UNIT- IV

CRO (Cathode Ray Oscilloscope)

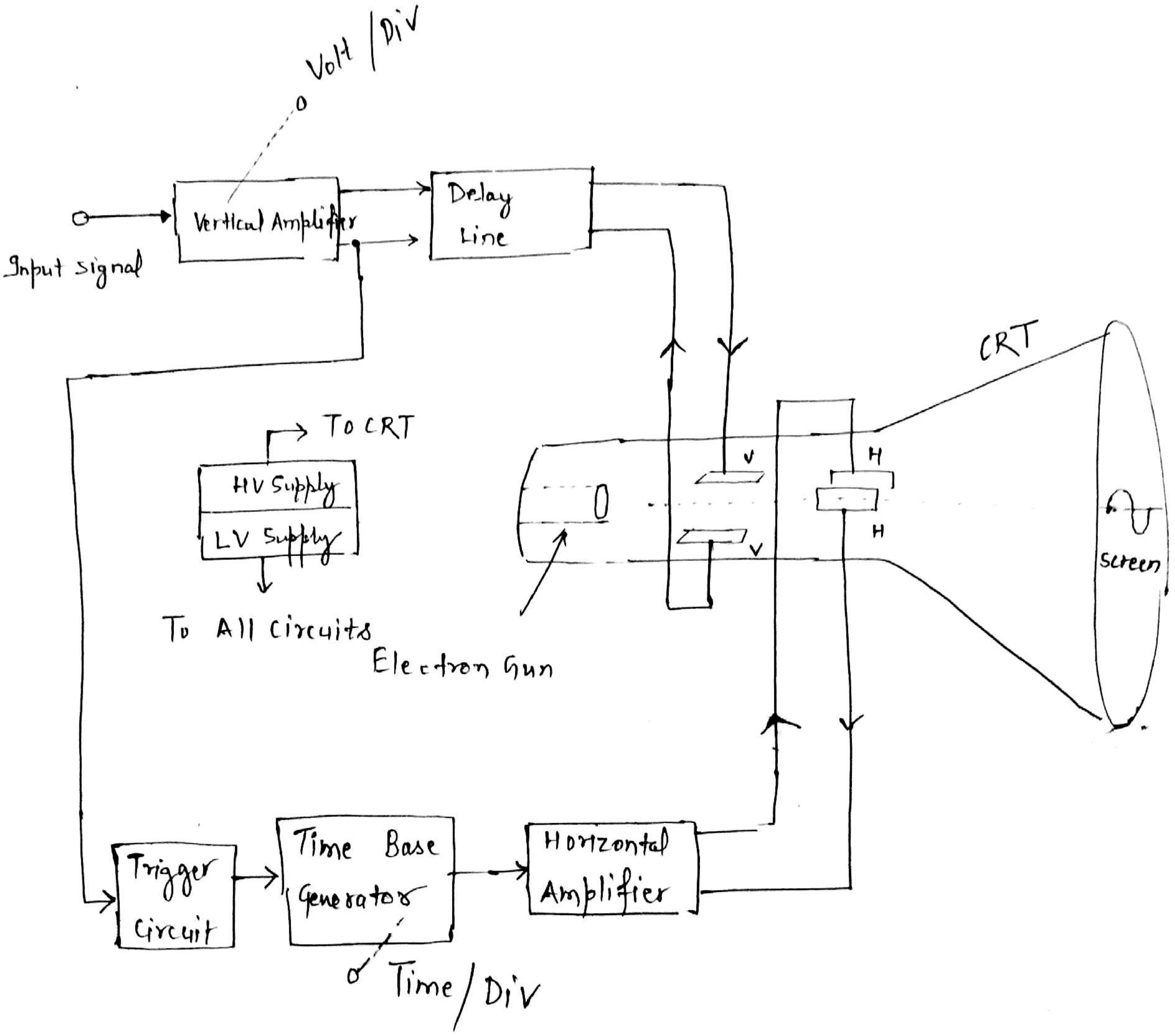
* The cathode ray oscilloscope (CRO) is a very useful and versatile Laboratory instrument used for display, measurement and analysis of waveforms and other phenomena in electrical and electronic circuits. CRO is in fact very fast X-Y plotter, displaying an input signal versus time or another signal. The stylus of this plotter is a Luminous spot which moves over the display area in response to an input voltage. The luminous spot is produced by a beam of electrons striking on a fluorescent screen.

* The normal form of CRO uses a horizontal input voltage which is an internally generated ramp voltage called "Time Base". This horizontal voltage moves the luminous spot periodically in a horizontal direction from Left to right over the display area on the screen.

* The vertical input to the CRO is the voltage under investigation. The vertical input voltage moves the luminous spot up and down in accordance with the instantaneous value of the voltage. The luminous spot thus traces the waveform of the input voltage with respect to time.

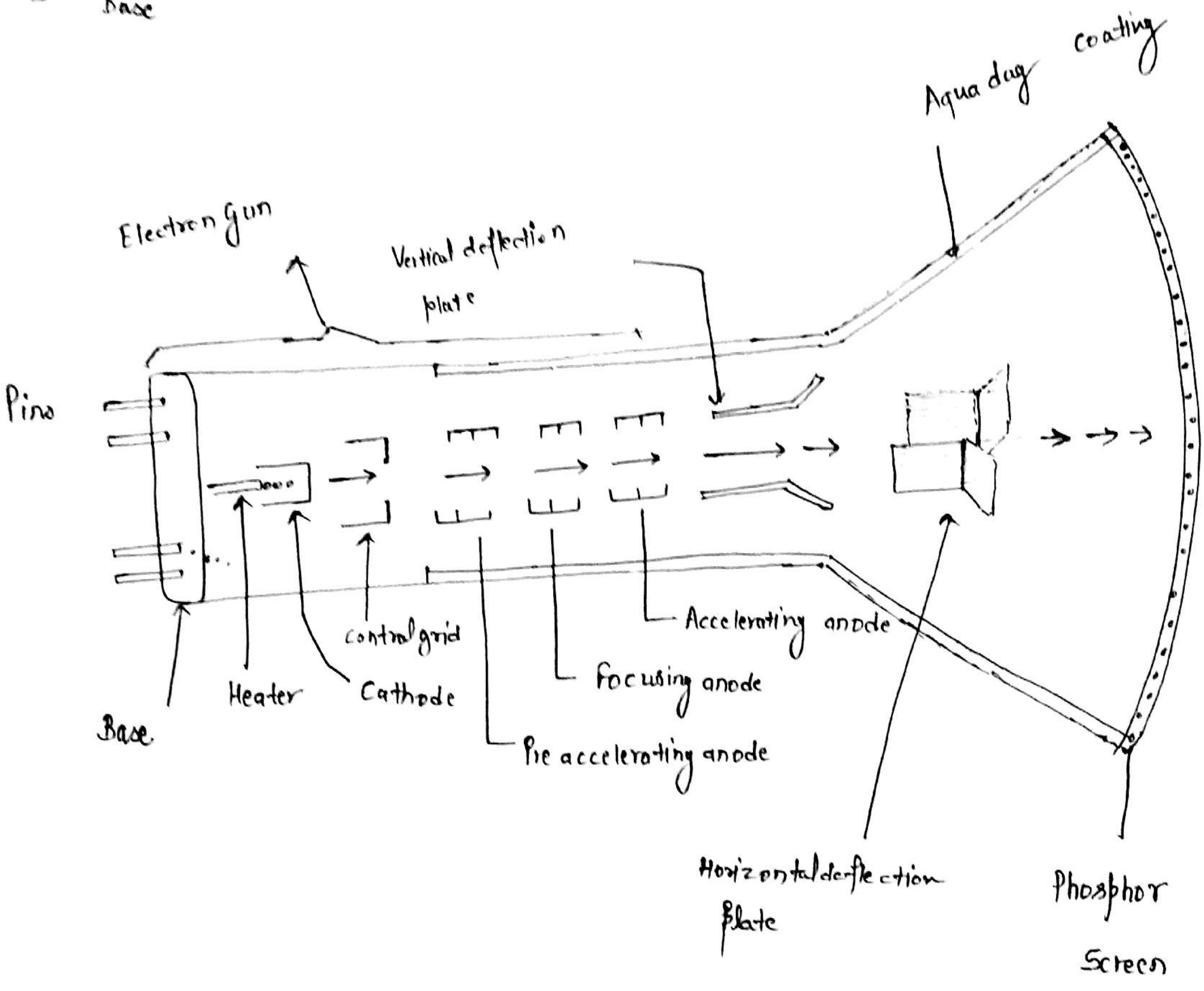
Block diagram of general purpose oscilloscope

