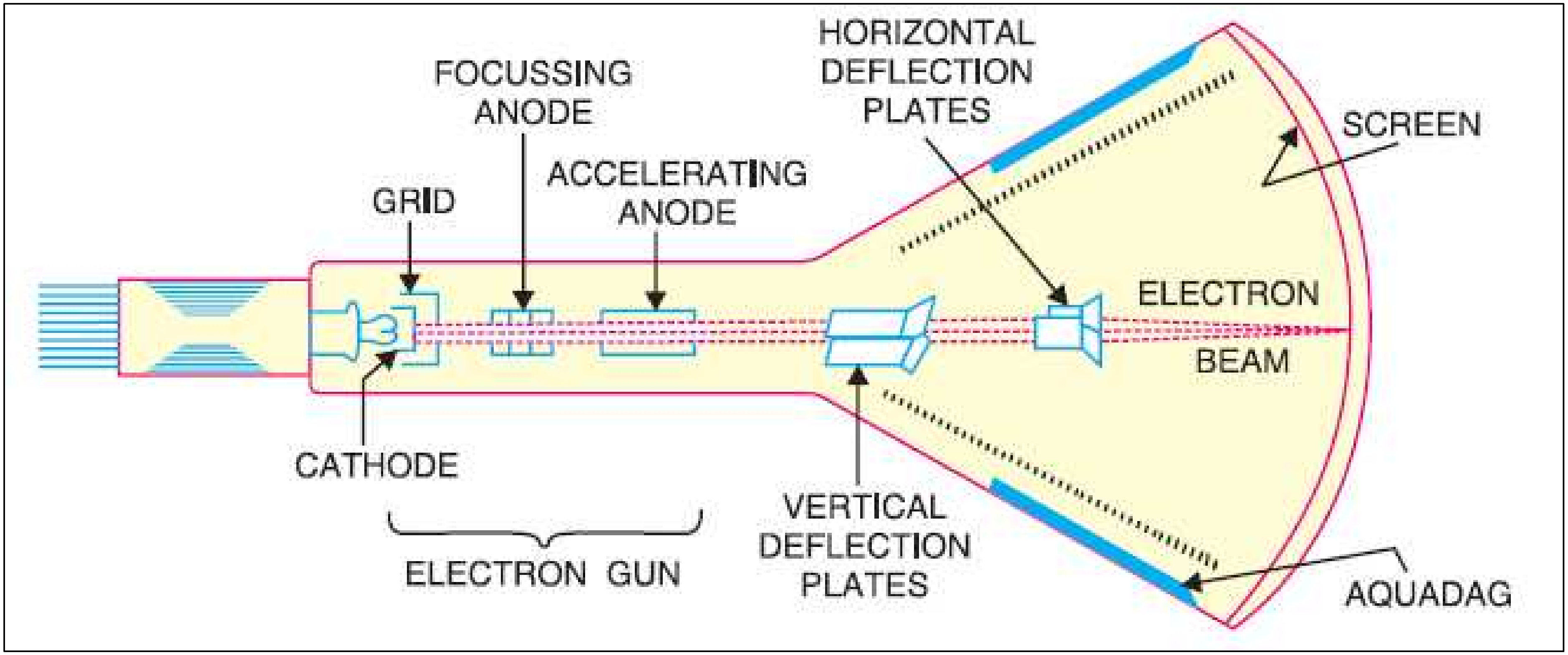


Figure 14-2 Components of a cathode-ray oscilloscope

Cathode Ray Tube



Electron Gun:

- The electron gun consists of **an indirectly heated cathode, a control grid, an accelerating anode and a focusing anode.**
- The electrodes are connected to the base pins. The cathode emitting the electrons is surrounded by a control grid with a fine hole at its centre.
- The accelerated electron beam passes through the fine hole.
- The negative voltage at the control grid controls the flow of electrons in the electron beam, and consequently, the brightness of the spot on the CRO screen is controlled.

Deflection Systems

- The deflecting system consists of a pair of horizontal and vertical deflecting plates.
- Let us consider two parallel vertical deflecting plates P1 and P2. The beam is focused at point O on the screen in the absence of a deflecting plate voltage.
- If a positive voltage is applied to plate P1 with respect to plate P2, the negatively charged electrons are attracted towards the positive plate P1, and these electrons will come to focus at point Y1 on the fluorescent screen.

Deflection Systems

The deflection is proportional to the deflecting voltage between the plates. If the polarity of the deflecting voltage is reversed, the spot appears at the point Y2, as shown in Fig. 14-3(a).

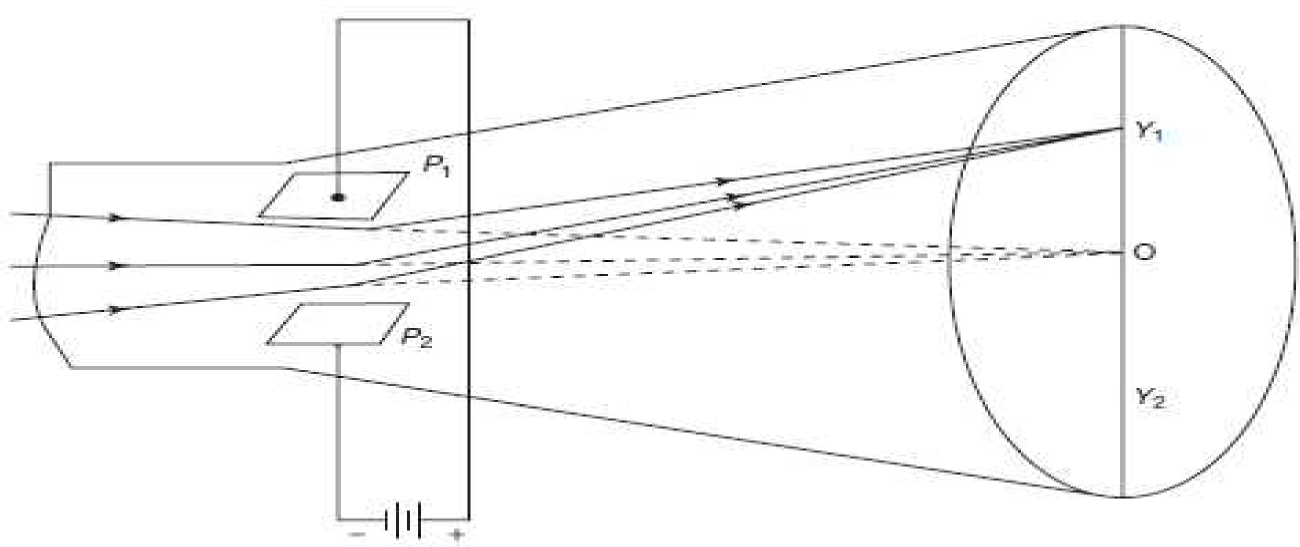


Figure 14-3(a) Deflecting system using parallel vertical plates

Deflection Systems

- To deflect the beam horizontally, voltage is applied to the horizontal deflecting plates and the spot on the screen horizontally, as shown in Fig. 14-3(b).
- The electrons will focus at point X2. By changing the polarity of voltage, the beam will focus at point X1. Thus, the horizontal movement is controlled along X1OX2 line.

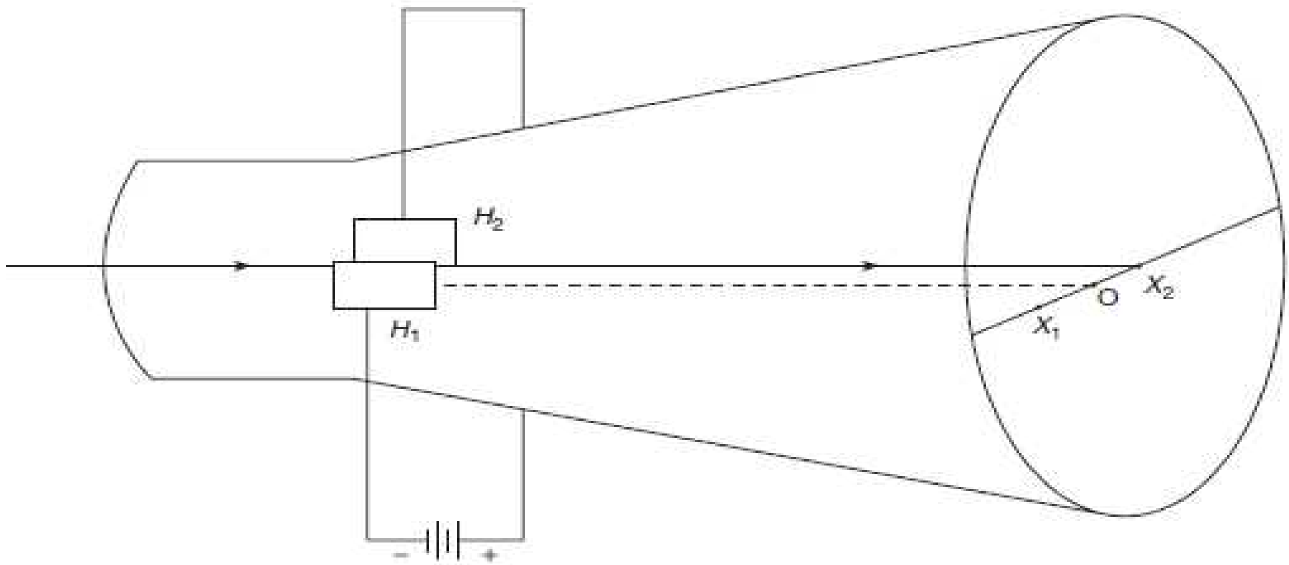


Figure 14-3(b) Deflecting system using parallel horizontal plate

Spot Beam Deflection Sensitivity:

