Electronics Measurement & Instrumentation
4EC3-06
Unit -3
Cathode Ray Oscilloscope

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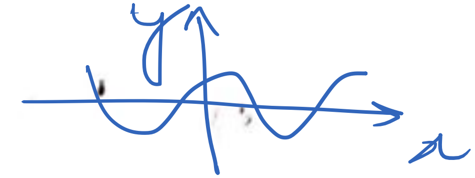
4EC3-06: Electronics Measurement & Instrumentation

Credit: 3 — **Max. Marks: 150(IA:30, ETE:120)**

3L+0T+0P — **End Term Exam: 3 Hours**

4	**OSCILLOSCOPES** – CRT Construction, Basic CRO circuits, CRO Probes, Techniques of Measurement of frequency, Phase Angle and Time Delay, Multibeam, multi trace, storage & sampling Oscilloscopes.	**7**

Cathod Ray Oscilluscope (CRO) :-



→ CRO's are very fast x-Y plotters displaying an input signal versus another signal. or versus time

→ CRO's are used to investigate wave forms, transient phenomena, and other time varying quantities from a very low freqn range to the radio freqn.

DSO

1 KHz — 20 MHz — 1 GHz

Application :

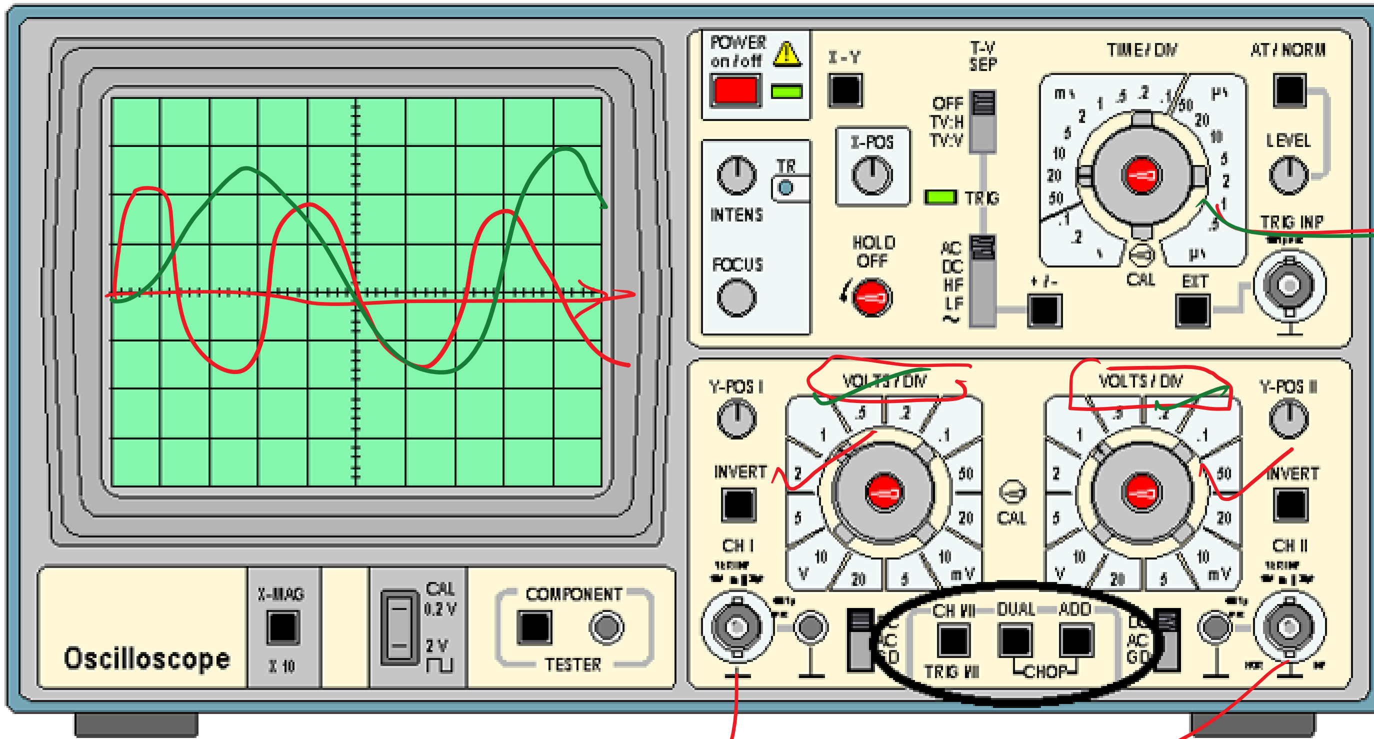
↳ Have ability to calculate rise time. or pulse width of the measured wave form;

2 Channels

→ most CROs. are capable of accepting two or more inputs displaying simultaneously.

→ Sampling oscilloscope are used for high speed application.

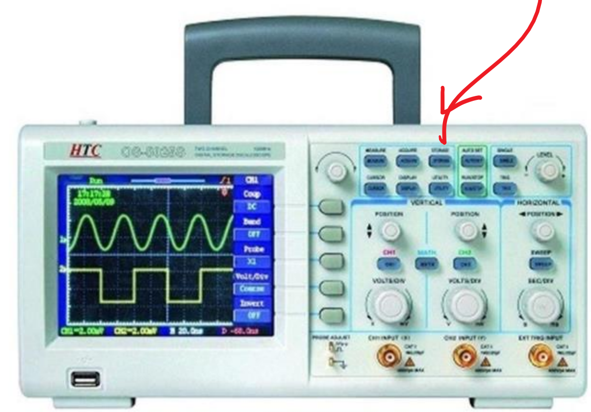
Analog CRO



Common

input

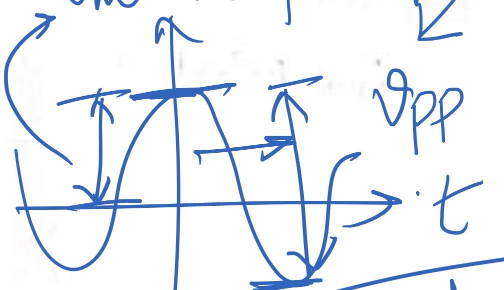
DSO



Advantages;

1. X-Y plotter
2. Vpp, Vm, Vrms, Vavg
3. V, I, ϕ, f, T
4. Digital instrument
5. High resolution
6. High Accuracy
7. Scale is easily expandable
8. Linear Device
9. Comparision of signal → DSO
10. Storage of data
11. Process the data with external devices.