* The heart of the oscilloscope is the cathode ray tube, which generates electron beam, accelerates the beam to a high velocity, deflects the beam to create image and contains the phosphor screen where the electron beam eventually (finally) becomes visible.



Cathode Ray Tube – A cathode ray oscilloscope consists of a cathode ray tube (CRT), which is the heart of the tube, and some additional circuitry to operate CRT. The main part of CRT are:–

1- Electron gun assembly
2- Deflection plate assembly
3- Fluorescent screen
4- Glass envelope
5- Base



Internal structure of CRT

* Electron gun assembly — It consists of a heater, a cathode, control grid, a pre accelerating anode, a focusing anode, and an accelerating anode.

* Control grid — The grid has negative voltage. It controls the number of electrons emitted from cathode and hence intensity is controlled by the grid.

* Pre accelerating and accelerating anode — Both are connected to a common positive high voltage of about 1500V.

* Focusing anode — It is connected to a lower adjustable voltage of 500V. In CRO, we use electrostatic method of focusing.

* Vertical deflecting plates (voltage) move the luminous spot up and down in accordance with the instantaneous value of input voltage.

* Horizontal deflecting plates (voltage) move the luminous spot in a horizontal direction from left to right over the display area or screen.

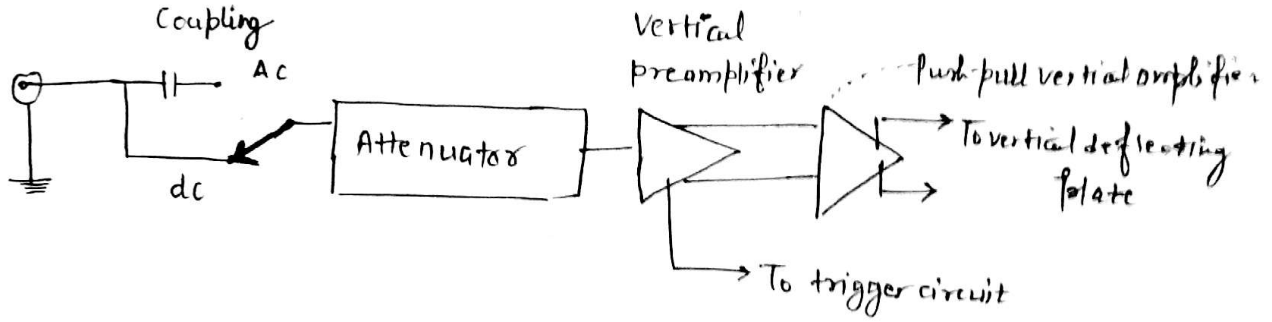
* When e- beam strikes on the screen, a spot of light is produced. We use phosphor for screen.

Note : Post accelerators or post deflection acceleration tube — When measurement are to be made above 10MHz then we use post accelerators. They have a large beam accelerating bias after the deflection plates so as to increase the beam energy and give a bright display on the screen.

* Aquadag — The electrons, striking the screen, release the secondary emission electrons. These secondary electrons

are collected by an aqueous solution of grafphite called 'Aquadag'.

Vertical deflection system- The input is given to the attenuator through coupling. After that signal goes to vertical pre amplifier followed by push-pull vertical amplifier. Finally signal goes to vertical deflection plate.



Horizontal deflection system-

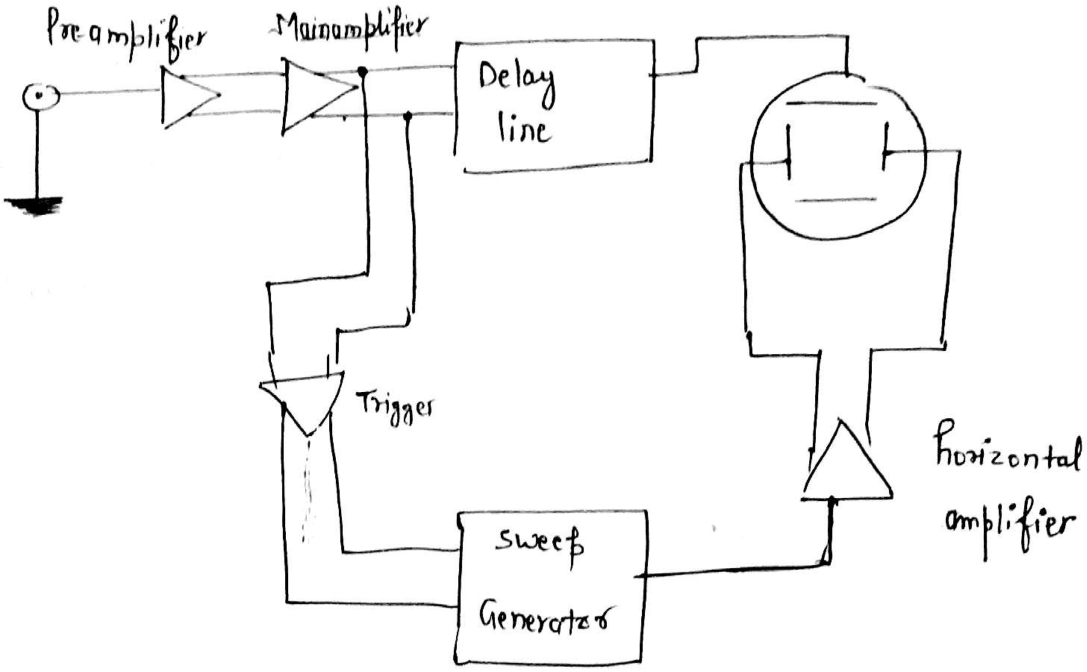
* It consists of a trigger circuit, time base generator, horizontal amplifier.
* It is used to deflect the horizontal portion of the trace at a constant rate with respect to time.