The deflection sensitivity of a CRT is defined as the distance of the spot-beam deflection on the screen per unit voltage. If l_{total} is the total amount of deflection of the spot beam on the screen for the deflecting voltage V_d, as shown in Fig.14-4, the sensitivity can be expressed as:

$$S = \frac{l_{total}}{V_d} \tag{14-1}$$

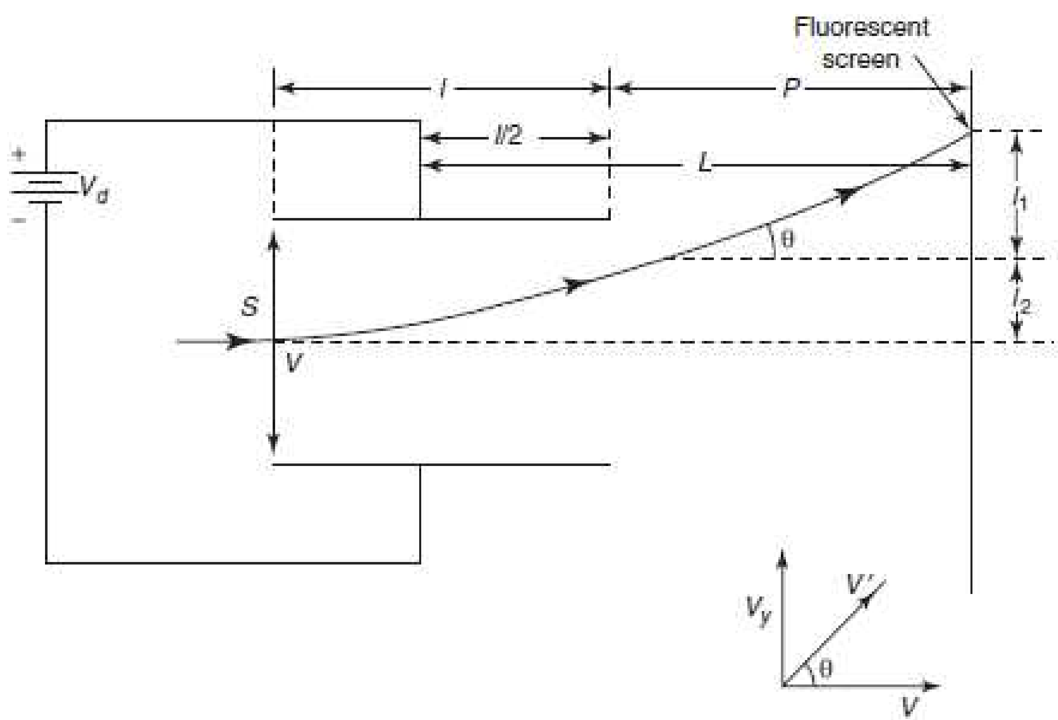


Figure 14-4 Schematic diagram of electrostatic deflection systems

Electrostatic Deflection:

Electrostatic Deflection

s = separation between deflecting plates

P = distance between the plate and screen S

l = length of each deflecting plate

V_d = deflecting voltage applied across the plates

m = mass of the electron

e = charge of the electron

v = velocity of the entering electron

V_a = accelerating anode voltage

Thus:

$$\frac{1}{2}mv^2 = eV_a \tag{14-2}$$

$$v^2 = \frac{2eV_a}{m} \tag{14-3}$$

Force exerted on the electron towards the positive deflecting plate is:

$$F.s = eV_d$$

$$F = \frac{eV_d}{s} \tag{14-4}$$

Electrostatic Deflection:

$$mf = \frac{eV_d}{s}$$

Hence, acceleration is:

$$f = \frac{eV_d}{ms} \qquad (14\text{-}5)$$

Time taken by the electron to move through the deflecting plates is:

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

Therefore, the upward velocity acquired by the emerging electron is:

$$v_y = ft$$

$$v_y = \frac{fl}{v}$$

$$v_y = \frac{fl}{v} = \frac{eV_d}{sm}\frac{l}{v} \qquad (14\text{-}6)$$

Electrostatic Deflection:

where, D is the distance traversed by an electron, u is the initial velocity, f is the acceleration of an electron, and t is the time taken.

As the electron is starting from rest, the initial velocity is zero, i.e., $u = 0$ and the distance travelled by the electron $D = l_2$.

Substituting this value of D in the expression for D, from the formula of mechanics, we get:

$$l_2 = \frac{1}{2} f t^2 \tag{14-7}$$

Substituting the value of t in Eq. (14-7) we get:

$$l_2 = \frac{1}{2} f (\tfrac{l}{v})^2 = \frac{eV_d}{2\,sm} (\tfrac{l}{v})^2 \tag{14-8}$$

$$\tan\theta = \frac{v_y}{v} = \frac{l_1}{P} \tag{14-9}$$

$$l_{total} = l_1 + l_2 = \frac{eV_d l}{smv^2} (\tfrac{l}{2} + P) \tag{14-10}$$

Here:

$$L = \left(\frac{l}{2} + P\right) \tag{14-11}$$

Electrostatic Deflection:

Substituting v^2 from Eq. (14-3) and L from Eq. (14-11) in Eq. (14-10) we have:

$$l_{\text{total}} = \frac{lLV_d}{2sV_a} \tag{14-12}$$

The deflection sensitivity of the CRT is, by definition:

$$S = \frac{l_{\text{total}}}{V_d} = \frac{lL}{2sV_a} \text{ m/V} \tag{14-13}$$

The deflection factor of the CRT is:

$$G = \frac{1}{S} = \frac{2sV_a}{lL} \text{ V/m} \tag{14-14}$$

Fluorescent Screen

- Phosphor is used as screen material on the inner surface of a CRT. Phosphor absorbs the energy of the incident electrons. The spot of light is produced on the screen where the electron beam hits.
- The bombarding electrons striking the screen, release secondary emission electrons. These electrons are collected or trapped by an aqueous solution of graphite called "Aquadag" which is connected to the second anode.
- Collection of the secondary electrons is necessary to keep the screen in a state of electrical equilibrium.
- The type of phosphor used, determines the color of the light spot. The brightest available phosphor isotope, P31, produces yellow–green light.

TIME-BASE GENERATORS:

- The CRO is used to display a waveform that varies as a function of time. If the wave form is to be accurately reproduced, the beam should have a constant horizontal velocity.
- As the beam velocity is a function of the deflecting voltage, the deflecting voltage must increase linearly with time.
- A voltage with such characteristics is called a ramp voltage. If the voltage decreases rapidly to zero—with the waveform repeatedly produced, as shown in Fig. 14-6—we observe a pattern which is generally called a saw-tooth waveform.

The time taken to return to its initial value is known as flyback or return time.