Vmax Amp. ∝ P

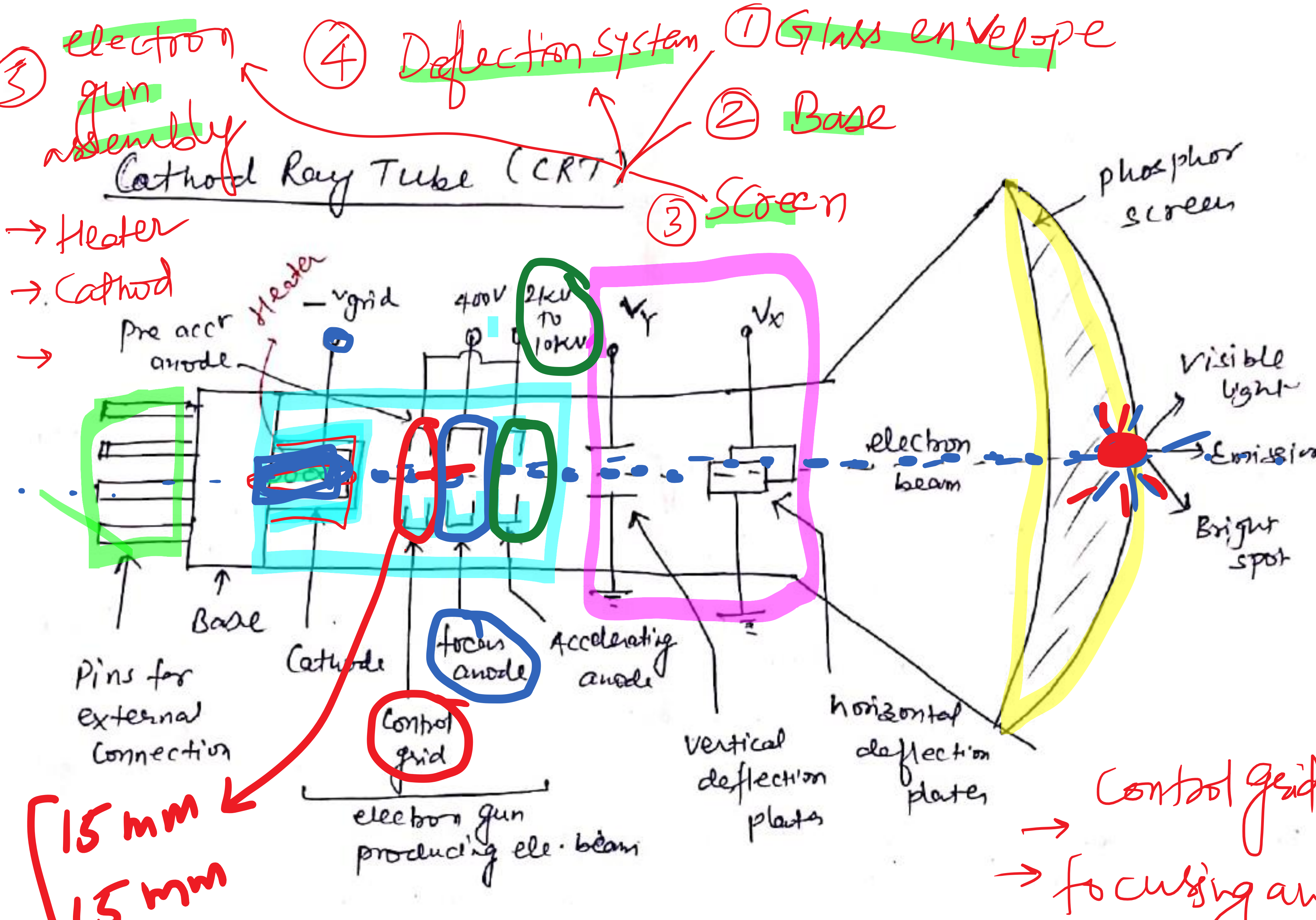


DSO

- Vpp =
- Vm =
- Vrms
- D ϕ
- Vavg
- T
- Ton

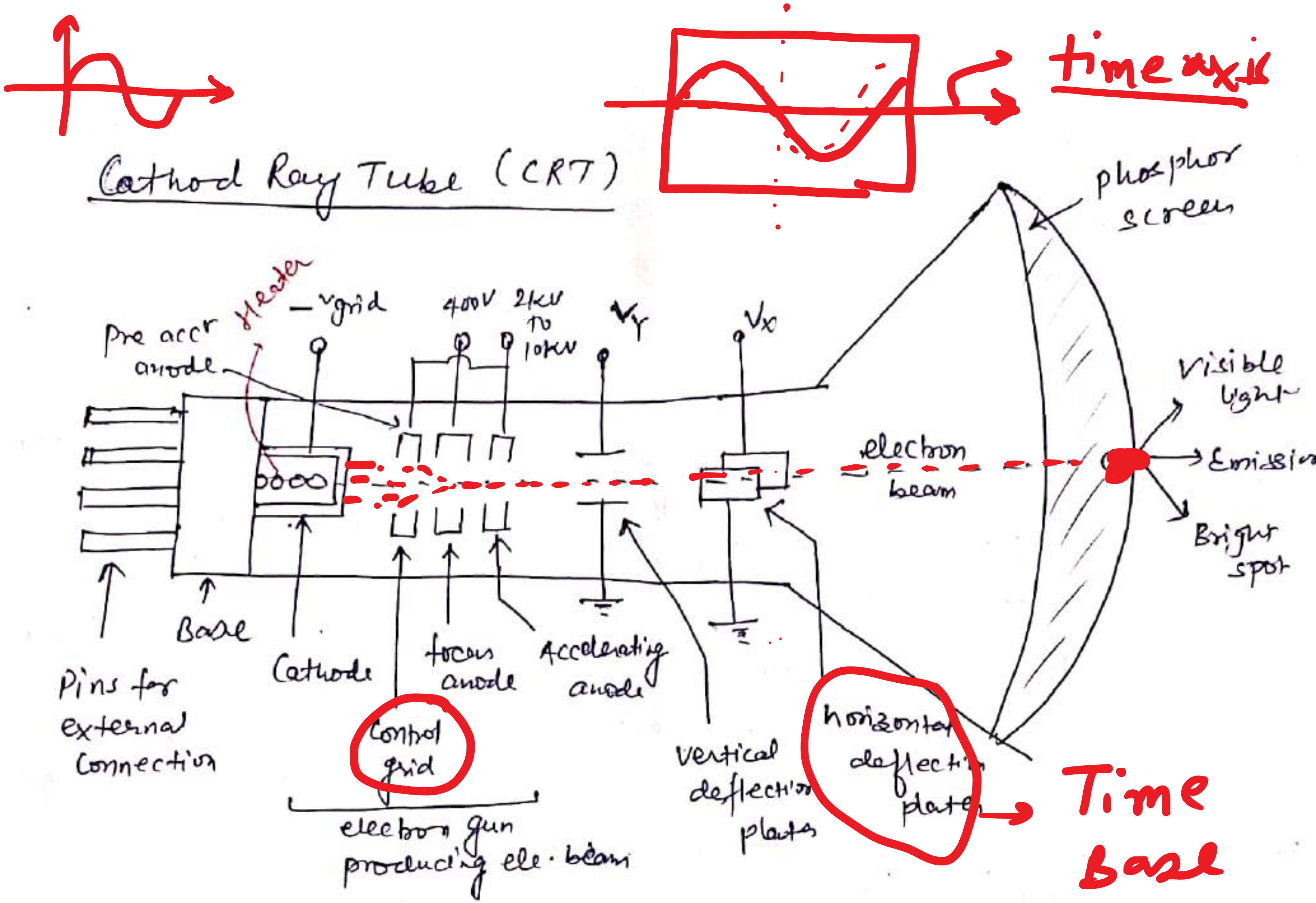
* Power measurement is not possible due to non linear nature of power.

$P = V^2 R$


3 electron gun assembly
4 Deflection system
1 Glass envelope
2 Base
3 Screen
Cathode Ray Tube (CRT)
→ Heater
→ Cathod
→
Pre accr anode
Heater
–Vgrid
400V
2KV To 10KV
V_Y
V_X
phosphor screen
visible light
Emission
electron beam
Bright spot
Pins for external Connection
Base
Cathode
focus anode
Accelerating anode
Control grid
electron gun producing ele. beam
vertical deflection plate
horizontal deflection plates
15 mm
15 mm
Control grid
→ focusing an
→ Accr Anod

Video animation of CRT

Cathod Ray Tube (CRT)



In CRT electron beams are generated, accelerated, deflected and displayed on the screen at the end.

- Glass Envelope
- Base for making Connections
- Screen
- Deflection system
  - Vertical deflecting plates
  - Horizontal def. plate
- Electron Gun assembly
  - Heater
  - Cathod
  - Control grid
  - pre acc. anode
  - focusing anode
  - Acc^r anode

(1) Heater: filament
↳ source of heat → current of few amp.

(2) Cathode:- source of e-beam
↳ outer surface is coated to ensure unidirection emission

Electron gun assembly: Produces a sharp focused beam of ele.. which are accelerated to high velocity. This focused beam of elec. strikes the fluorescent screen with sufficient energy to cause a luminous spot on the screen.

Heater :- elec are emitted from heated cathod. A layer of barium & strontium oxide is deposited on the end of cathod to obtain high emission of ele. at moderate temp.

Cathod : 600mA, 6.3V

Control grid : It is a nickle cylinder ; with centrally located hole ~~cox~~ co-axial with CRT axis, metal cup of steel. 15mm in dia & 15 mm ~~log~~ long.

intensity of ele. beam depends on no. of ele. emitted

→ grid controls no. of ele. emitted. ⇒ intensity is controlled by grid.

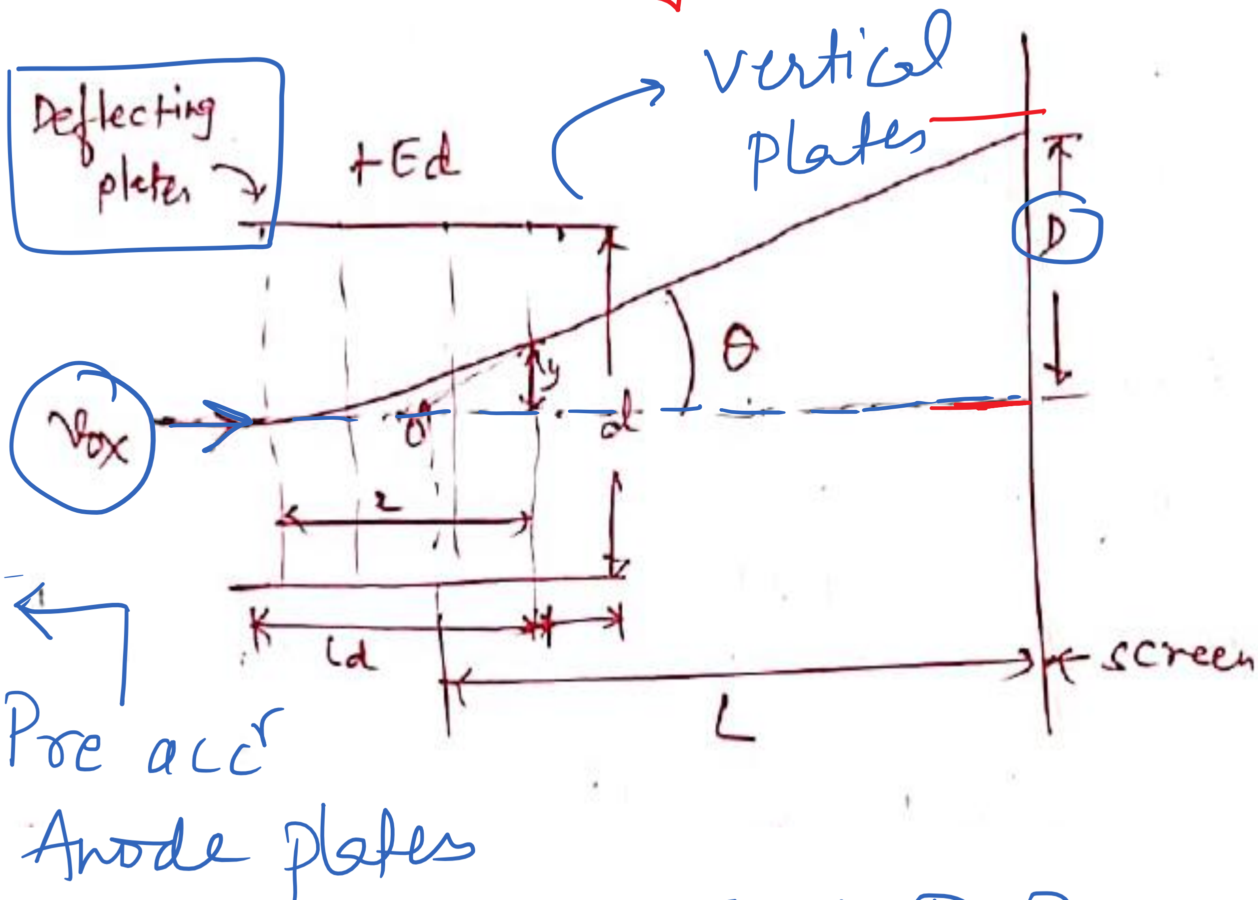
pre accr / accr anodes :- High positive potential

↳ to accr the elec. from grid

focusing anode : to focus the ele. beam.

↳ electrostatic focusing is used

Electro static deflection;



E_a = pre acc^r anode voltage

V_{ox} = vel. of ele. entering def. plate

E_d = pot. B/w def. plates

l_d = length of def. plates

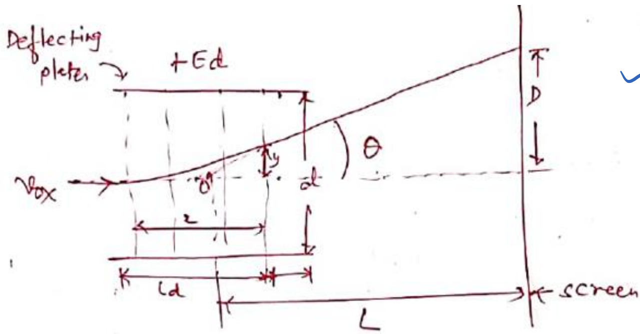
L = dis. B/w centre of def. plate from screen

d = dis. B/w def. plates

D = def. of ele. beam

Find D ?