Delay line :

* Signal, reaching at vertical deflecting plates and horizontal deflecting plates, is not synchronised (at same time).

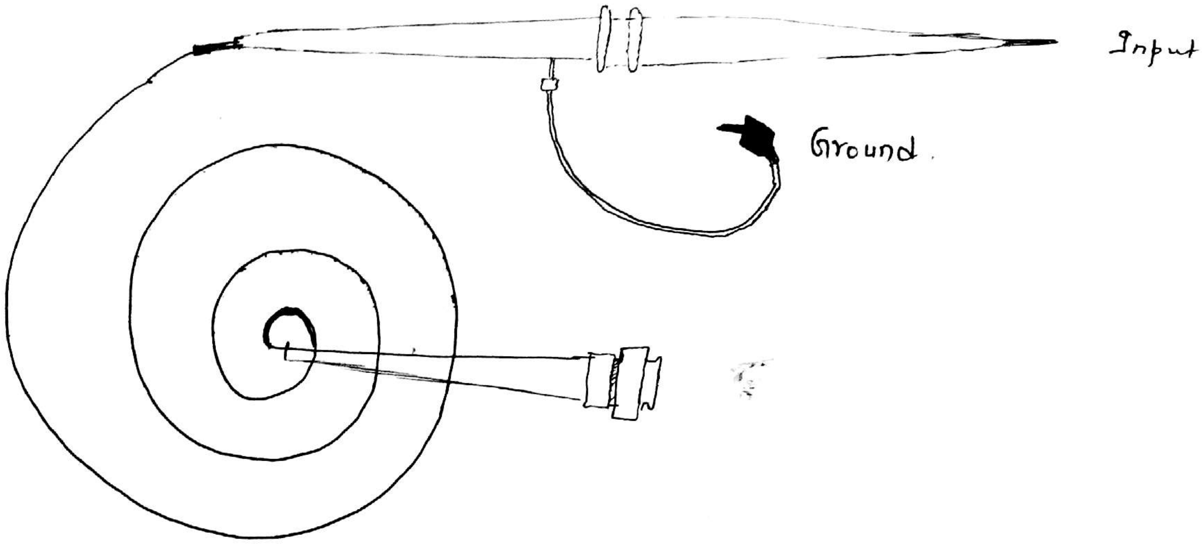
* Signal reaching at horiztal deflecting plates takes extra time because of the internal circuit.

* To synchronize the signal reaching at vertical and horizontal deflecting plates, we shall use delay line as shown below.



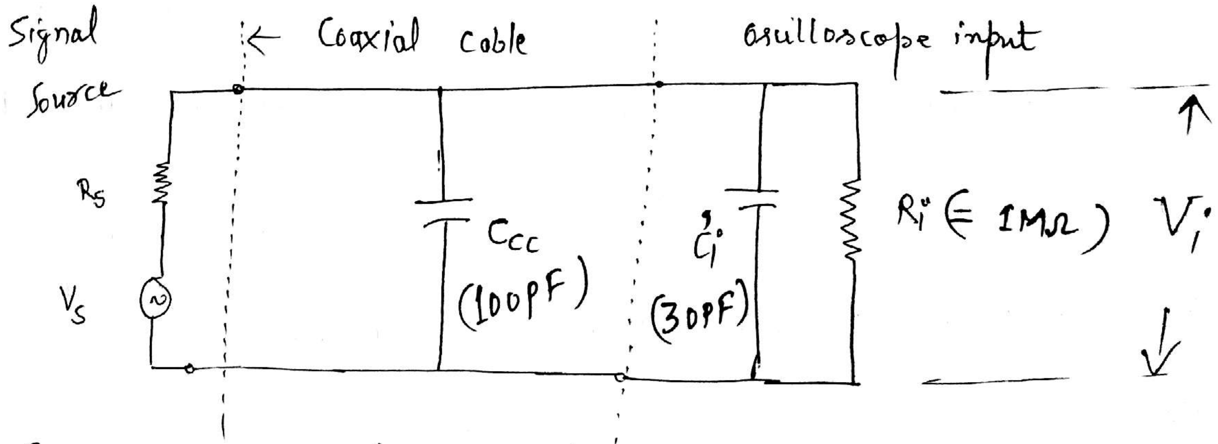
PROBE

1:1 Probe :



* The input signals to an oscilloscope are usually connected via coaxial cables with probes on one end.

* In 1:1 Probe, it does not contain resistors to attenuate the signal.
* The input impedance of the oscilloscope at the front panel is typically 1 MΩ in parallel with 30 pF.



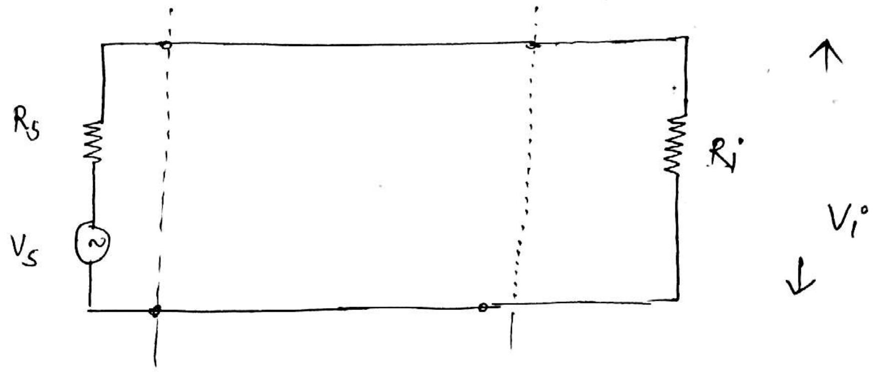
C_{CC} → Capacitance of co-axial cable.

At low frequency -

$$X_C \uparrow = \frac{1}{2\pi f \downarrow C}$$

$$f \downarrow \Rightarrow X_C \uparrow$$

Then we can neglect the effect of capacitance.