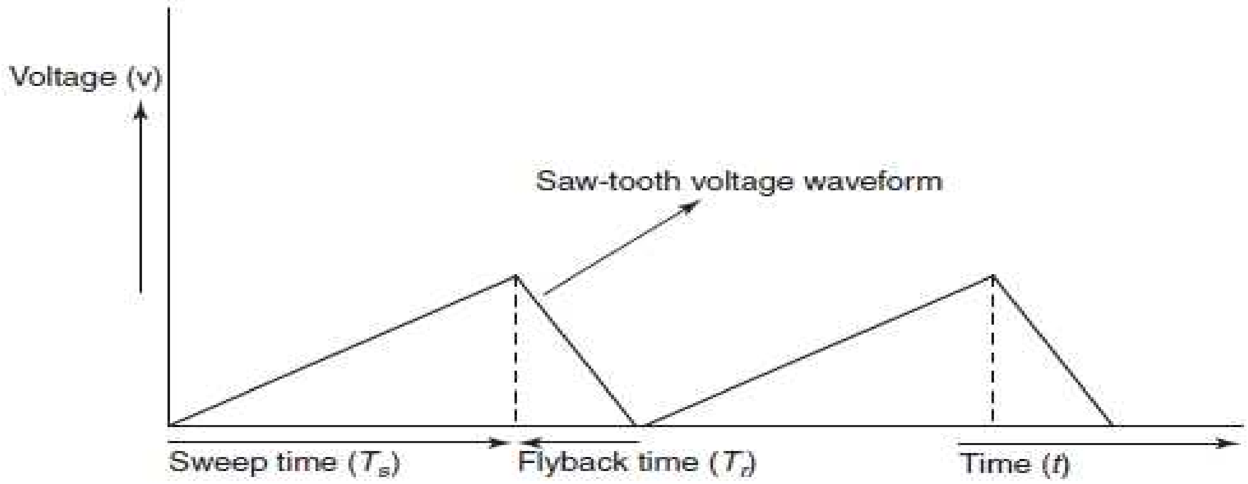
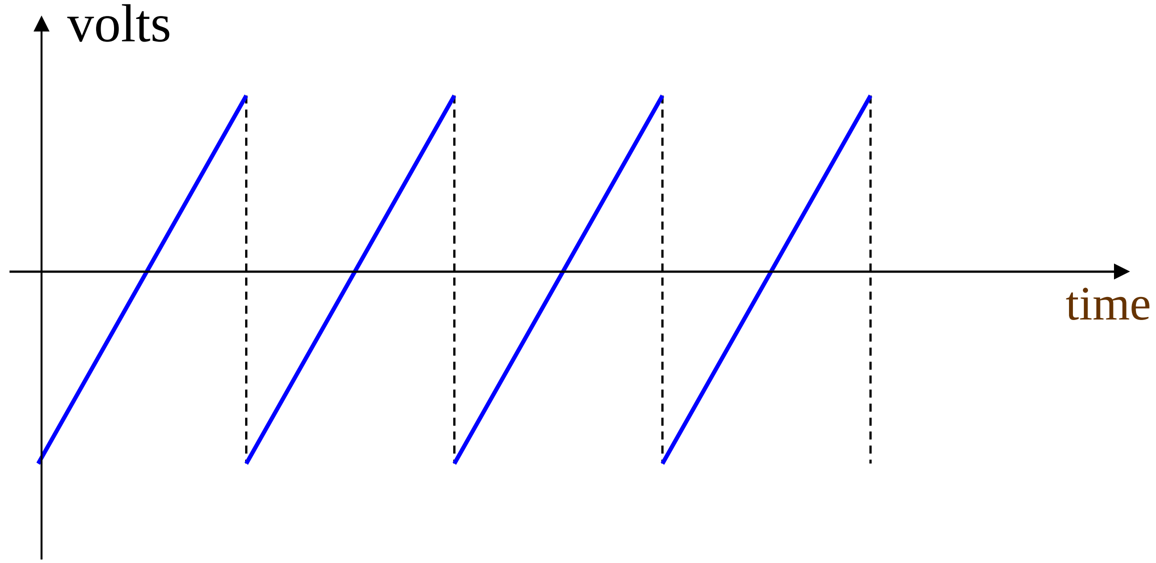


Figure 14-6 Typical saw-tooth waveform applied to the horizontal deflection plates

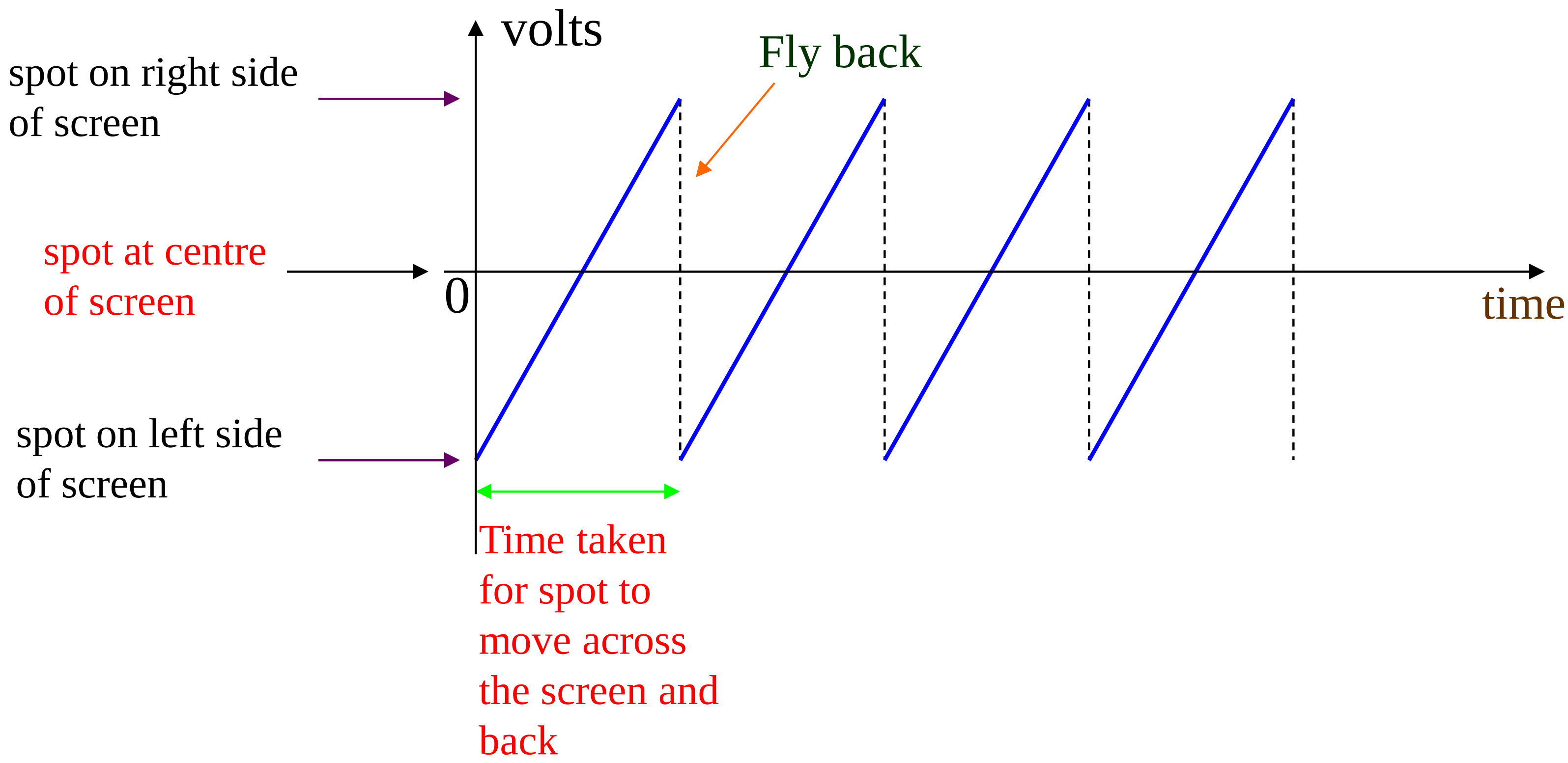
Time Base

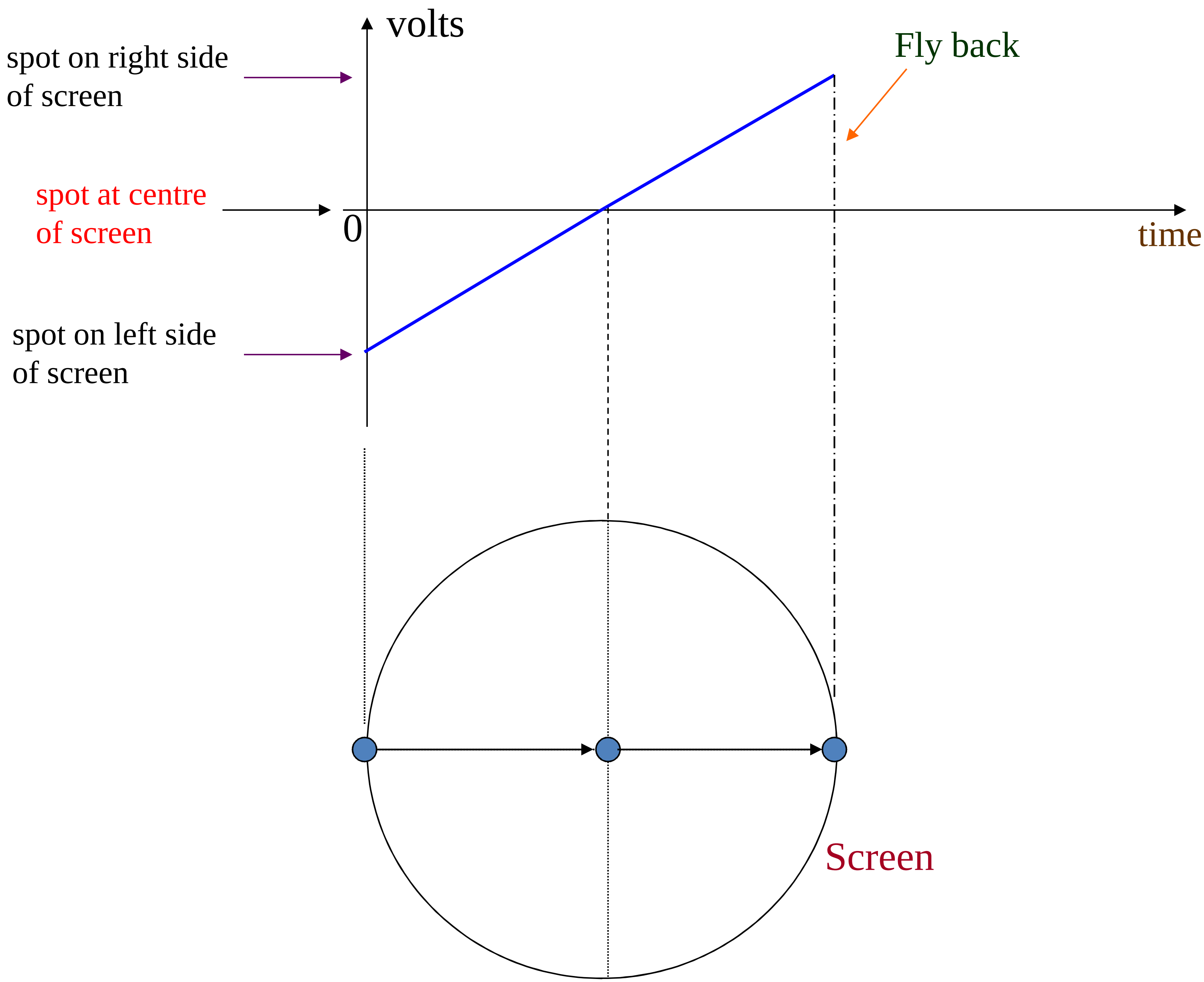
- is a ***saw-tooth*** voltage applied internally across the X-plates.