Apply energy conservation



loss in P.E. when e^- move from cathode to acc^n anode

$$P.E = e\,E_a \quad \text{—— (1)}$$

gain in K.E. $= \frac{1}{2} m v_{ox}^2$ —— (2)

$\because$ P.E. = K.E.

$$\Rightarrow v_{ox} = \sqrt{\frac{2eE_a}{m}} \quad \text{—— (3)}$$

E.F. into in y dir^n $\quad \mathcal{E}_y = E_d/d$

Force on ele. in y dir^n $\quad F_y = e\mathcal{E}_y = \frac{eE_d}{d}$

so; $\quad a_y = \frac{eE_d}{md}$ —— (4)

displacement y at any instant t in y direction

$$y = \frac{1}{2} a_y t^2 = \frac{1}{2} \frac{eE_d}{md} \cdot t^2 \quad \text{—— (5)}$$

in x dir^n = $\quad x = v_{ox} t$

$$t = x/v_{ox} \quad \text{—— (6)}$$

$$y = \frac{1}{2} \frac{eE_d}{m \cdot d} \cdot \frac{x^2}{v_{ox}^2}$$

Slope at any pt. (x,y) = ; $\frac{dy}{dx} = \frac{eE_d}{m \cdot d} \cdot \frac{x}{v_{0x}^2}$

at $x = l_d$; $\frac{dy}{dx} = \tan\theta$; $\tan\theta = \frac{eE_d}{m \cdot d} \cdot \frac{l_d}{v_{0x}^2}$

$$D = L\tan\theta = \frac{L \cdot e E_d \cdot l_d}{m d\, v_{0x}^2}$$

$v_{0x} = \sqrt{\frac{2eE_a}{m}}$

$$D = \frac{L \cdot l_d E_d}{2 d E_a}$$

$$D = \frac{L \times l_d \times E_d}{2 \times d \times E_a}$$

① $D \propto E_d$; CRT may be used as linear indicating device

② def. is independent of e/m ratio (negative ions are present) electrostatic def. system does not produce an ion beam

Deflection sensitivity; It is defined as deflection of the screen per unit deflection voltage

$$S = \frac{D}{E_d} = \frac{L\, l_d}{2 d E_a} \ \text{m/V}$$

Typical values: 0.1 mm/V, 1 mm/V

Deflection Factor (G) $= \frac{1}{S}$ = reciprocal of sensitivity

$$= \frac{2 d E_a}{L\, l_d} \ \text{V/m}$$

$S \propto \frac{1}{E_a}$ ↑ ↓E_a has disadvantage; luminosity of spot dec. as E_a ↓

high value of E_a → produce bright spot.

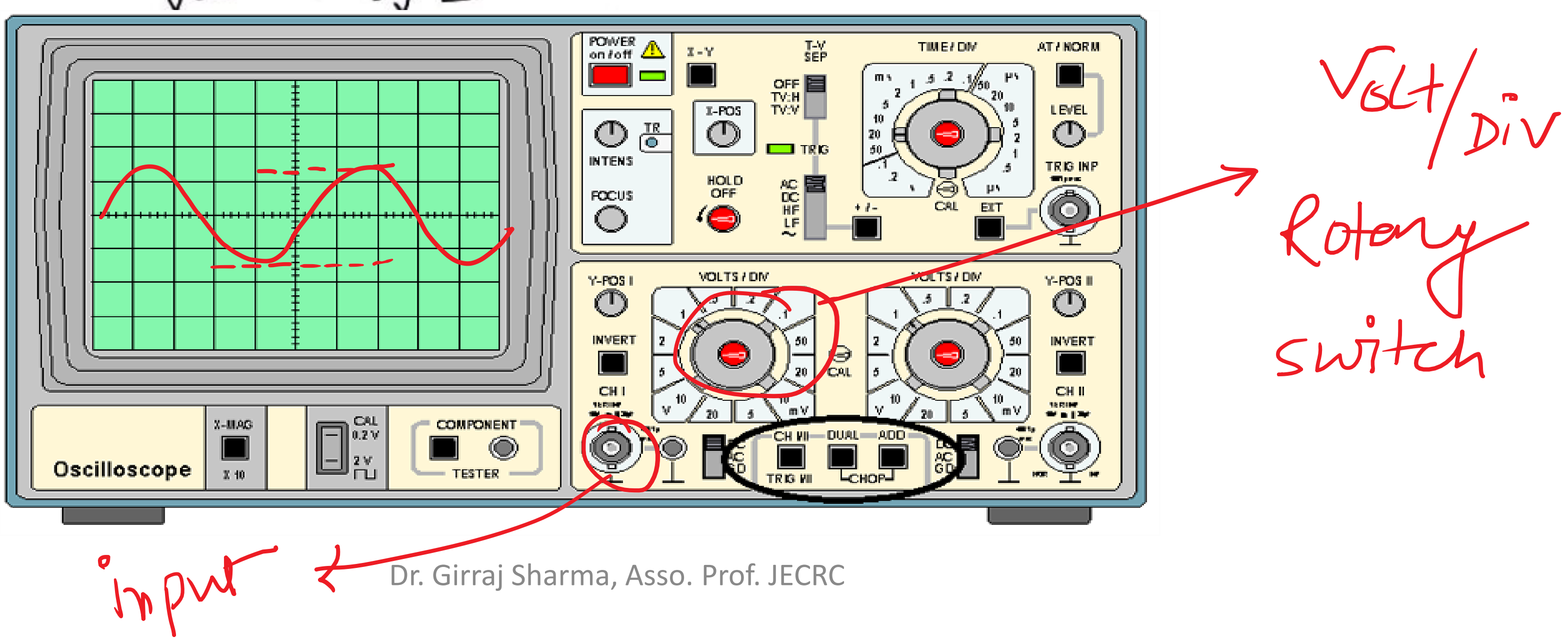
CRO Measurement:

(1) Voltage measurement:

- set the 'volts/div' by the panel of CRO
- set the signal to calculate peak to peak value of signal
- take p-p reading by counting no. of div.
- V_{pp} = No. of div. × volts/div.

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

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{V_{pp}}{2\sqrt{2}} \quad \text{(for sinusoids)}$$



② Phase Measurement:

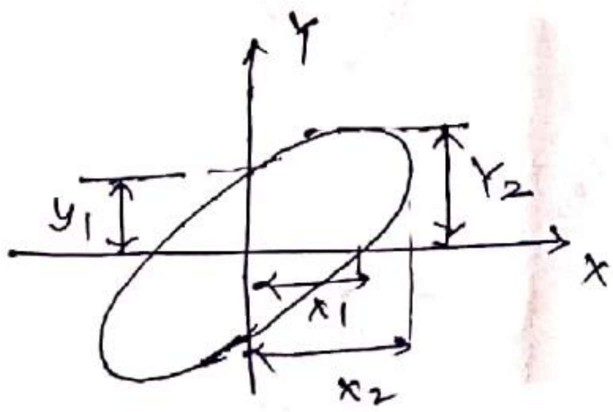
↳ using Lissajous pattern

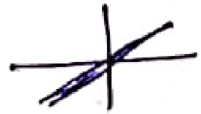
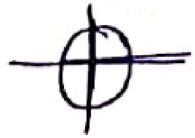
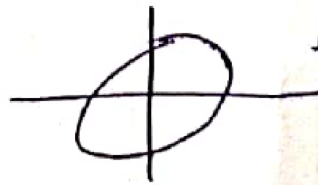
↳ Known signal is applied to the horizontal plate & unknown signal is applied at vertical plate.

Shape of Lissajous depends on

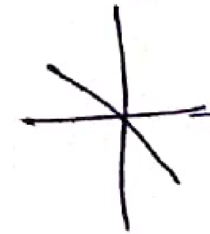
- Amp. of applied signals
- phase diff. b/w two signals
- Ratio of freqn of two signals

phase diffn $\phi = \sin^{-1}\frac{y_1}{y_2} = \sin^{-1}\frac{x_1}{x_2}$



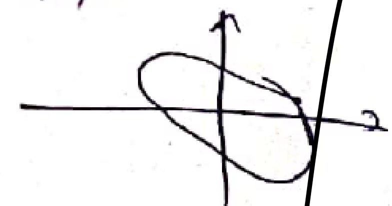
Phase diff ϕ	LP	
(i) 0° or 360°		straight line
(ii) 90° or 270°		circle
(iii) $0 < \phi < 90^\circ$ $270^\circ < \phi < 360^\circ$		ellipse