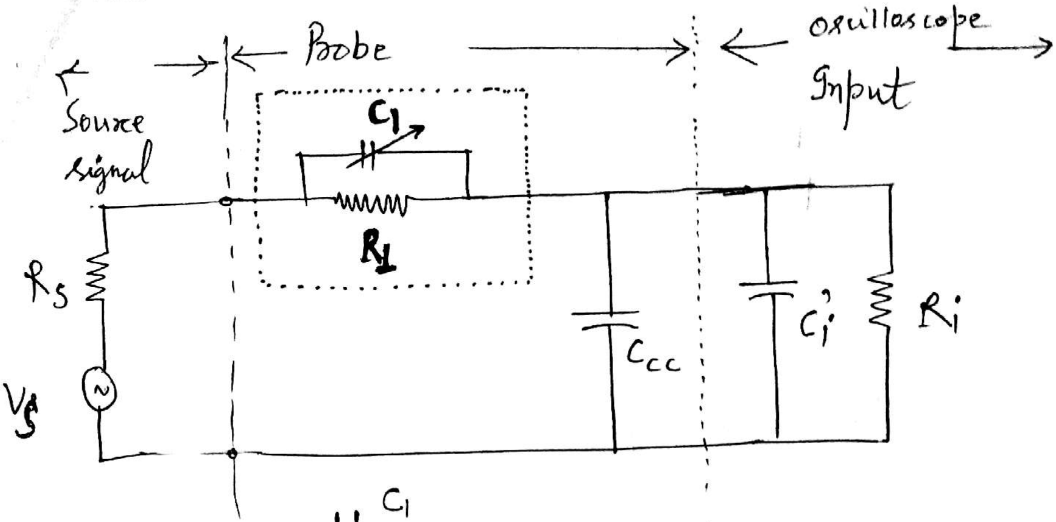


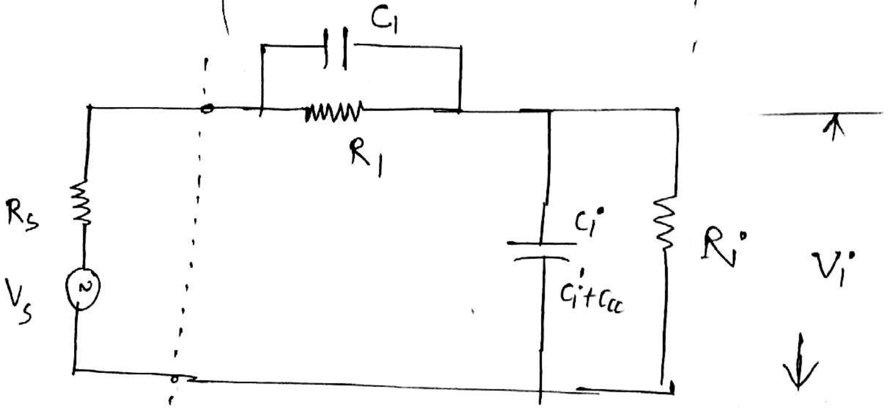
$$V_i = \frac{R_i}{R_i + R_S} * V_S$$

$V_i \longrightarrow$ This is the input voltage to the CRO.

Attenuation probe :: [K:1 or 10:1]

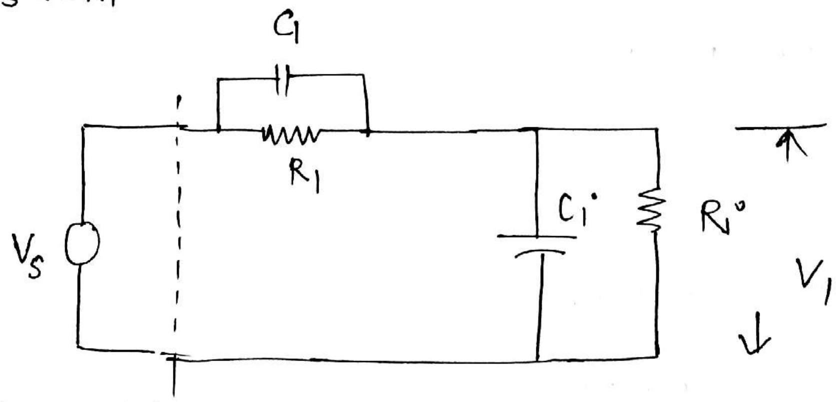
* Now our objective is to increase the input resistance and to reduce the input (or total) capacitance and also wants to design attenuation probe. all thing can be achieved by conneting a probe having resistance R_1 and capacitance C_1 as shown Below.





$$\boxed{C_i = C_i' + C_{cc}}$$

$R_s << R_1$



* When resistors are acting alone ⇒

$$\frac{V_i}{V_s} = \frac{1}{K} = \frac{R_i}{R_1 + R_i}$$

$$K R_i = R_1 + R_i$$

$$\boxed{R_1 = (K-1) R_i} \tag{1}$$

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* When capacitors are acting alone ⇒

$$\frac{V_i}{V_s} = \frac{1}{K} = \frac{\frac{1}{wC_i}}{\frac{1}{wC_1} + \frac{1}{wC_i}} = \frac{C_1}{C_i + C_1}$$

$$K C_1 = C_i + C_1$$

$$(K-1) C_1 = C_i$$

$$\boxed{C_1 = \frac{C_i}{(K-1)}} \quad \text{—— (2)}$$

Total resistance $= R_1 + R_i$

$$= (K-1) R_i + R_i$$

$$= K R_i - \cancel{R_i} + \cancel{R_i}$$

$$\boxed{R_{Total} = K R_i} \quad \text{—— (3)}$$

Total capacitance $= \dfrac{C_1 * C_i}{C_1 + C_i}$

$$C_{Total} = \frac{\frac{C_i}{K-1} * C_i}{\frac{C_i}{K-1} + C_i} = \frac{1}{\cancel{1} + K - \cancel{1}} C_i$$

$$= \frac{C_i}{K}$$

$$\boxed{C_{Total} = \frac{C_i}{K}} \quad \text{—— (4)}$$

From equation ③ and ④, Total resistance is ~~decreased~~ increased ($R_{Total} = KR_i$) and total capacitance C_{Total} is decreased ($C_{Total} = \frac{C_i}{K}$).

Note

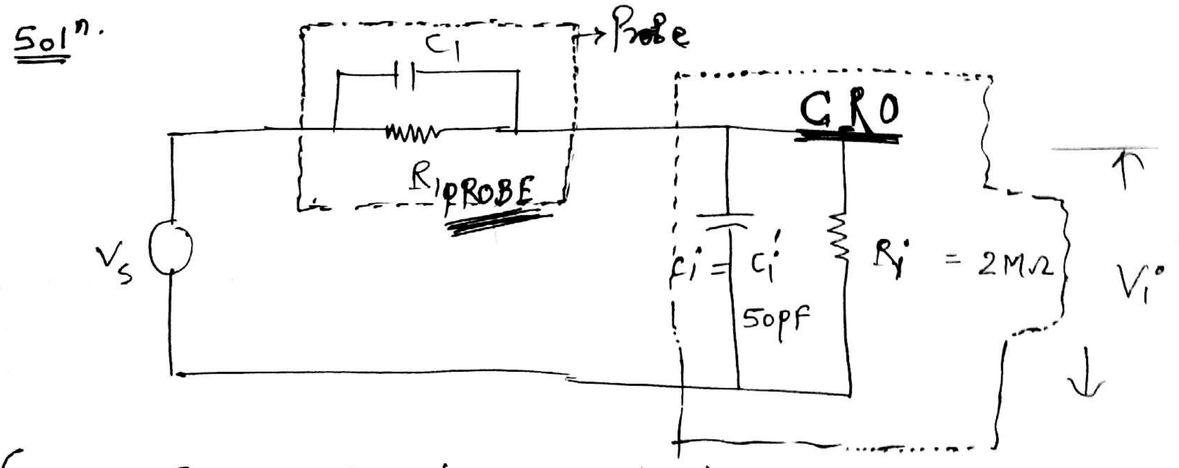
$$\frac{R_i}{R_1 + R_i} = \frac{C_1}{C_i + C_1}$$

$$R_i C_i + \cancel{R_i C_1} = R_1 C_1 + \cancel{R_i C_1}$$

$$\boxed{R_i C_i = R_1 C_1}$$

Q: A CRO has an input capacitance of 50pF and a resistance of 2MΩ, and voltage divider ratio of 10. Calculate the parameters of high impedance probe:

Sol^n.