Time Base

- controls the speed at which the spot sweeps across the screen horizontally from left to right.

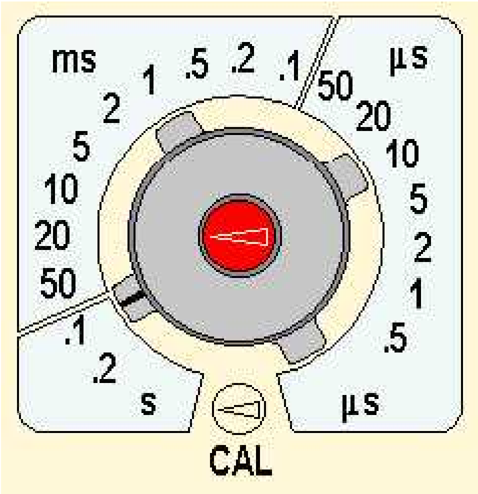




volts
Fly back
spot on right side of screen
spot at centre of screen
0
time
spot on left side of screen
Screen

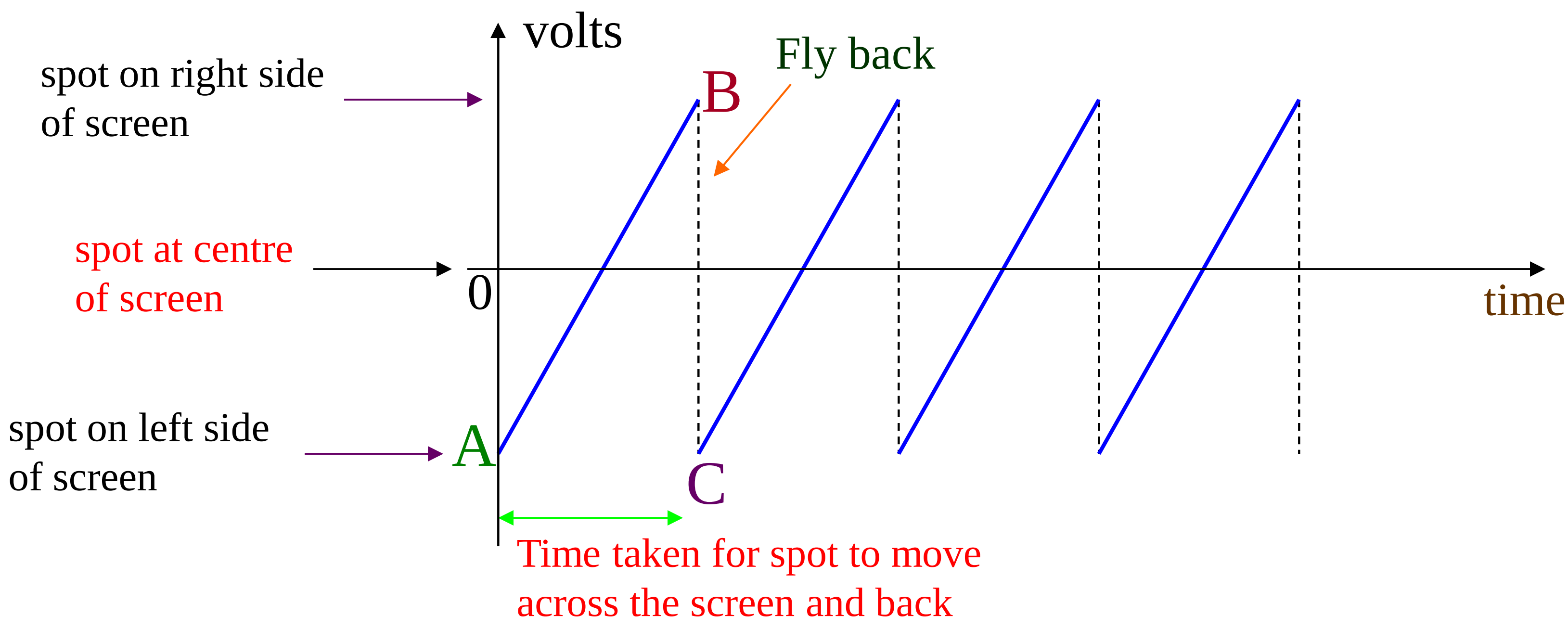
Time Base

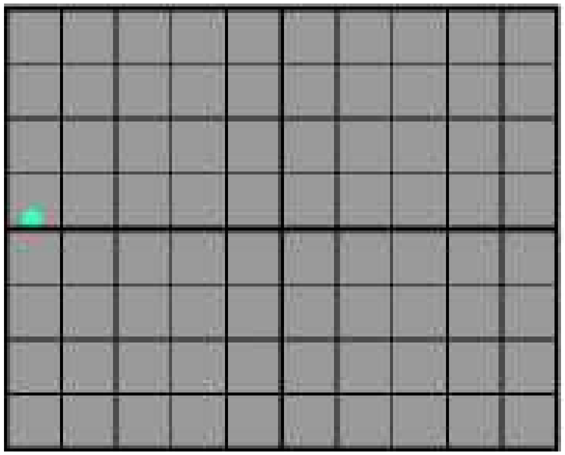
- it helps to display the actual waveform of any a.c. applied across the Y-plates
- normally calibrated in
  - s/cm
  - ms/cm
  - μs/cm

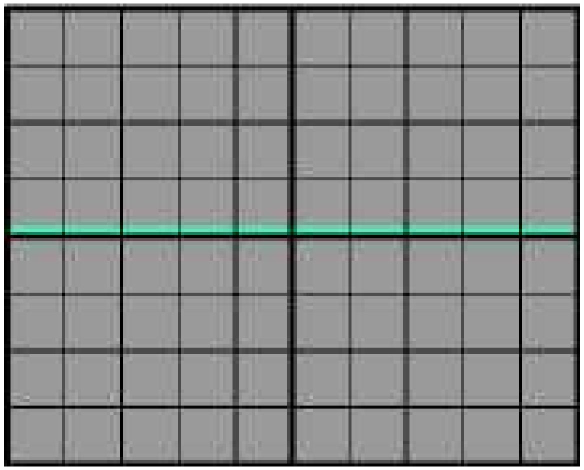


    - gives the time required for the spot to sweep 1 cm horizontally across the screen.

Time Base: How It Works







Triggering circuit

- The TRIGGER controls are used to maintain a steady trace on the screen.
- To display stationary wave pattern sweep voltage is synchronised with input signal
- SYNCRONISATION is the method of locking frequency of time base generator to the frequency of input signal.
- If not synchronised they are set wrongly you may see a trace drifting sideways, a confusing 'scribble' on the screen, or no trace at all!

- One of the method to achieve synchronisation is trigger circuit.
- In trigger circuit part of vertical amplifiers output is feed to trigger generator (fig.)
- The trigger generator produces a pulse of voltage which act as a start command to the time base generator and it starts one sweep cycle of the time base.

Vertical Amplifier

- Vertical amplifiers determines the sensitivity and bandwidth of an oscilloscope. Sensitivity, which is expressed in terms of V/cm.
- The gain of the vertical amplifier determines the smallest signal that the oscilloscope can satisfactorily measure by reproducing it on the CRT screen.
- The sensitivity of an oscilloscope is directly proportional to the gain of the vertical amplifier. So, as the gain increases the sensitivity also increases.

Horizontal Amplifier

- The sweep generator output can't drive horizontal plates, it must be initially amplified by horizontal amplifier.
- Voltage to horizontal plate can be applied by internal source (INT) or external source (EXT)
- When switch at EXT mode – plates disconnected from INT sources beam is stationary and spot at the center of screen.
- When switch at INT mode wave form will appear on screen.