(iv) $\phi = 180^\circ$



(V) $90^\circ < \phi < 180^\circ$

$180^\circ < \phi < 270$



HDP – $v_x = v_m \sin \omega_x t$

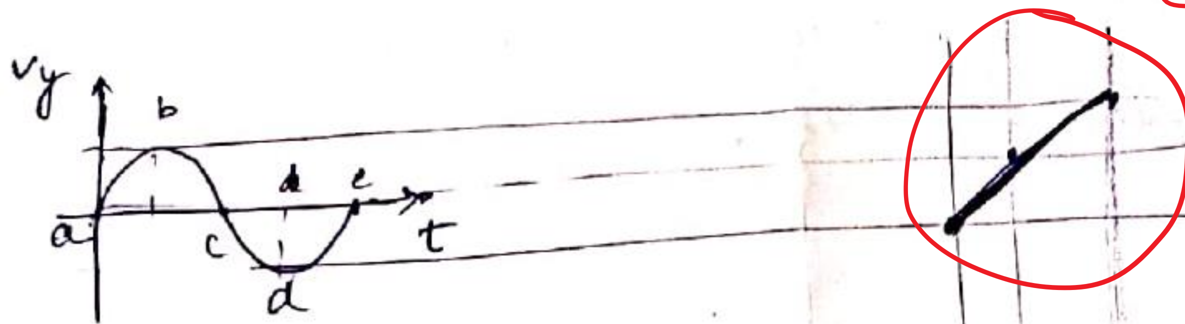
VDP – $v_y = v_m \sin \omega_y t$

Case I

$\phi = 0^\circ$

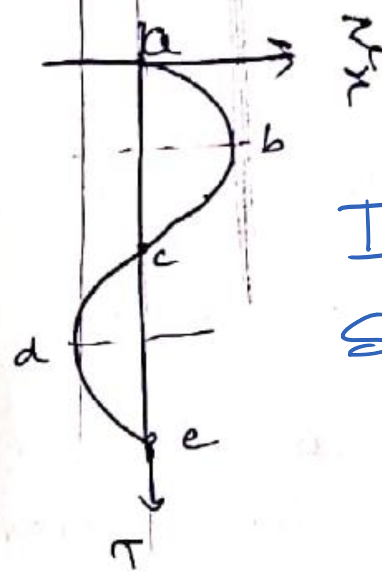
$\omega_x = \omega_y = \omega$

(i) $\phi = 0$, $v_{m_1} = v_{m_2} = v_m$



Lissajous Figure

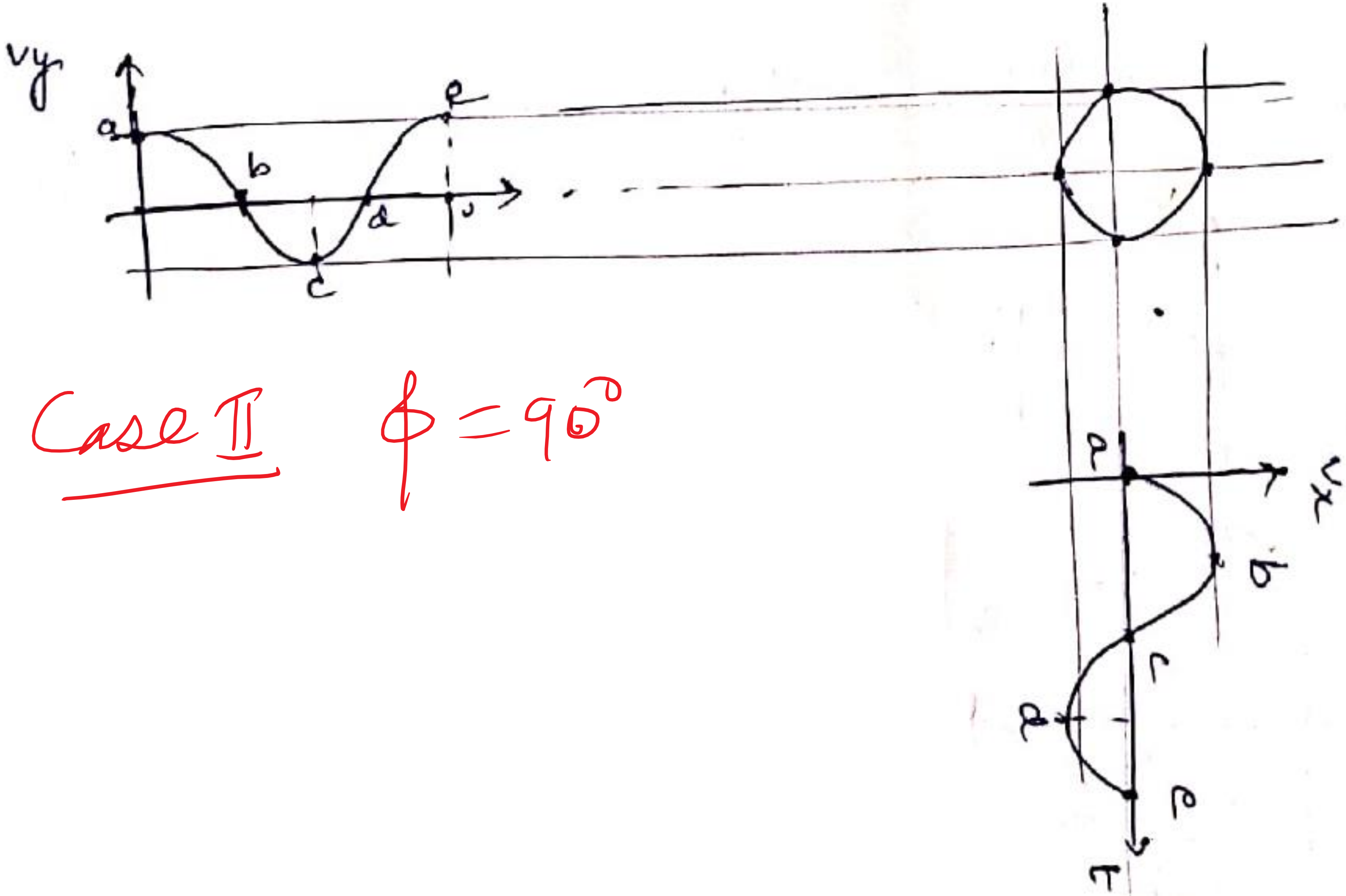
I signal



II signal

Taking projections of both signals

(ii) $\phi = 90^\circ$ $\quad v_y = V_m \sin \omega t$



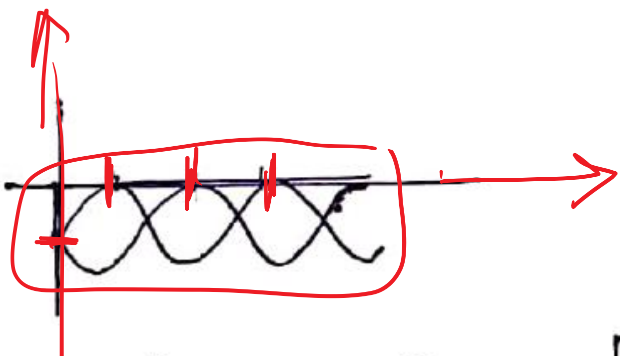
Case II $\phi = 90^0$

Freqⁿ measurement using lissajous pattern

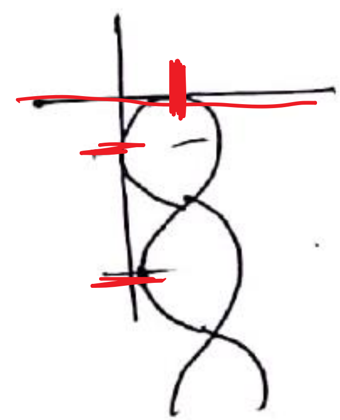
f_H → unknown freqⁿ – applied at HDP

f_V → known freqⁿ applied at VDP

$$\frac{f_V}{f_H} = \frac{\text{No. of horizontal tangencies}}{\text{No. of vertical tangencies}} \qquad \frac{3}{1}$$



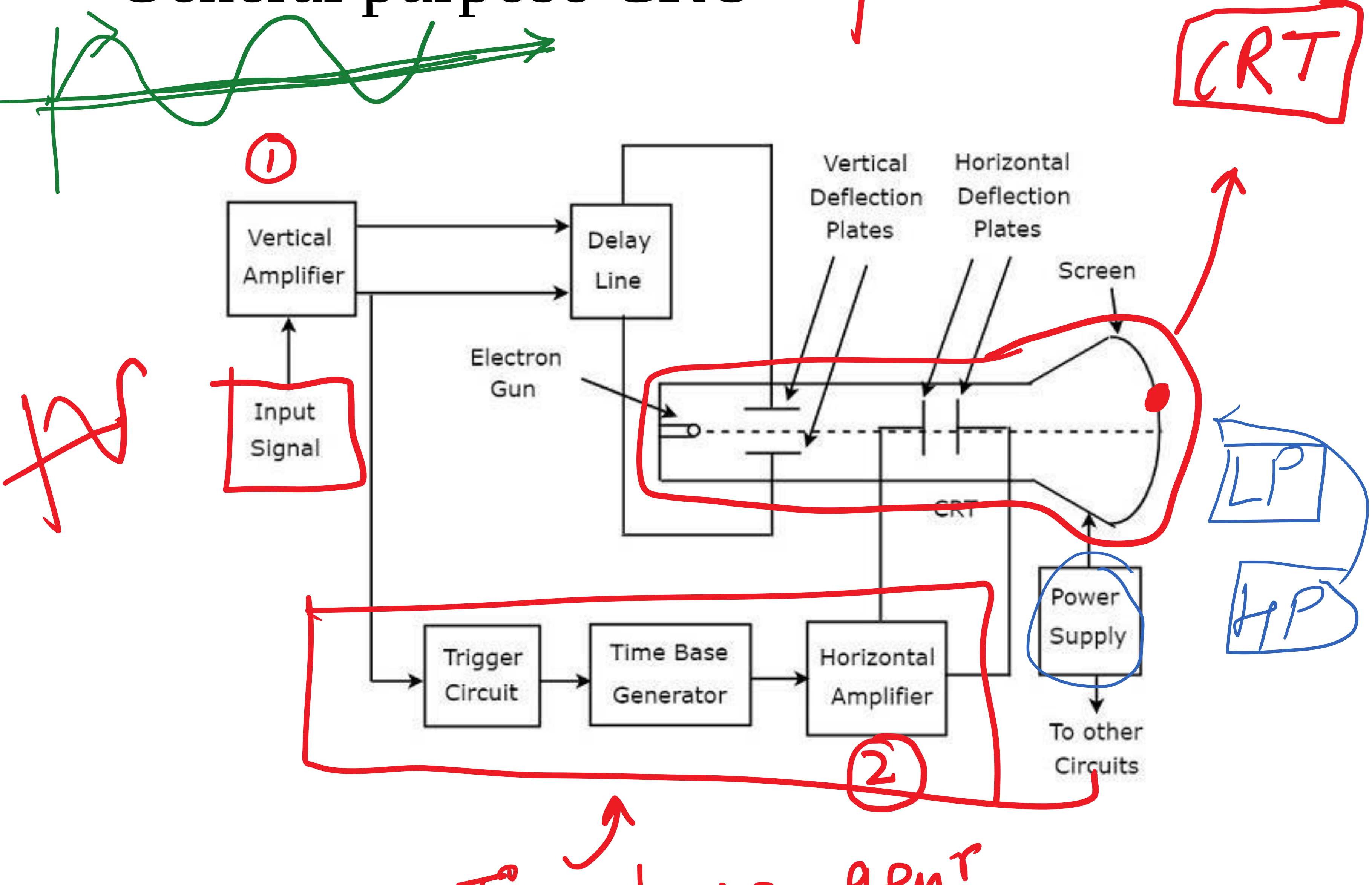
$$\frac{f_V}{f_H} = \frac{3}{1} \Rightarrow \boxed{f_V = 3 f_H}$$