(assume $C_{cc} = 0\,pF$ because it is not given)

From formula:

$$R_1 = (K-1)\,R_i = (10-1) * 2M\Omega = 9 \times 2M\Omega = 18M\Omega$$

$$C_1 = \frac{C_i}{(K-1)} = \frac{50pF}{(10-1)} = \frac{50}{9}pF = 5.55\,pF$$

Ans.

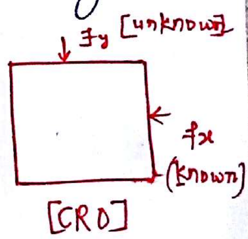
Oscilloscope techniques :-

* When the oscilloscope time base is disconnected and sine waves are applied to both horizontal and vertical inputs, the resulting display depends on the relationship between the two sine waves. Very simple displays occur when the waveforms are equal in frequency. Quite complex figures may be produced with sine waves having different frequencies. In all cases these are known as Lissajous patterns.

Frequency measurement- The signal whose frequency is to be measured is applied to the Y plates. A known standard variable frequency source is used to supply voltage to the X-plates. [Internal time base generated is disconnected.]

* The known frequency is adjusted untill pattern appears stationary.

Method - I



* Let f_y = frequency of the signal applied to Y plates.

  f_x = frequency of the signal applied to X plates

$$\boxed{\frac{f_y}{f_x} = \frac{\text{Number of times tangent touches top or bottom}}{\text{Number of times tangent touches either side}}}$$

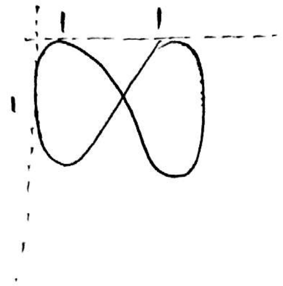
$$\boxed{\frac{f_y}{f_x} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}}}$$

* Note the formula discussed above, does not valid for Lissajous patterns with <u>free ends</u>.

Note **Example**

Pattern

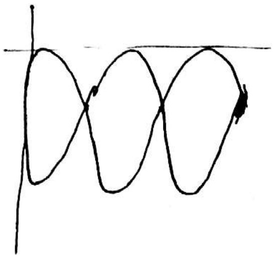
(i)



$$\frac{f_y}{f_x} = \frac{1+1}{1} = \frac{2}{1}$$

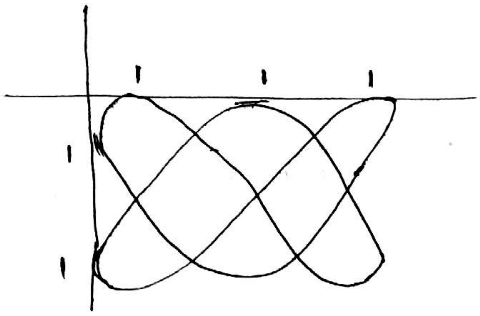
$$= 2:1$$

(ii)



$$\frac{f_y}{f_x} = \frac{1+1+1}{1} = \frac{3}{1}$$

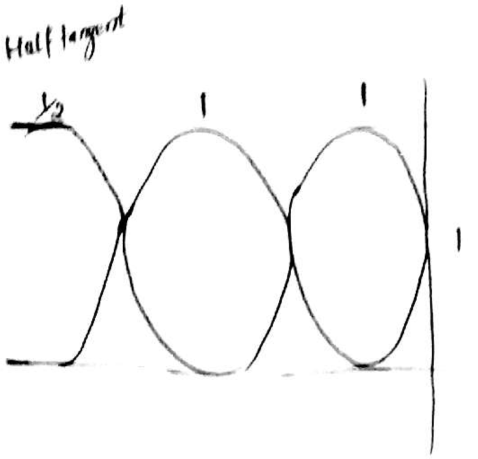
(iii)



$$\frac{f_y}{f_x} = \frac{1+1+1}{1+1} = \frac{3}{2}$$

* <u>When open ended Lissajous pattern is given</u> :. In this case open end is treaded as half tangent.

$$\frac{f_y}{f_x} = \frac{\text{Number of horizatal tangencies}}{\text{Number of vertical tangencies}}$$

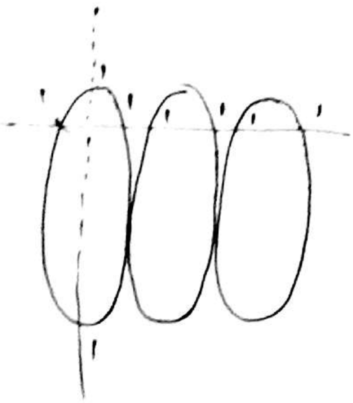


$$\frac{f_y}{f_x} = \frac{1+1+\frac{1}{2}}{1} = \frac{2+\frac{1}{2}}{1} = \frac{5}{2}$$

Method II It is valid for both open and close end.

$$\frac{f_y}{f_x} = \frac{\text{Number of intersections of horizontal line with the curve}}{\text{Number of intersections of vertical line with the curve}}$$

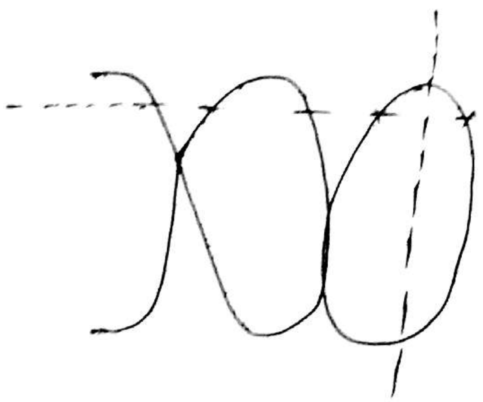
Example (i)



$$\frac{f_y}{f_x} = \frac{1+1+1+1+1+1}{1+1} = \frac{6}{2} = \frac{3}{1}$$

$f_y : f_x = 3:1$

(ii)



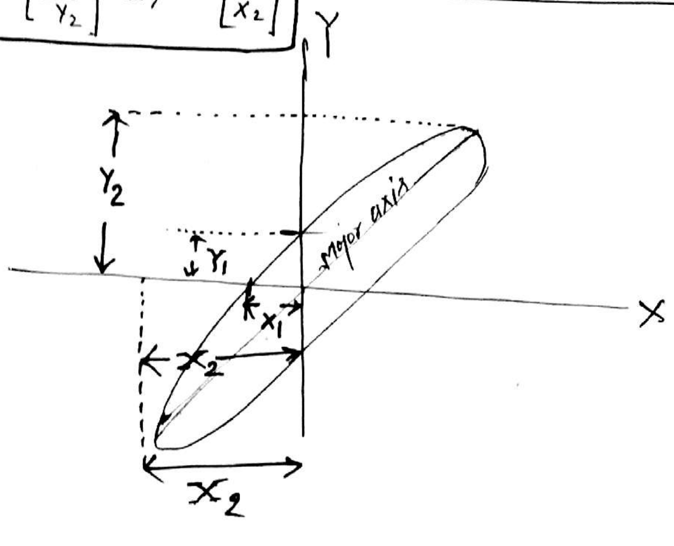
$$\frac{f_y}{f_x} = \frac{1+1+1+1+1}{1+1} = \frac{5}{2}$$

$$\frac{f_y}{f_x} = \frac{5}{2}$$

Phase measurement :: In this case two signals (may be equal or may not be equal in amplitude) are applied which have equal frequency But there is a phase difference between theses then we can calculate the phase on the Basis of following rule. In this Case pattern on CRO screen may be a straight line or ellipse or circle etc.