Power supply

- Low voltage power supply
- It supplies power to
- 1) amplifiers 2) Trigger generator 3) Time base generator.
- This voltage of the order of few tens or hundreds of volts.
- High voltage power supply
- It supplies power to electrodes of electron gun
- It supplies voltage of 1600 – 2200 volts.

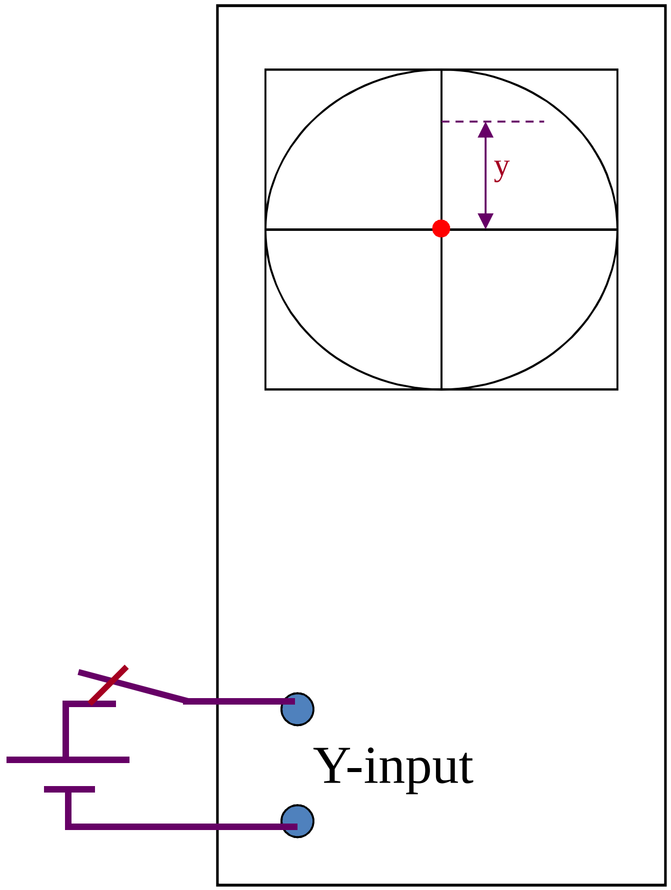
Uses of c.r.o.

- Measure potential difference
  - d.c.
  - a.c.
- Display waveforms of alternating p.d.
- Measure short intervals of time, and
- Compare frequencies

Measuring d.c. Potential Difference

- switch off the time-base
- a spot will be seen on the c.r.o. screen
- d.c. to be measured is applied to the Y-plates
- spot will either deflected upwards or downwards
- deflection of the spot is proportional to the d.c. voltage applied

Measuring d.c. Potential Difference



If the Y-gain control is set at 2 volts/division

And the vertical deflection, y, is 1.5

Then d.c. voltage

$$= 1.5 \times 2$$

$$= 3.0 \text{ V}$$

Measuring a.c. voltage

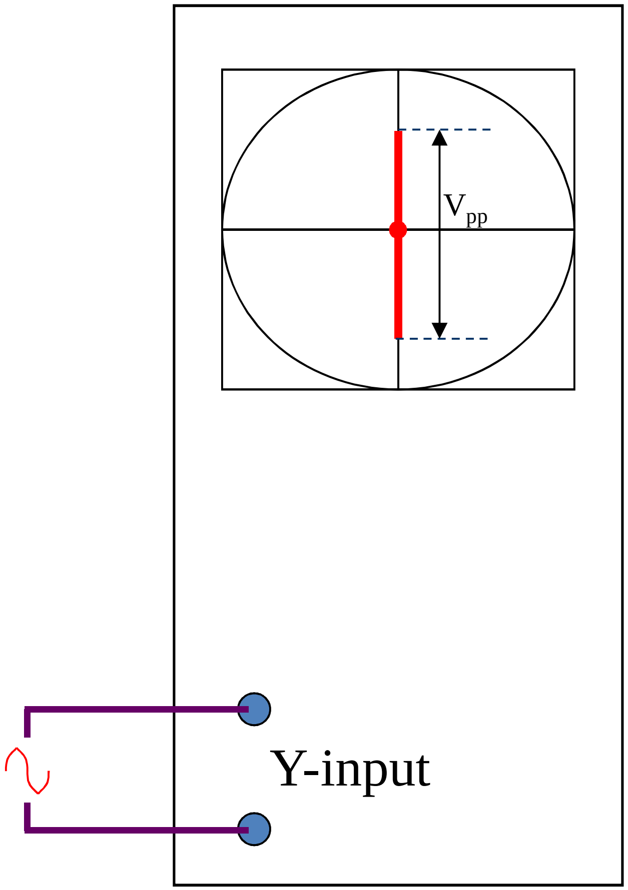
- switch off the time-base
- a spot will be seen on the c.r.o. screen
- a.c. to be measured is applied to the Y-plates
- spot will move up and down along the vertical axis at the same frequency as the alternating voltage
  - spot moves to the top when the voltage increases to its maximum (positive)
  - spot moves to the bottom when the voltage decreases to its lowest (negative)

Measuring a.c. voltage

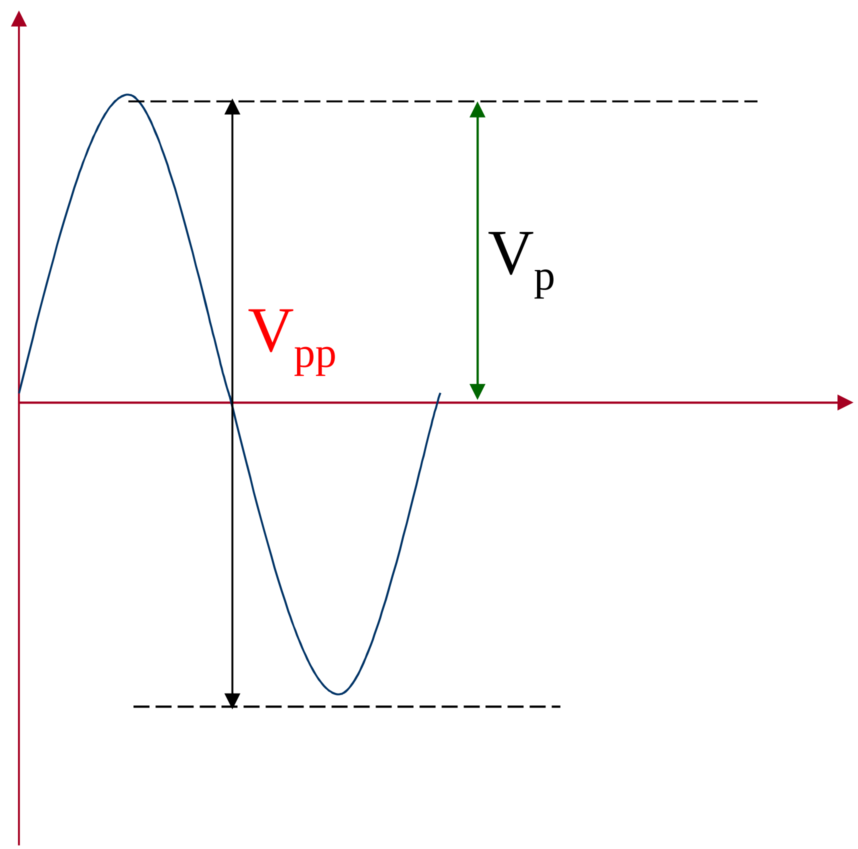
- When the frequency is high
  - the spot will move so fast that a vertical line is seen on the screen
- Length of the vertical line gives the peak-to-peak voltage (V_{pp}) applied to the Y-plate
- The peak voltage (V_p) is

$$= V_{pp}/2$$

Measuring a.c. voltage



Measuring a.c. voltage



$$V_p = V_{pp}/2$$

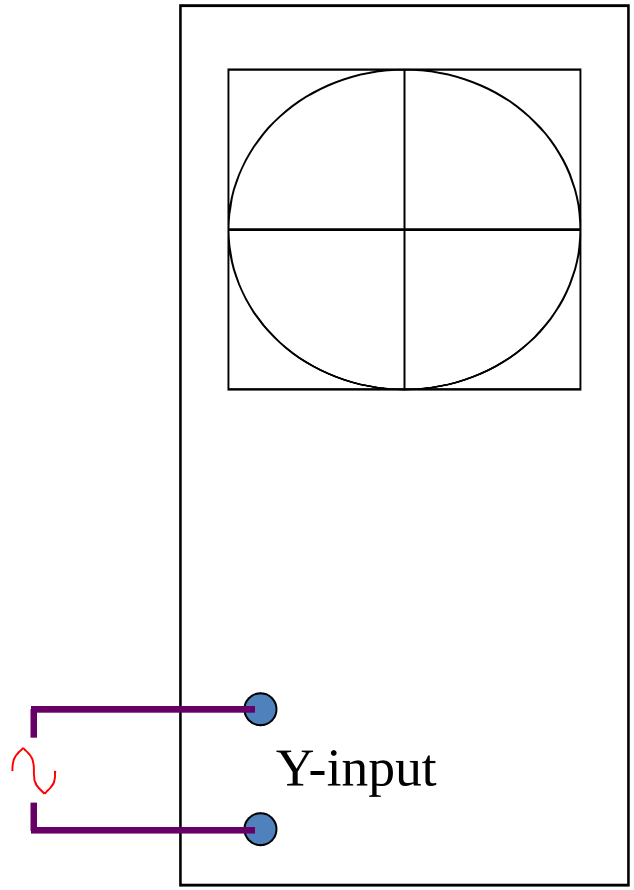
C.R.O. as a Voltmeter

- it has nearly infinite resistance (between the X- and Y-plates), therefore draws very little current;
- it can be used to measure both d.c. and a.c. voltages; and
- it has an immediate response.