$$\frac{f_V}{f_H} = \frac{1}{2}$$

$f_V = f_H/2$

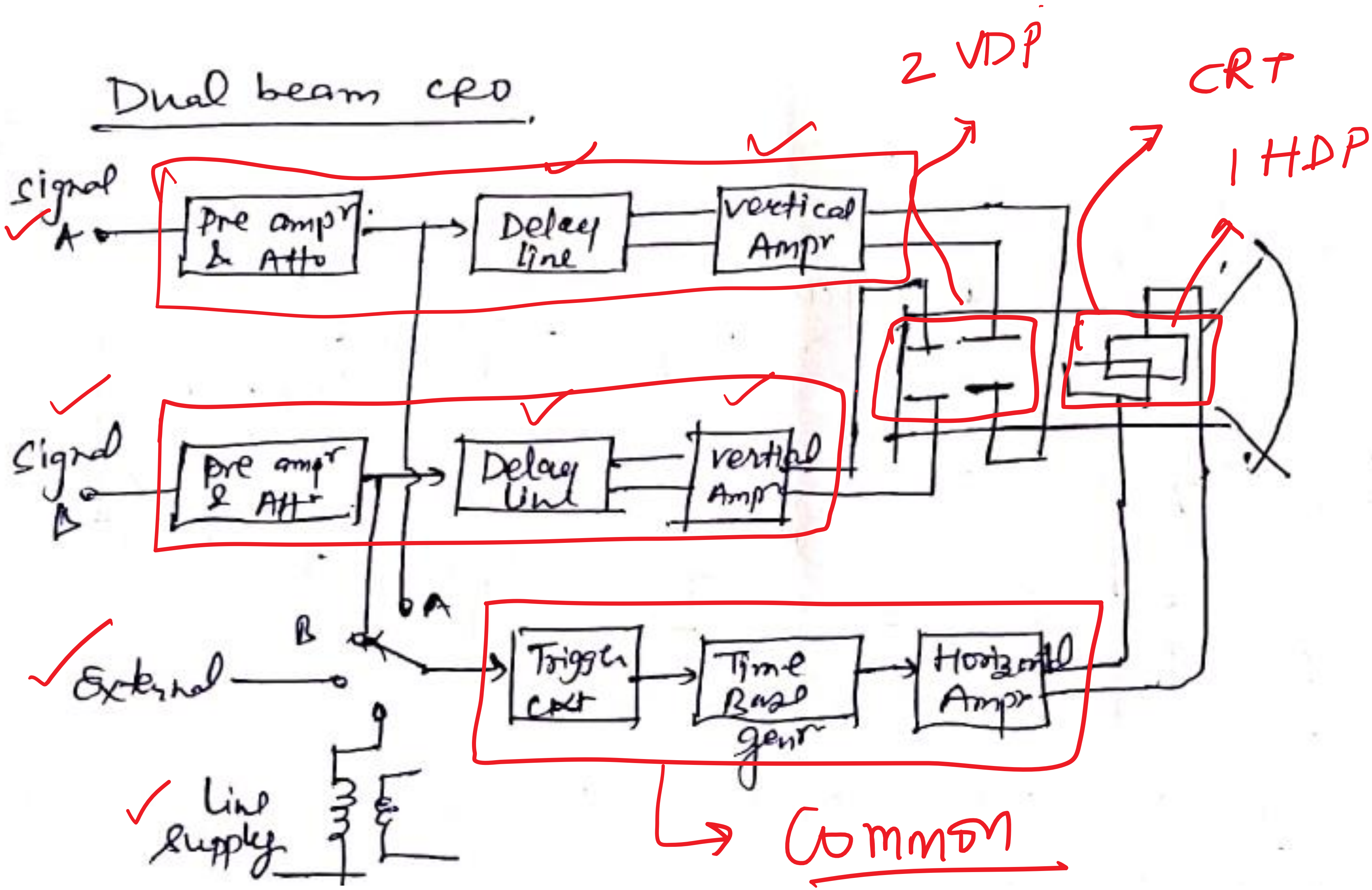
General purpose CRO

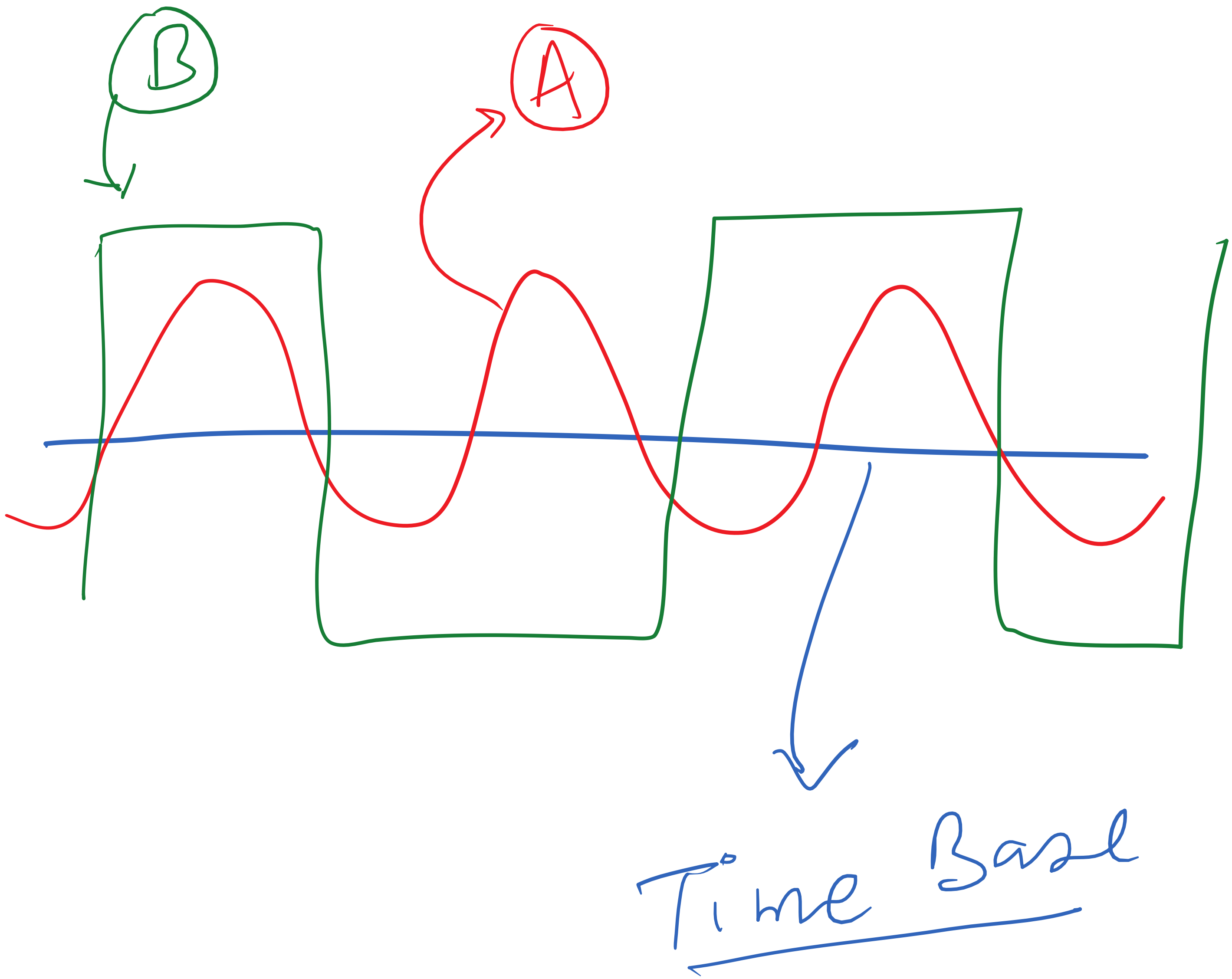


The **function** of each block of CRO is mentioned below.

- **Vertical Amplifier** − It amplifies the input signal, which is to be displayed on the screen of CRT.
- **Delay Line** − It provides some amount of delay to the signal, which is obtained at the output of vertical amplifier. This delayed signal is then applied to vertical deflection plates of CRT.
- **Trigger Circuit** − It produces a triggering signal in order to synchronize both horizontal and vertical deflections of electron beam.
- **Time base Generator** − It produces a sawtooth signal, which is useful for horizontal deflection of electron beam.
- **Horizontal Amplifier** − It amplifies the sawtooth signal and then connects it to the horizontal deflection plates of CRT.
- **Power supply** − It produces both high and low voltages. The negative high voltage and positive low voltage are applied to CRT and other circuits respectively.
- **Cathode Ray Tube (CRT)** − It is the major important block of CRO and mainly consists of four parts. Those are electron gun, vertical deflection plates, horizontal deflection plates and fluorescent screen.

Dual beam CRO

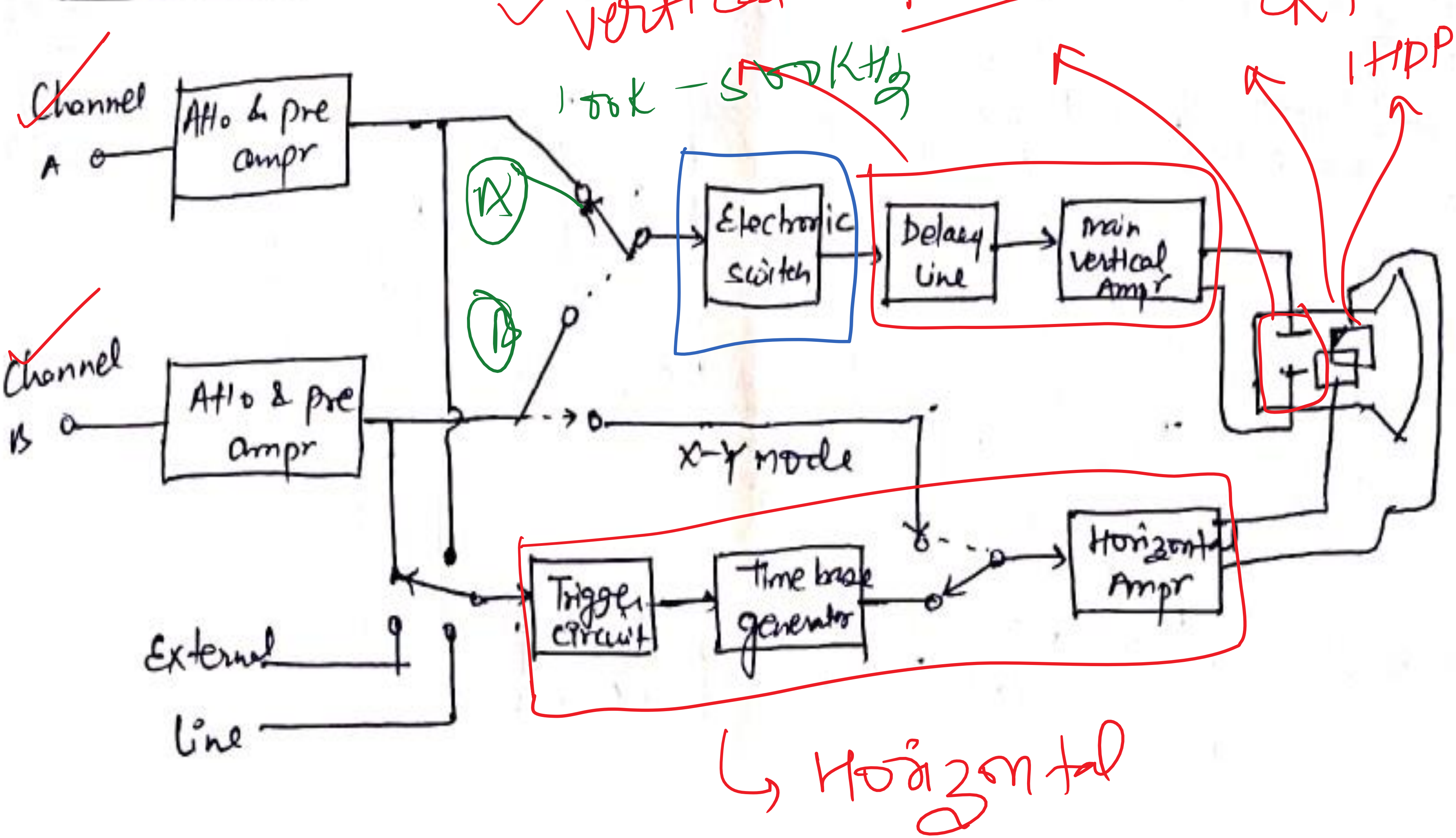



B
A
Time Base

* When more than one signals are given to the vertical plate of oscilloscope simultaneously than the CRO is known as multibeam or multitrace CRO.

* **Dual beam**: Compare one signal with another.
  - Each input signal is fed to two separate vertical ampr
  - Connected to two separate set of vertical def' plates
  - CRT produces two completely separate ele-beams that can be independently deflected in the vertical dirn
  - Single horizontal ampr & single set of horizontal def. plate so both images of input signal sweep at the same rate.
  - Sweep generator (time base genr) can be triggered internally from either channnel, from an externaly applied trigger signal or from the line voltage.

Dual trace


Vertical
1 VDP
CRT
1 HDP
100K – 500KHz
Channel A
Att & pre ampr
Channel B
Att & pre ampr
A
B
Electronic switch
Delay line
main vertical Ampr
X-Y mode
Trigger circuit
Time base generator
Horizontal Ampr
External
line
Horizontal

→ Single ele. gun → produces a dual trace display by means of electronic switching.

→ Two seperate vertical channels — A & B < amplitude of each can be independently controlled by preampr.

→ electronic switch ; passing one signal at a time to main vertical ampr.

→ Two common operating modes of electronic switch.
- → alternate mode
- → chope mode.

(1) Alternate mode ; The ele. switch alternately connects to main vertical ampr to channels A & B and adds a different DC component to each signal.

(2) Chopped mode ; Elec. switch free runs at a high freqⁿ of the order of 100k to 500kHz.