Let ellipse pattern is formed on the CRO screen as shown Below. If ϕ is the phase difference then :.

$$\boxed{\begin{aligned} \sin\phi &= \frac{Y_1}{Y_2} = \frac{X_1}{X_2} \\ \therefore \phi &= \sin^{-1}\left[\frac{Y_1}{Y_2}\right] = \sin^{-1}\left[\frac{X_1}{X_2}\right] \end{aligned}} \quad \text{—— (1) (General formula)}$$



Y_1 =
Y_2 =
X_1 =
X_2 =

} as shown in figure.

Note

$$\phi = \sin^{-1}\left(\frac{Y_1}{Y_2}\right) = \sin^{-1}\left(\frac{X_1}{X_2}\right)$$ → If top of ellipse is in Q-I

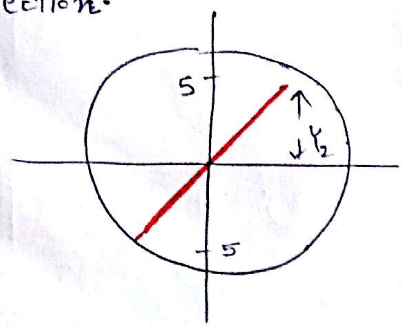
$$\phi = 180^\circ - \sin^{-1}\left(\frac{Y_1}{X_2}\right) = 180^\circ - \sin^{-1}\left(\frac{X_1}{X_2}\right)$$ → If top of the ellipse is in Q II

* If the direction of the trace is clockwise then the phase difference will be in between 0 to 180°. [Direction of the trace is indicated by an arrow.]

* If the direction of the trace is anticlockwise then the phase difference will be in between 180° to 360°. [Direction of the trace is indicated by an arrow]

Example: Lissajous patterns are given below. Calculate the phase difference between two signals. The spot generating the patterns moves in clockwise direction.

(i)



$$\begin{bmatrix} y_1 = 0 \\ y_2 = 5 \end{bmatrix}$$

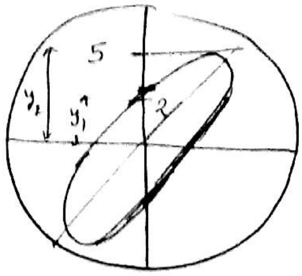
$$\phi = \sin^{-1}\left[\frac{Y_1}{Y_2}\right]$$

$$\phi = \sin^{-1}\left[\frac{0}{5}\right]$$

$$\phi = \sin^{-1}(0)$$

$$\phi = 0^\circ$$

(ii)

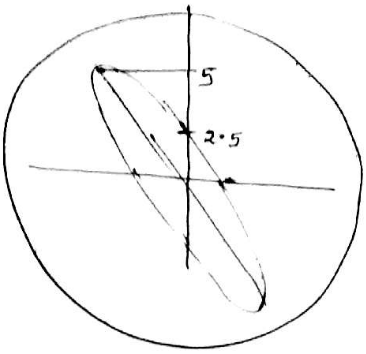


$\sin\phi = \frac{2.5}{5} = \frac{1}{2}$

$\sin\phi = \sin 30°$

$\therefore \phi = 30°$

(iii)



$\sin\phi = \frac{2.5}{5} = \frac{1}{2}$

$\sin\phi = \sin 30°$

$\phi = 30°$

Since top of the ellipse lies in II quadrant

So $\phi = 180° - 30° = 150°$

Note - If the spot generating the patterns moves in anti-clock wise direction then angle will be

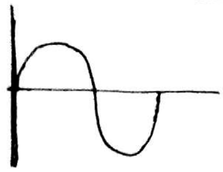
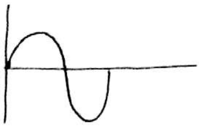
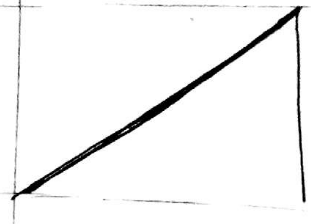
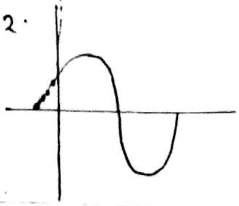
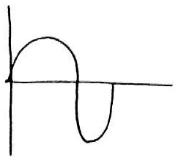
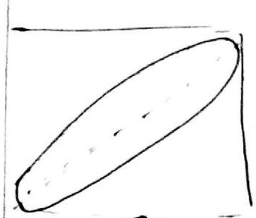
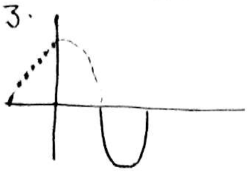
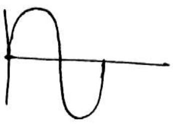
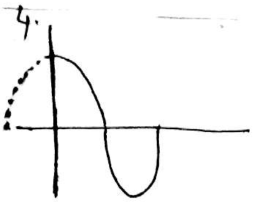
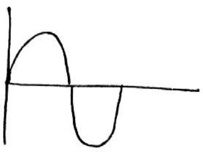
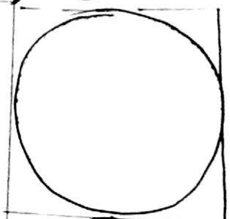
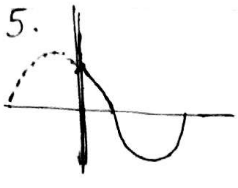
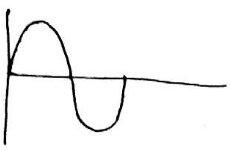
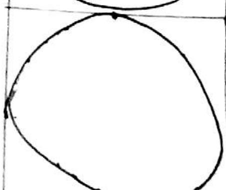
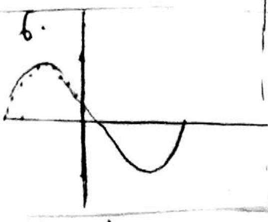
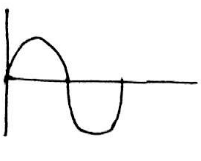
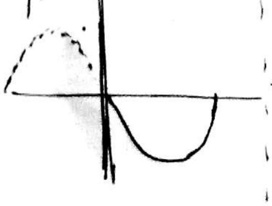
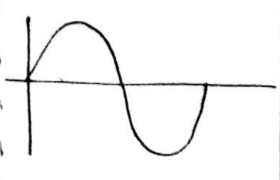
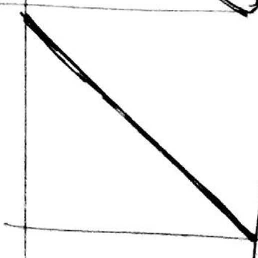
(i) $180°$