Displaying Waveforms

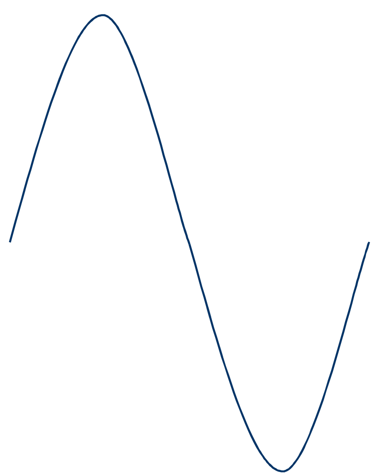
- Set the time-base to a suitable frequency,
- Apply the input to the Y-plate
  - a steady waveform of the input will be displayed on the c.r.o.

Displaying Waveforms

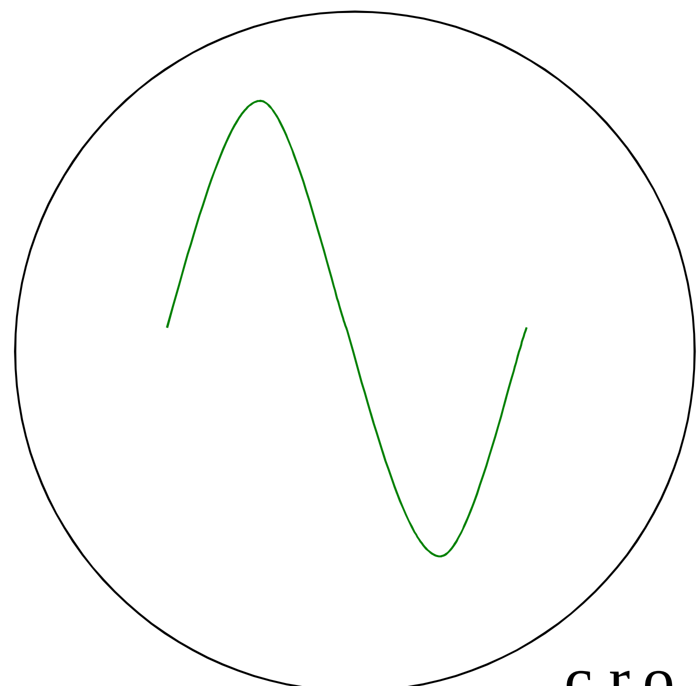


Displaying Waveforms

- When input voltage frequency is the **<u>same</u>** as the time-base frequency



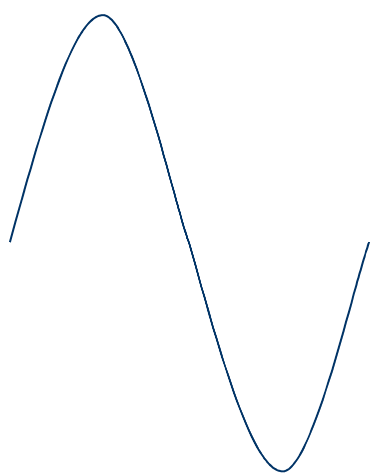
Input Voltage



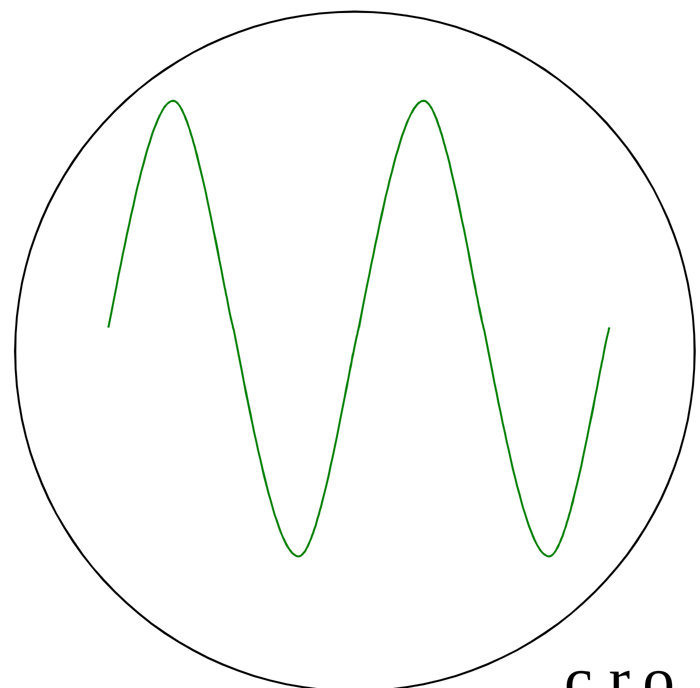
c.r.o. screen

Displaying Waveforms

- When input voltage frequency is the **twice** the time-base frequency



Input Voltage



c.r.o. screen

Measuring Short Time Intervals

- Set time-base to its lowest frequency range
- Connect microphone to the Y-input
- Blow two short whistles into the microphone
  - two short pulses, at short interval apart will be displayed on the c.r.o. screen