→ Small segments from channel A & B are connected alternately to the vertical ampr. & displayed on the screen.

Sr. No.	Dual trace CRO	Dual beam CRO
1.	One electron beam is used to generate two traces.	Two electron beams are used
2.	One vertical amplifier is used.	Two vertical amplifiers are used
3.	The two signals are not displayed simultaneously in real time but appears to be displayed simultaneously.	The two signals are displayed simultaneously
4.	Same beam is shared between the two signals hence difficult to switch quickly between the traces.	Two separate beams are used hence easy to switch between the traces.
5.	As two signals are displayed separately, the signals may have different frequencies.	The two signals must have same frequency or their frequencies must be integer multiples of each other.
6.	The size and weight is less.	The size and weight is more.
7.	Cannot be operated at fast speed hence two separate fast transient signals cannot be grabbed.	Can be operated at very high speed hence two separate fast transient signals can be easily grabbed.
8.	The cost is less due to single beam.	The cost is more due to two beams.
9.	The two different modes of operation are alternate and chop.	The two different types are using double gun tube or split beam using single electron gun

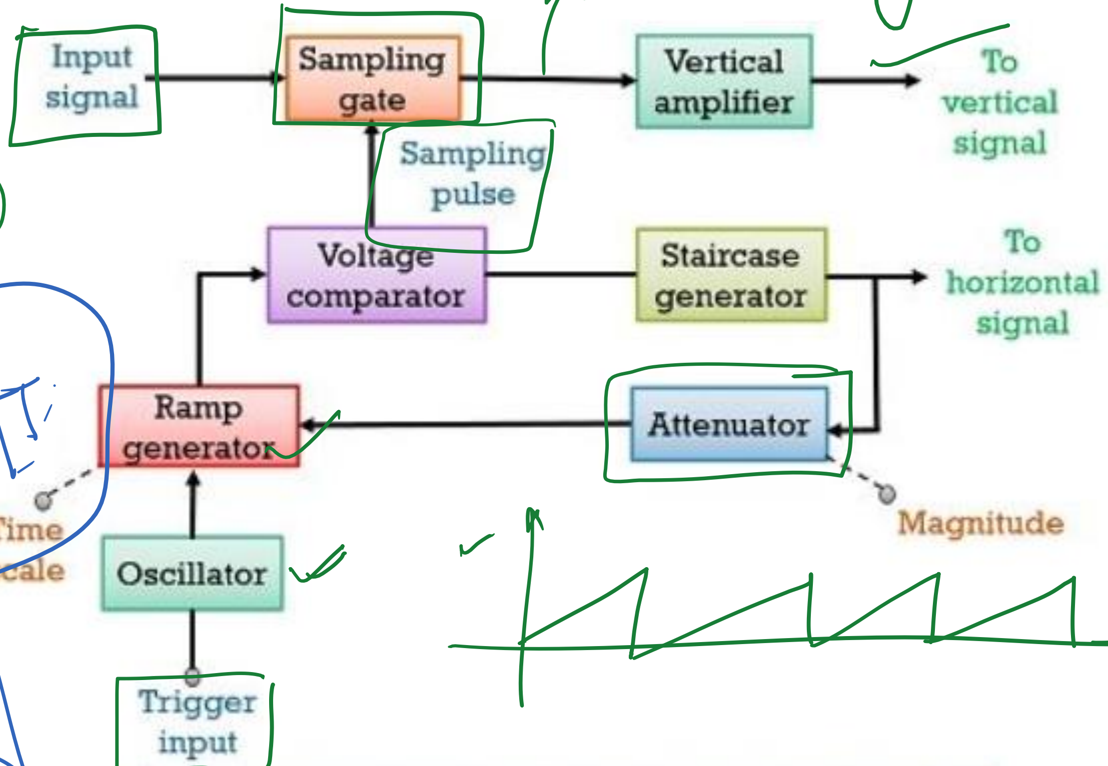
Sampling Oscilloscope

→ fast

Continuous domain → discrete

sampled signal

ADC



Block diagram of Sampling Oscilloscope

sampled signal

Quantization → digital

→ used to examine very fast signals
→ samples are taken at differ portions of the waveform over successive cycles, and then total picture is stretched.
→ used to measure very high speed event;
sweep speed — 10 ps per div
B.W — ~15 GHz.

→ Draw back → can only be used for repetitive waveform.
→ conventional CRO → limited sensitivity & B.W. & small display size.

→ i/p signal is delayed & sampled by a diode gate.
→ sampled signal is saved on a capacitor store. amplified & fed to vertical plates
→ unity f/b is used from ampr to sampling gate to ensure voltage on capa store only incr by incremental value of i/p voltage change.
→ staircase is reset after certain no. of steps (100)
→ staircase waveform also feeds the horizontal plate of CRT. & used to move the spot across the screen

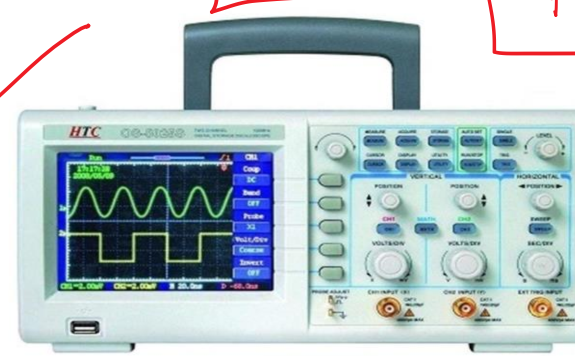
Digital Storage Oscilloscope

Digital Storage Oscilloscope is an instrument that **analyses the signal digitally** and **stores the data in the electronic digital memory**. By examining the stored traces in memory, it can display **visual** as well as **numerical values**.

- It digitizes the input signal in order to have subsequent digital signals. The input is stored in digital memory in the form of **0** and **1**. This stored digitized signal is then viewed on the **CRT screen** after the signal reconstruction in analog form.

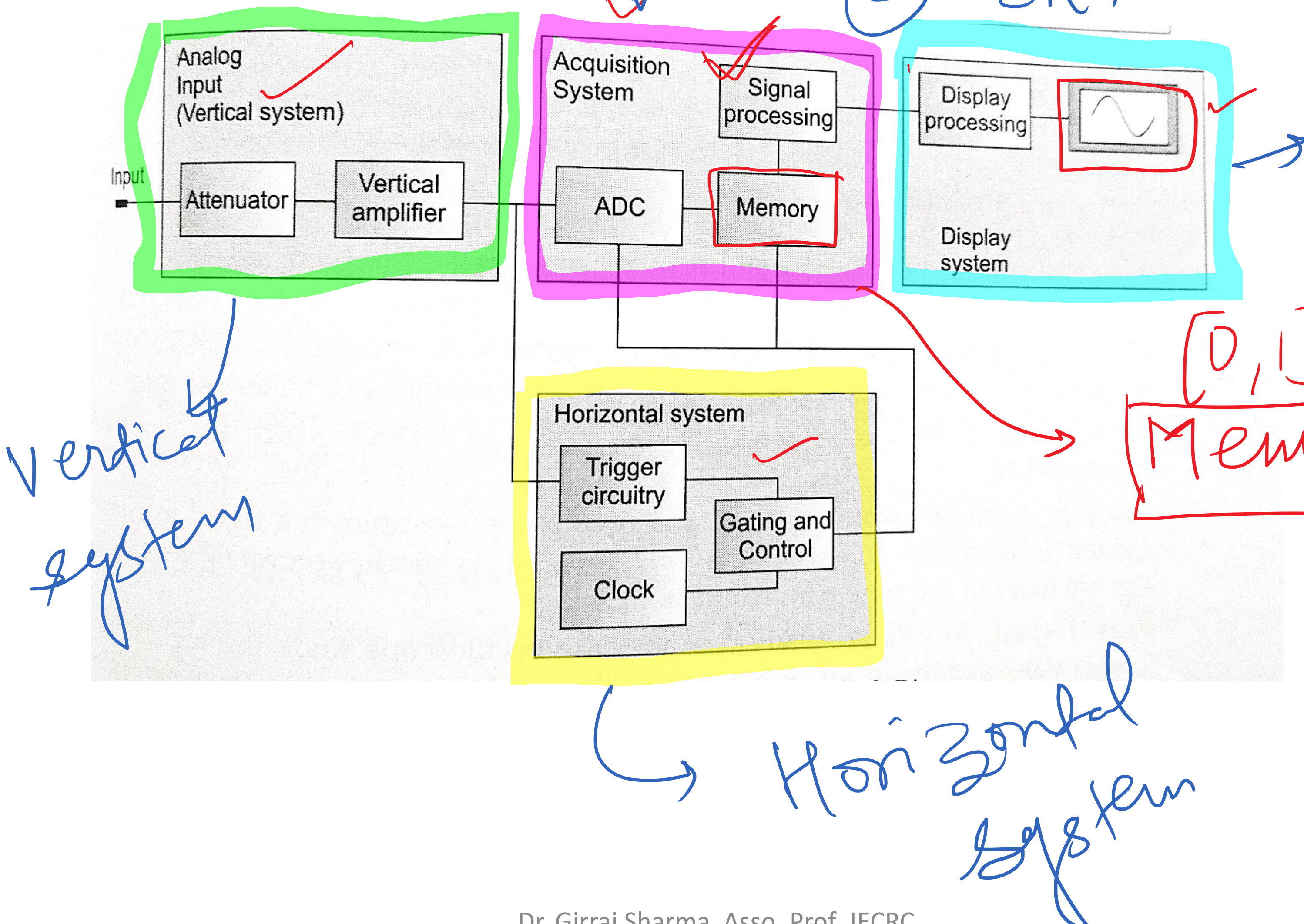
- Here, the digital copy of input waveform is stored and further analysed using **Digital Signal Processing techniques**.