(ii) $-30°$ or $+330°$
or $360° - 30° = +330°$

(iii) $360 - 150° = 210°$

[18]

Lissajous patterns with different phase shift

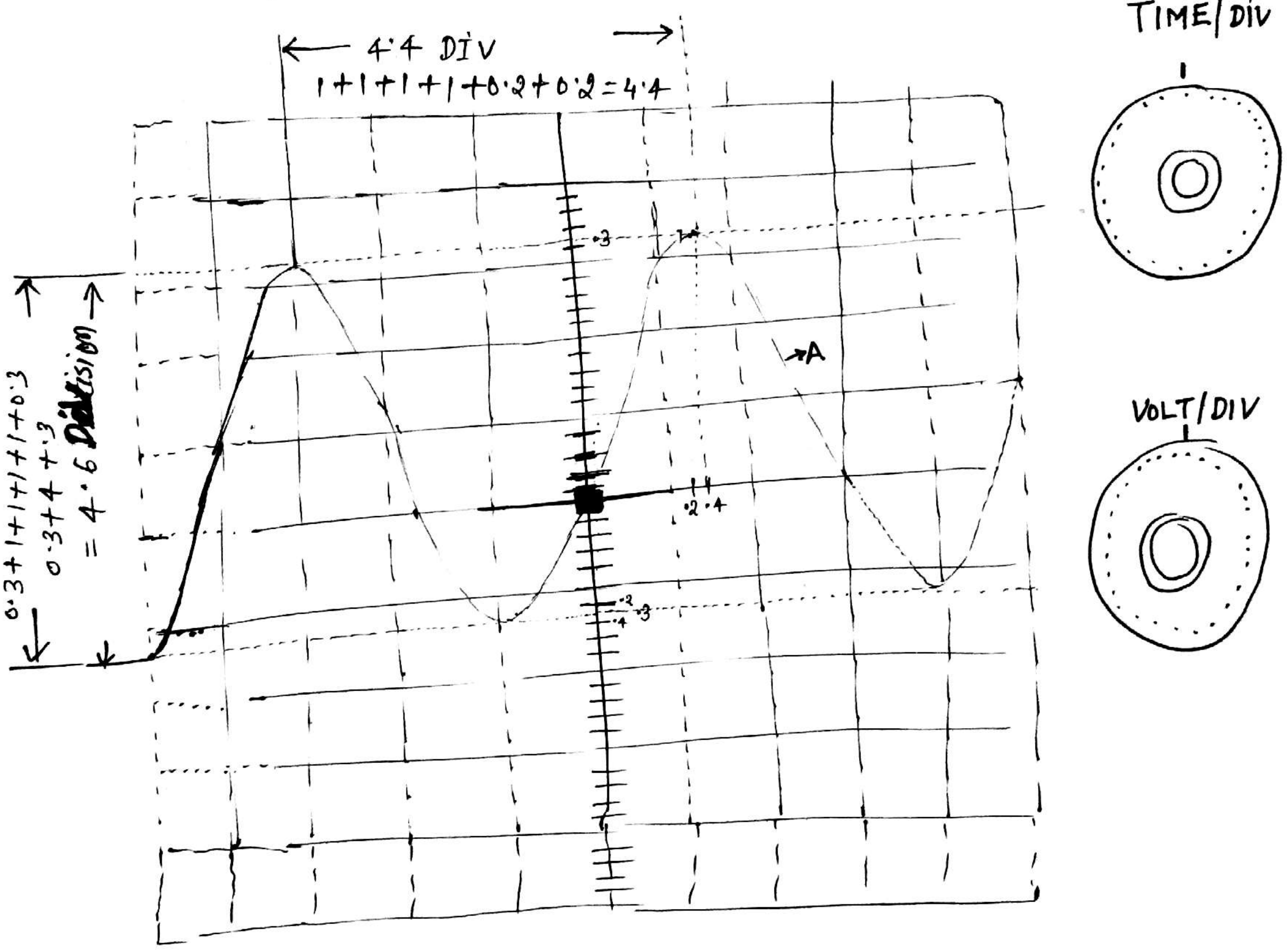
Vertical Deflection Voltage	Horizontal Deflection voltage	ϕ	Resulting Pattern on CRO Screen	
1. 		0°		Straight
2. 		30° or 330°		Ellipse
3. 		60° or 300°		Ellipse
4. 		90° or 270°		circle
5. 		120° or 240°		Ellipse
6. 		150° or 210°		Ellipse
7. 		180°		Straight line

[Not in theory syllabus]

Peak to peak voltage measurement.

* Waveform A has peak to peak amplitude of 4·6 divisions on the graticule [screen].

Let VOLTS/DIV control is at 100mV.



$$V_{p-p} = 4{\cdot}6 \text{ divisions} * \frac{\text{Volts}}{\text{div}}$$

$$V_{p-p} = 4{\cdot}6 * 100\,mV$$

$$V_{p-p} = 460\,mV$$

$$\boxed{V_{p\text{-}p} = (\text{Vertical p to p divisions}) * \text{VOLTS / DIV}}$$

Frequency determination/or Time period determination :

$$\boxed{T = \left(\text{horizontal divisions / cycle}\right) * (\text{TIME/DIV})}$$

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

Let TIME/DIV = 0.5 ms

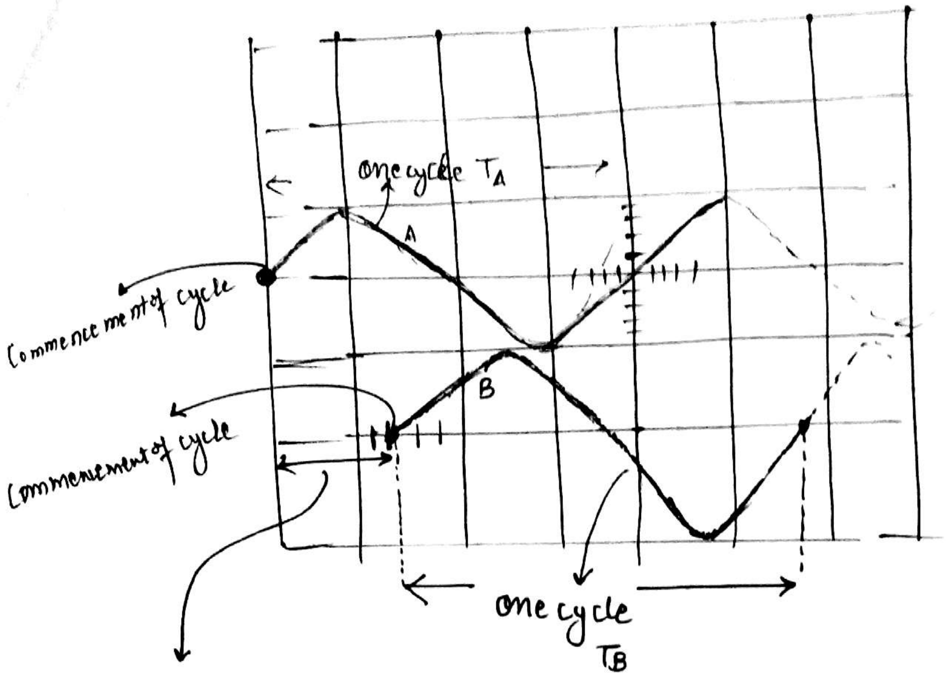
$$T = (4.4 \text{ divisions}) * 0.5\,ms$$