Measuring Short Time Intervals

If the time-base is 10 ms/division

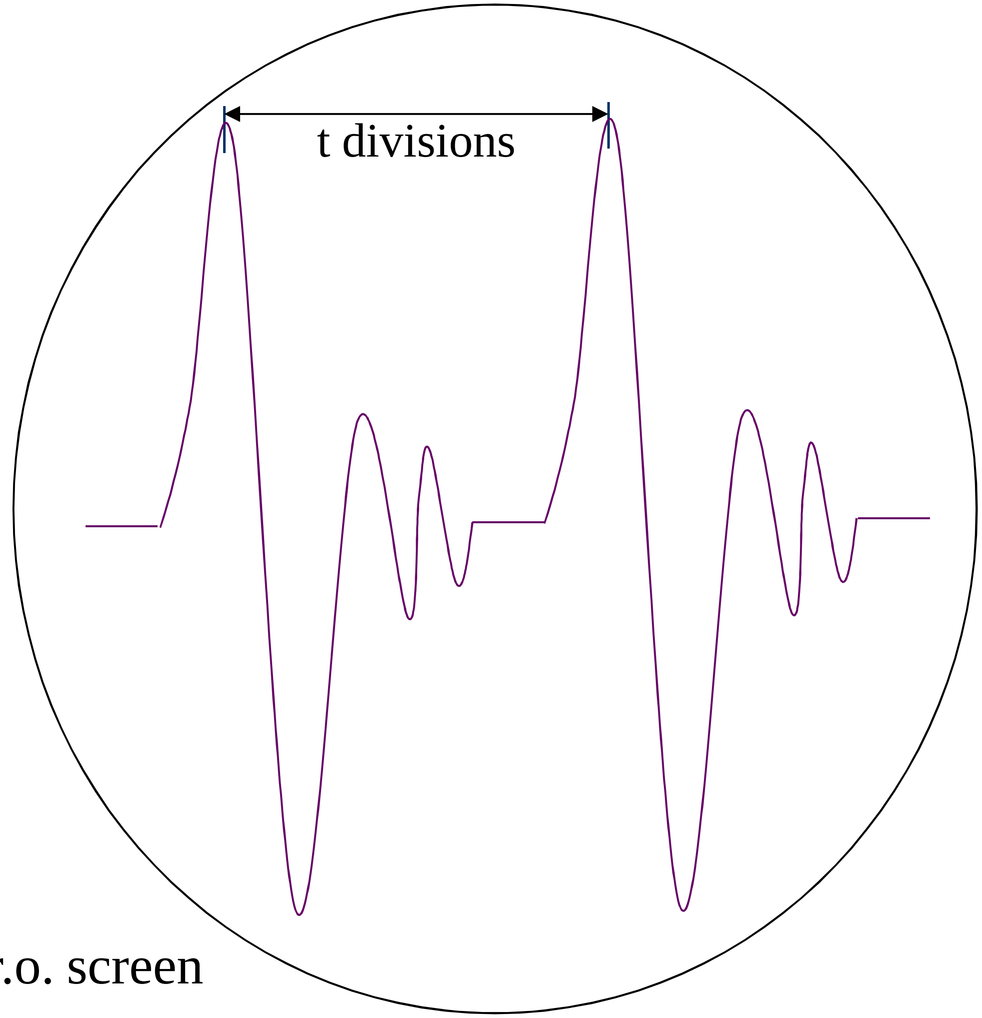
and

if the separation between pulses

is t divisions

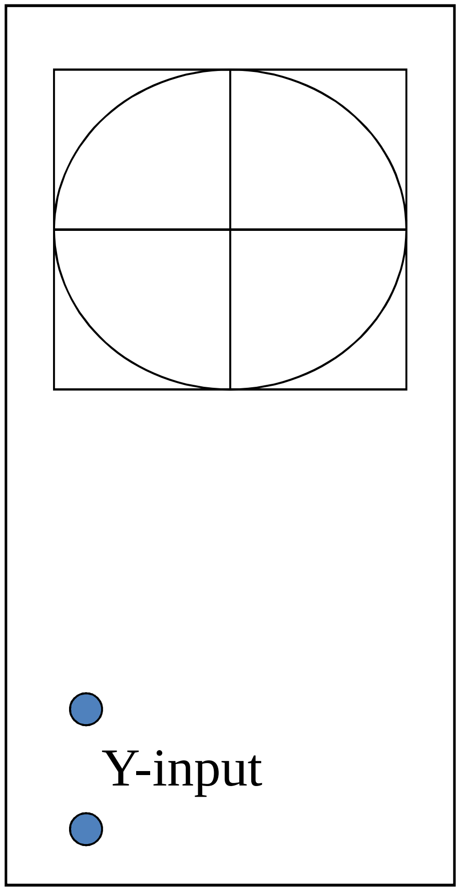
then

time interval is 10t ms



c.r.o. screen

Measuring Short Time Intervals

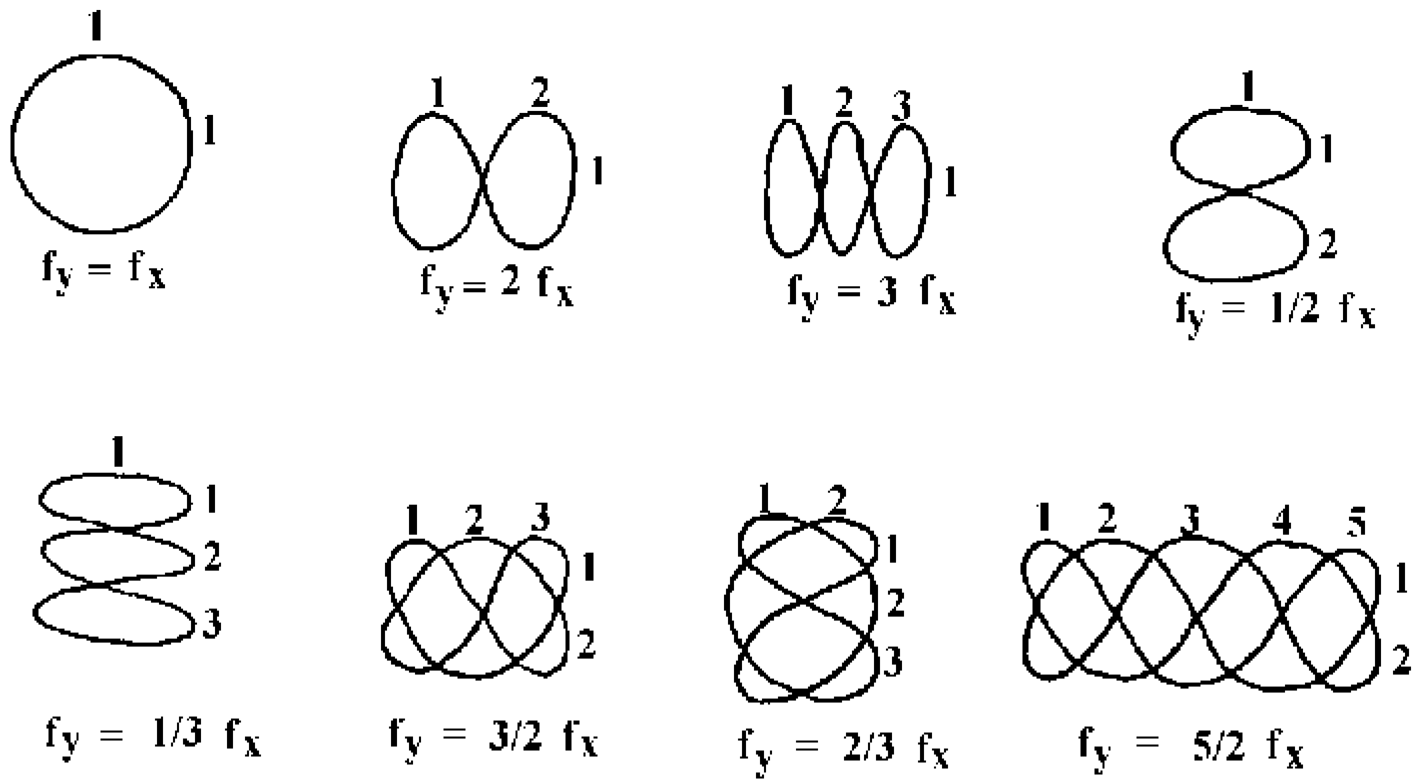


Lissajous’ Figures

- Lissajous’ figure can be displayed by applying two a.c. signals simultaneously to the X-plates and Y-plates of an oscilloscope.
- As the frequency, amplitude and phase difference are altered, different patterns are seen on the screen of the CRO.

Lissajous' Figures

Same amplitude but different frequencies



MEASUREMENTS USING THE CATHODE-RAY OSCILLOSCOPE:

1) Measurement of Frequency:

Time-base Measurement

Time-base measurement helps to determine the frequency of a time-varying signal displayed on the CRT screen. If a time interval t has x complete cycles, then the time period of the signal is:

$$T = \frac{t}{x}$$

or,

$$f = \frac{1}{T} = \frac{x}{t}$$

Hence, the frequency is determind.

Measurement Using Lissajous Figures

The application of sinusoidal waves at the same time to the deflection plates produces various patterns. These patterns, are generated on the basis of the relative amplitudes, frequencies and phases of the different waveforms and are known as Lissajous figures.

Figure 14-9 shows the Lissajous figure as a form of ellipse.

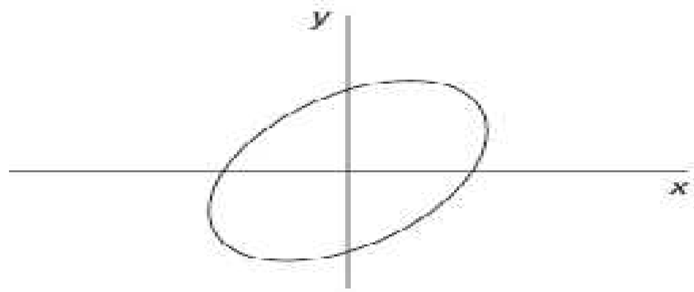


Figure 14-9 Lissajous figure as a form of ellipse

Frequency can be determined from:

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

where, f_v and f_h are the frequencies of the vertical and the horizontal signals, respectively.

MEASUREMENTS USING THE CATHODE-RAY OSCILLOSCOPE:

- ## 2) Measurement of Phase:

The phase difference of two different waveforms displayed on the CRT screen can be found from the time axis. Two sinusoidal signals of time period T are in the same phase at time t_1 and t_2 respectively, and the phase difference between them is expressed as:

$$\varphi = \frac{2\pi}{T}(t_1 - t_2) \qquad (14\text{-}16)$$

Figure 14-10 shows the phase difference of two different waveforms.

- ## 3 Measurement of Phase Using Lissajous Figures:

Lissajous figures are used to measure the phase difference between two sinusoidal voltages of the same amplitude and frequency. The signals are applied simultaneously to the horizontal and vertical deflection plates. The values of the deflection voltages are given by:

$$v_y = A \sin(\omega t + \varphi) \qquad (14\text{-}17)$$

and

$$v_x = A \sin \omega t \qquad (14\text{-}18)$$

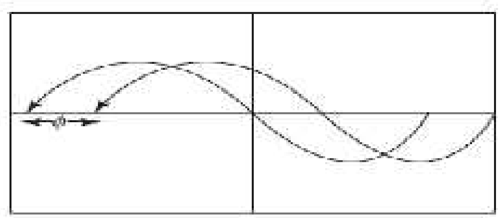


Figure 14-10 Measurement of phase difference

Measurement of Phase Using Lissajous Figures:

The values of the deflection voltages are given by:

$$v_y = A \sin(\omega t + \varphi)$$

$$v_x = A \sin \omega t$$

Here A is the amplitude, ω is the angular frequency and φ is the phase angle by which v_y leads v_x. Eq. (14-17) can be expanded as:

$$v_y = A \sin \omega t \cos \varphi + A \cos \omega t \sin \varphi \quad (14\text{-}19)$$

Equation (14-18) yields:

$$A \cos \omega t = \sqrt{A^2 - v_x^2} \quad (14\text{-}20)$$

Substituting the sine and cosine terms from Eqs. (14-17) and (14-18) in Eq. (14-19), we get:

$$v_y = A \sin \omega t \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y = v_x \cos \varphi + \sqrt{A^2 - v_x^2} \sin \varphi$$

$$v_y - v_x \cos \varphi = \sqrt{A^2 - v_x^2} \sin \varphi$$

$$(v_y - v_x \cos \varphi)^2 = (A^2 - v_x^2)\sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi \, v_y + v_x^2 \cos^2 \varphi = A^2 \sin^2 \varphi - v_x^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi \, v_y + v_x^2 \cos^2 \varphi \, v_x^2 \sin^2 \varphi = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi \, v_y + v_x^2 (\cos^2 \varphi + \sin^2 \varphi) = A^2 \sin^2 \varphi$$

$$v_y^2 - 2v_x \cos \varphi \, v_y + v_x^2 = A^2 \sin^2 \varphi$$

$$v_x^2 + v_y^2 - 2v_x v_y \cos\varphi = A^2 \sin^2 \varphi. \quad (14.21)$$

The Lissajous figure is thus, an ellipse represented by Eq. (14-21). The ellipse is depicted in Fig. 14-9.