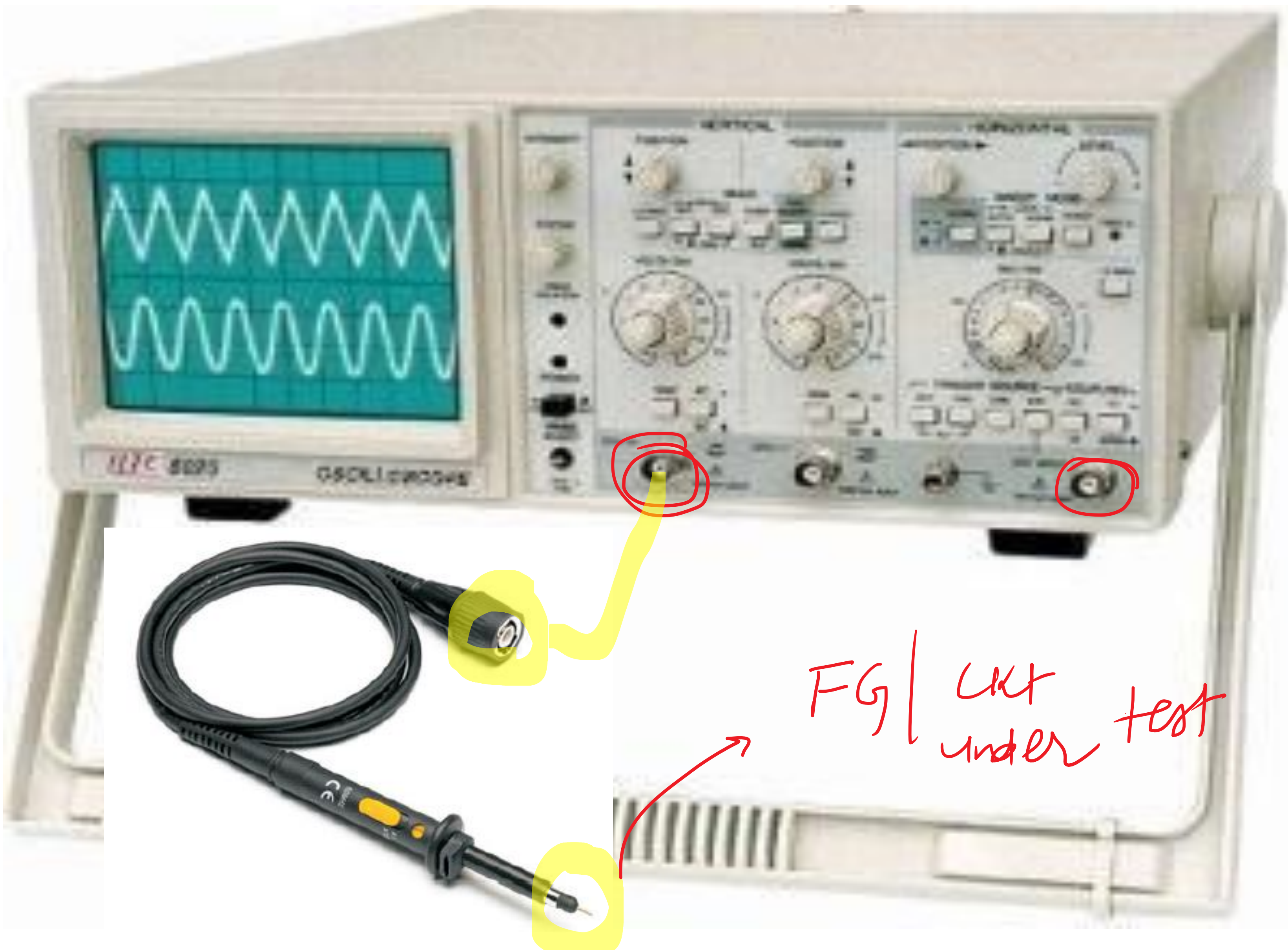
- The **maximum frequency** that can be measured by using Digital Oscilloscope basically **depends** on **sampling rate** and **nature of converter**.



Block diagram of a DSO

1. Vertical system
2. Horizontal System
3. CRT




FG | ckt
under test

Oscilloscope (CRO) Probes

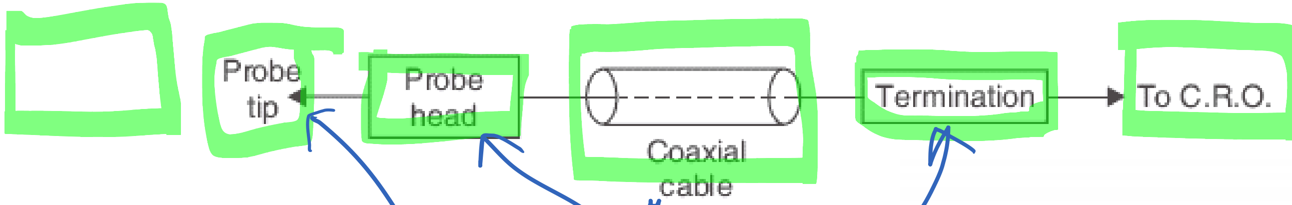
- Oscilloscope Probes are a conducting wire which is used to establish a connection between the circuit under test and the measuring instrument. While connecting the test circuit, the probe does not alter, load or disturbs the circuit and signal conditions to be analyzed.

- Any signal going to the oscilloscope will first pass through the probe. Therefore bandwidth of probes combines with the bandwidth of CRO. The probe bandwidth must be higher than the oscilloscope bandwidth. The probe bandwidth is chosen to at least 10 times of CRO frequency.

- The probe should have high impedance. The probe bandwidth should be as high as possible. It should be about 10 times the bandwidth of the oscilloscope. The ideal oscilloscope probes offer the following key attributes:

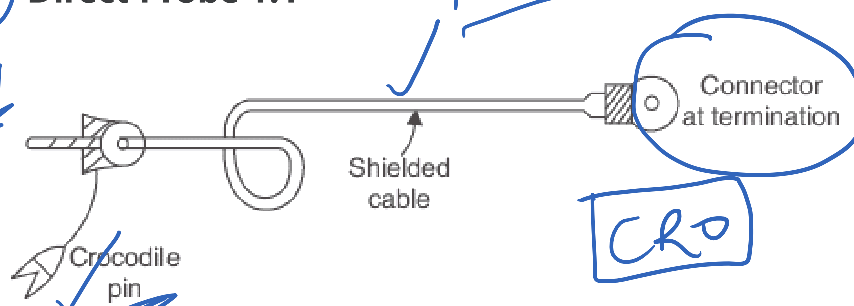
1. Ease of connection
2. Absolute signal fidelity
3. Zero signal source loading
4. Complete noise immunity

The general diagram of the oscilloscope probes is shown in the Figure below.

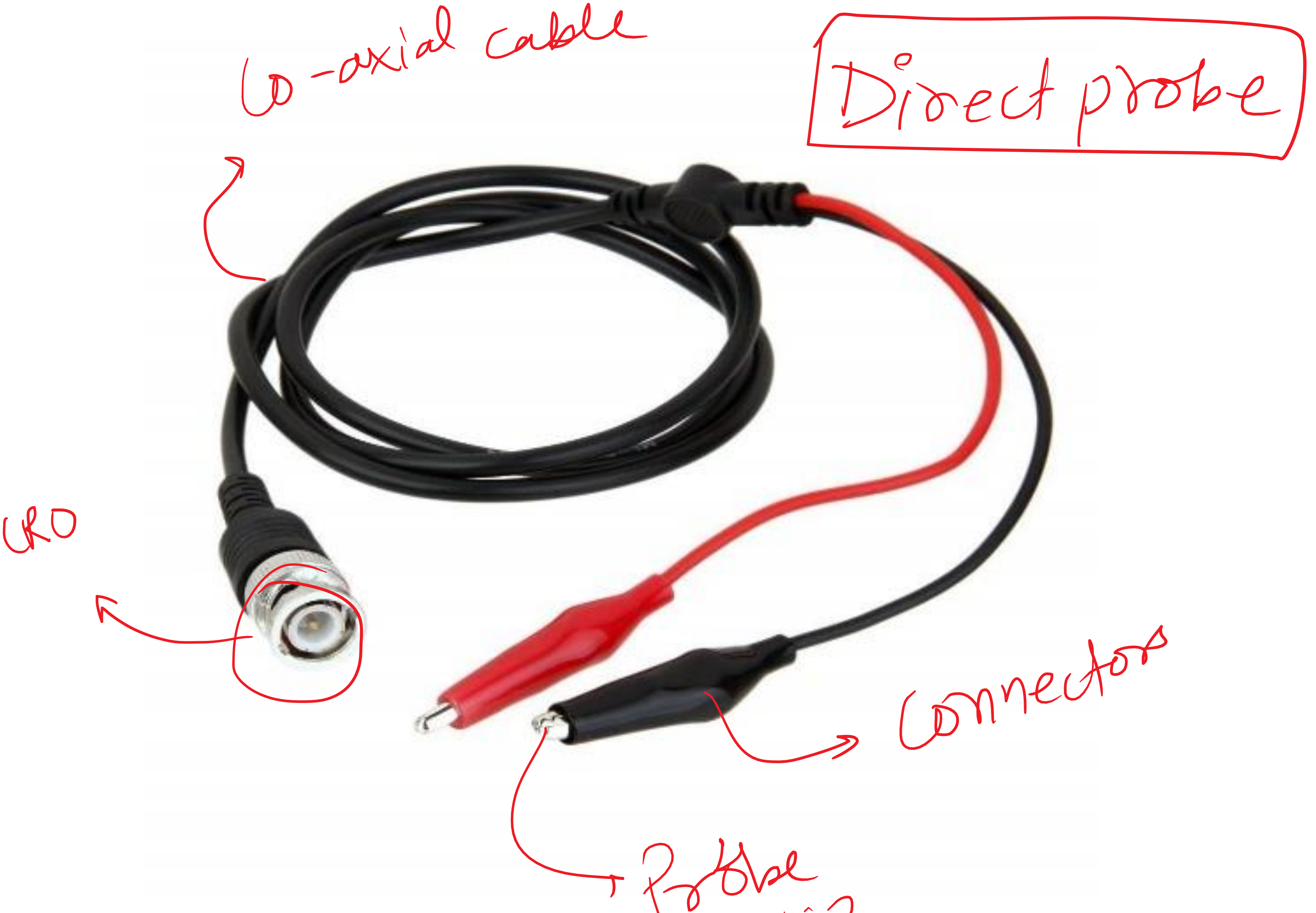


1. **Direct probe**
2. **Isolation Probe**
3. **High impedance or 10: 1 Probe**
4. **Active Probes**
5. **Current Probe**
6. **Differential Probes**

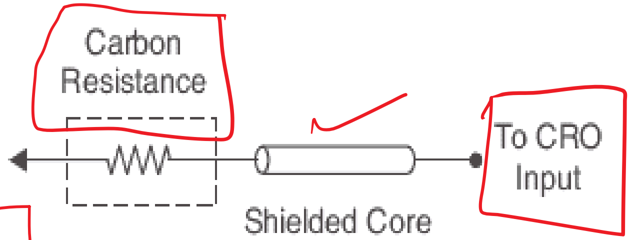
Direct Probe 1:1



- These are the simplest type of probes.
- These probes terminate with banana tips or other types of tips.
- The tip of the probe has crocodile clips or other means of connecting the oscilloscope to the test circuit.
- The probes use shielded co-axial cable.
- This type of probe does not provide any improvement in the input impedance. They are called as “1X probes”.