$$T = 2.2\,ms$$

$$f = \frac{1}{T} = \frac{1}{2.2 \times 10^{-3}} = \frac{1000}{2.2} = 454.54\,Hz$$

Phase measurement :

* Let both are having same frequency.



($T_A = T_B$)

$1 + 0.2 + 0.2 = 1.4$ Divisions.

One cycle $= 360°$

one cycle has 4 divisions.

4 divisions $= 360°$

1 division $= \frac{360°}{4} = 90°$.

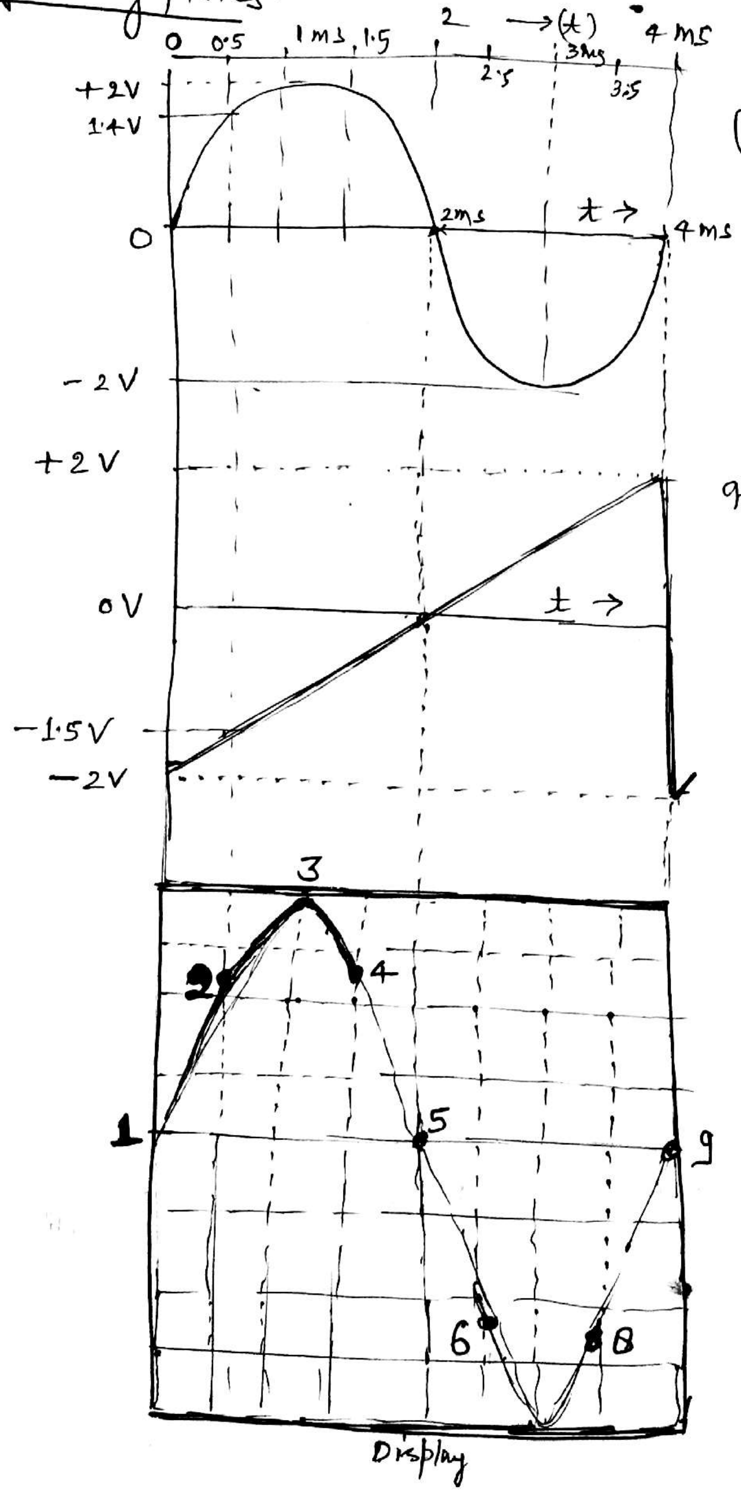
Therefore the phase difference ϕ = 1.4 divisions * $(90°/\text{div})$

$= 126°$

$$\boxed{\phi = \text{Phase difference in divisions} * (\text{Degree}/\text{div})}$$

Waveform display :-

* Input (unknown) voltage is applied to vertical deflecting plates.
* Sawtooth sweep (ramp voltage) voltage is applied to horizontal deflecting plates.



(a) Input to vertical plates

Input to horizontal plates (B)

(c) Display

* Let deflection sensitivity = $2 cm/V$

(i) At $t = 0$ $V_y = 0$ and $V_x = -2V$

So vertical deflection is zero and horizontal deflection is 4 cm left from the centre of the screen.

(ii) When $t = 0.5 ms$ $V_y = +1.4 V$ $V_x = -1.5 V$

So vertical deflection = $1.4 \times 2 = 2.8 cm$ above the centre of the screen, and horizontal deflection is 3 cm left from the centre of the screen. It is indicated by 2, and so on.

Summarized table :

t (ms)	0	0.5	1	1.5	2	2.5	3	3.5	4
Vertical Voltage (V)	0	1.4	+2	+1.4	0	-1.4	-2	-1.4	0
Vertical Deflection (cm)	0	2.8	+4	+2.8	0	-2.8	-4	-2.8	0
Horizontal Voltage (V)	-2	-1.5	-1	-0.5	0	+0.5	+1	+1.5	+2
Horizontal Deflection (cm)	-4	-3	-2	-1	0	+1	+2	+3	+4
Point	1	2	3	4	5	6	7	8	9

* At point 9 horizontal deflecting voltage rapidly goes to $-2V$ again ($+2V$ to $-2V$), so the beam returns to the left side of the screen. From here it is ready to repeat the waveform trace.

* It is seen that with a sawtooth applied to the horizontal

deflecting plates, any waveform applied to the vertical deflecting plates will be displayed on the screen of the CRT.

Special oscilloscope –

1. Storage oscilloscope
2. Sampling oscilloscope.

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Book – Modern Electronic Instrumentation & Measurement Techniques
By <u>William D. Copper</u>