Measurement of Phase Using Lissajous Figures:

Case I: When $\varphi = 0°$, cos $\varphi = 1$, sin$\varphi = 0$

Then, Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - 2v_x v_y = 0$$

$$(v_x - v_y)^2 = 0$$

$$v_x = v_y \tag{14-22}$$

Equation (14-22) represents a straight line with slope 45°, i.e., $m = 1$. The straight line diagram is shown in Fig. 14-11(a).

Case II: When $0 < \varphi < 90$, $\varphi = 45°$, cos $\varphi = \frac{1}{\sqrt{2}}$, sin $\varphi = \frac{1}{\sqrt{2}}$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 - \sqrt{2}v_x v_y = \frac{A^2}{2} \tag{14-23}$$

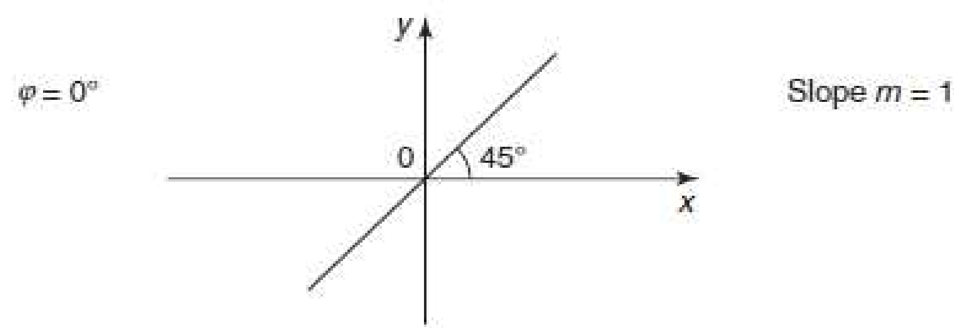


Figure 14-11(a) Lissajous figure at $\varphi = 0°$ is a straight line with slope $m = 1$

Measurement of Phase Using Lissajous Figures:

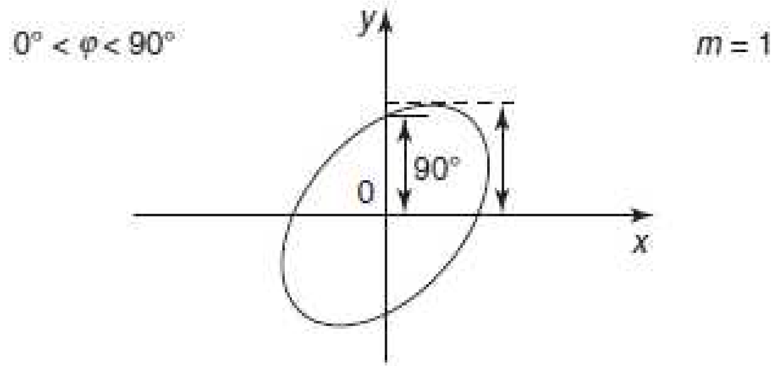


Figure 14-11(b) Lissajous figure at 0° < φ < 90 takes the shape of an ellipse

Equation (14-11) represents an ellipse, as shown in Fig. 14-11(b).

Case III: When $\varphi = 90°$, $\cos\varphi = 0$, $\sin\varphi = 1$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 = A^2 \qquad (14\text{-}24)$$

Equation (14-24) represents a circle shown in Fig. 14-12.

Case IV: When $90 < \varphi < 180$; say $\varphi = 135°$,

$\cos\varphi = -\frac{1}{\sqrt{2}}$, $\sin\varphi = \frac{1}{\sqrt{2}}$

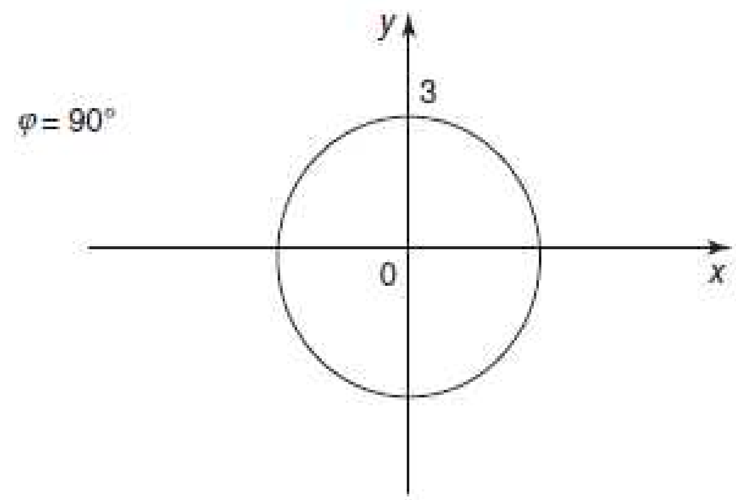


Figure 14-12 Lissajous figure at φ = 90°: it forms a circle

Measurement of Phase Using Lissajous Figures:

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + \sqrt{2}v_x y_y = \frac{A^2}{2} \qquad (14\text{-}25)$$

Equation (14-25) represents an ellipse shown in Fig. 14-13.

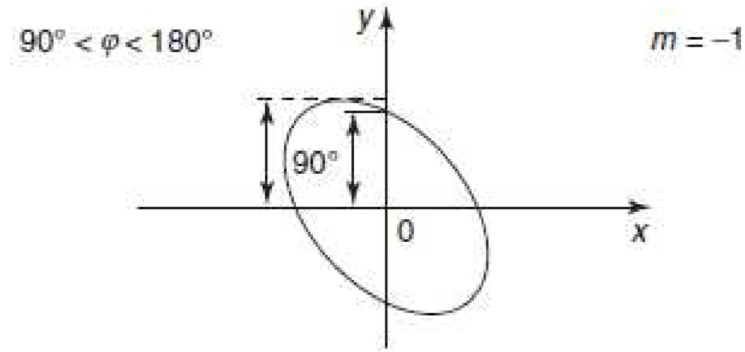


Figure 14-13 Lissajous figure when $90 < \varphi < 180$

Case V: $\varphi = 180°$, $\cos\varphi = -1$, $\sin\varphi = 0$

Then Eq. (14-21) reduces to:

$$v_x^2 + v_y^2 + 2v_x v_y = 0$$

$$(v_x + v_y)^2 = 0$$

$$v_x = -v_y \qquad (14\text{-}26)$$

Equation (14-26) represents a straight line with slope $m = -1$; a slope of 45° in the negative direction of the x-axis, as shown in Fig. (14-14).

The maximum y-displacement, A, and the vertical displacement, V_y, at time $t = 0$ can be measured from the vertical scale of the CRO. Putting $t = 0$ in Eq. (14-17), we get:

$$v_{y0} = A\sin\varphi \qquad (14\text{-}27)$$

$$\sin\varphi = \frac{v_{y0}}{A} \qquad (14\text{-}28)$$

Thus, the phase angle can be found from Eq. (14-28) using any form of the Lissajous figure.

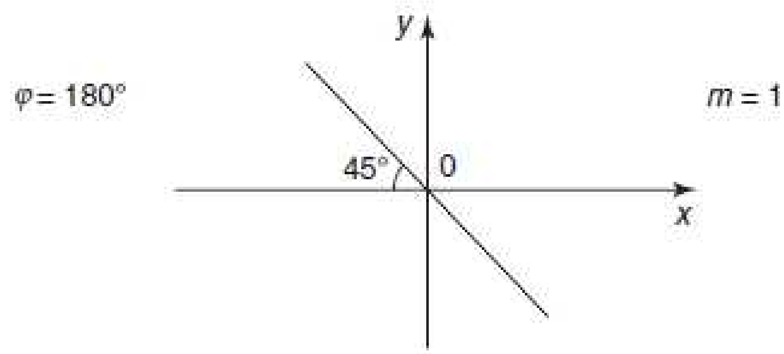


Figure 14-14 Lissajous figure at $\varphi = 180°$ with negative slope $m = -1$