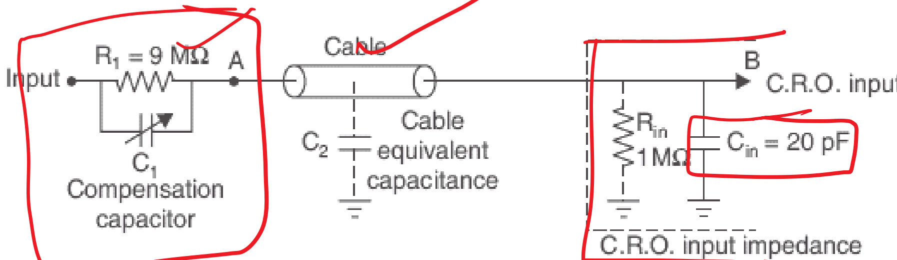

Direct probe
Co-axial cable
CRO
Connector
Probe tip

Isolation Probe



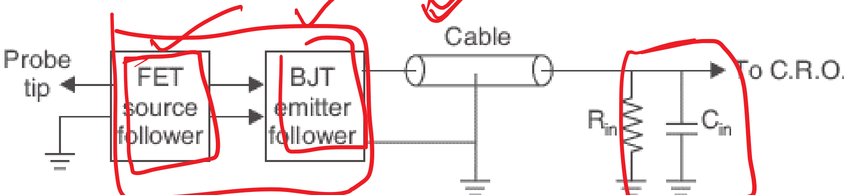
- The input capacitance of the oscilloscope and the stray capacitance of the test lead are very high. It causes the sensitive circuit to break into oscillation when CRO is connected.
- This effect can be prevented by an isolation probe. The isolation probe is made by placing a carbon resistor in series with a test lead.
- An isolation probe is employed to avoid the undesirable circuit loading effect of the shielded probe.

High Impedance or 10: 1 Probe



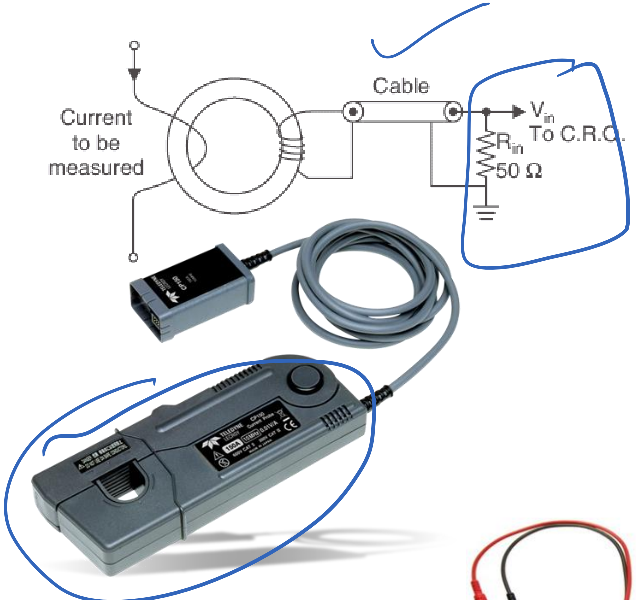
- This probe is also known as a passive voltage probe.
- The basic function of this probe is to increase the input impedance and reduce the effective input capacitance of an oscilloscope.
- This probe head uses a parallel resistor and capacitor combination.
- The resistance R1 is shunted by an adjustable capacitor C1. This capacitor is called a compensating capacitor.
- The resistor R1 and C1 are designed such that, input increases by factor 10 and input capacitance decreases by a factor of 10. Therefore this combination of R_1 and C_1 is called **x10 probe**.

Active Probe



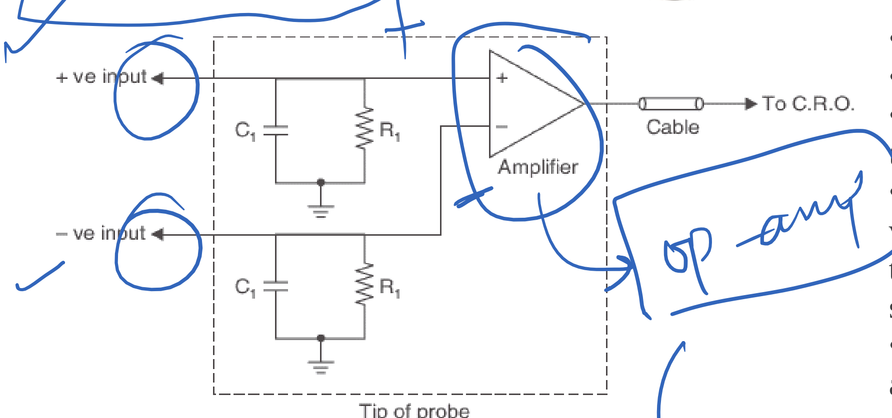
- The active probes are used for connecting fast-rising and high-frequency signals.
- These probes are very useful for small signal measurements as their attenuation factor is very small.
- The active probe consists of an active element like FET source follower circuit and BJT emitter follower circuit along with a co-axial cable termination.
- FET source follower provides high input impedance which reduces loading effect.

Current Probe



•CRO can be used to measure current if the current is converted to a voltage. It is done by the current probe.
•It uses the concept of the Hall Effect. According to Hall Effect, when a current flow in conductor or semiconductor which is perpendicular to the magnetic field, a potential difference appears between the opposite edges of conductor or semiconductor at right angles to the current and to the magnetic field.
•This probe provides a method of inductively coupling the signal to the CRO input.
•The direct electrical connection between the test circuit and CRO is not necessary.
•This probe can be clamped around a wire carrying an electrical current without any physical contact to the probe. Thus the magnitude of current with a frequency range from d.c to 50 MHz can be measured using this probe.

Differential Probes



•They are an active probe.
•It has two inputs, positive and negative.
•It has a separate ground lead and it drives single terminated 50Ω cable to transmit its output to one oscilloscope channel.
•The output voltage signal is proportional to the difference between the voltages appearing to the input terminals. There is a restriction that the two input signals must be within a few volts from the ground so that signals can stay within the dynamic range of the probe.
•The output is proportional to the difference between the two inputs and hence the name, differential probe.

Numerical Problems

PROBLEM 8.1 Calculate the amplitude and rms value of the sinusoidal voltage of the waveform shown in Figure 8.19. The vertical attenuator is set at 2 mV/div.

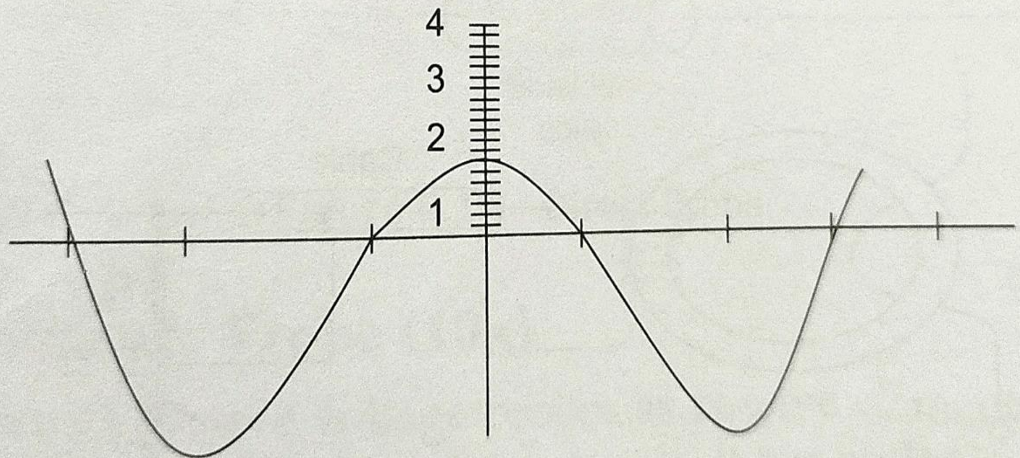


Figure 8.19

Solution: It can be seen in the figure that the screen divided as one part is subdivided into 5 units. So, 1 subdivision = 1/ 5 = 0.2 units.

So, the peak value of the sinusoidal voltage will be,

$$\begin{aligned} \text{2 full parts + 3 subdivisions} &= 2 + 3 \times 0.2 \\ &= 2.6 \text{ units} \end{aligned}$$

So, $V_{p-p} = 2.6 + 2.6 = 5.2$ units.

So, V_{p-p} = no. of divisions × volts/division

$= 5.2 \times 2 \times 10^{-3} = 10.4$ mV

and V_m = Amplitude = $V_{p-p}/2$

$= 10.4/2 = 5.2$ mV

rms value of the sinusoidal voltage of the waveform shown in Figure 8.19.

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{5.2\,\text{mV}}{\sqrt{2}} = 3.6769 \text{ mV}$$

PROBLEM 8.2 The Lissajous pattern is obtained on the CRO screen by applying the horizontal frequency of 1 kHz. The Lissajous pattern has 5 vertical tangencies and 10 horizontal tangencies, calculate the vertical frequency applied.

Solution: Given,

$f_H = 1\ KHz$ $\quad$ $t_v = 5$

$f_v = ?$ $\quad$ $t_h = 10$

$$\frac{f_v}{f_H} = \frac{t_h}{t_v} = \frac{10}{5} = \frac{f_v}{1}$$

$f_v = 2\ KHz$

PROBLEM 8.2 The Lissajous pattern is obtained on the CRO screen by applying the horizontal frequency of 1 kHz. The Lissajous pattern has 5 vertical tangencies and 10 horizontal tangencies, calculate the vertical frequency applied.

Solution: Given,

No. of vertical tangencies = 5

No. of horizontal tangencies = 10

So, by the formula,

$$\frac{f_V}{f_H} = \frac{\text{Number of horizontal tangencies}}{\text{Number of vertical tangencies}}$$

$$= 10/\ 5 = 2$$

Vertical frequency applied, $f_V = 2 \times f_H = 2 \times 1 \text{ kHz} = 2 \text{ kHz}$

PROBLEM 8.3 Calculate the maximum velocity of electrons in a CRT having cathode-anode voltge of 1000 V. Assume the electrons to leave the cathode with zero velocity, Charge of electron = 1.6×10^{-19} C and mass of electron = 9.1×10^{-31} kg.

PROBLEM 8.3 Calculate the maximum velocity of electrons in a CRT having cathode-anode voltge of 1000 V. Assume the electrons to leave the cathode with zero velocity, Charge of electron = 1.6×10^{-19} C and mass of electron = 9.1×10^{-31} kg.

Solution: Accelerating voltage $V_a = 1000$ V , $e = 1.6 \times 10^{-19}$ C, m = 9.1×10^{-31} kg

$$\text{Maximum velocity of electrons} = \sqrt{2 \times V_a \times \frac{e}{m}}$$

$$= \sqrt{\frac{2 \times 1000 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}} = 18.75 \times 10^{6} \text{ m/s}$$

PROBLEM 8.6 The deflection sensitivity of a CRO is 0.02 mm/V. If an unknown voltage is applied to the horizontal plates, the spot shifts 4.0 mm horizontally. Find the value of unknown voltage.

PROBLEM 8.6 The deflection sensitivity of a CRO is 0.02 mm/V. If an unknown voltage is applied to the horizontal plates, the spot shifts 4.0 mm horizontally. Find the value of unknown voltage.

Solution: Peak-to-peak value of unknown AC voltage

$$V_{\text{peak-to-peak}} = \frac{\text{Length}}{\text{Deflection sensitivity in mm / V}}$$

$$= \frac{4}{0.02} = 200 \text{ V}$$

Peak value of unknown voltage

$$V_{\text{peak}} = \frac{V_{\text{peak-to-peak}}}{2} = \frac{200}{2} = 100 \text{ V}$$

RMS value of unknown voltage

$$V_{\text{rms}} = \frac{V_{\text{peak}}}{\sqrt{2}} = \frac{100}{\sqrt{2}} = 70.7 \text{ V}$$