UNIT-V
OSCILLOSCOPE

CRO

In studying the various electronic circuits, we come across signals which are functions of time. Such signals may be periodic or non periodic. CRO is a device which allows the amplitude to be displayed as a function of time.

The CRO is a voltmeter, instead of mechanical deflection of a pointer, CRO uses the movement of an election beam against a fluorescent screen, which produces the movement of a visible spot. The movement of the spot is proportional to the varying magnitude of the signal.

The election beam can be deflected in two directions, horizontal or x-direction and vertical or y-direction. Thus CRO can be regarded as a xy plotter.

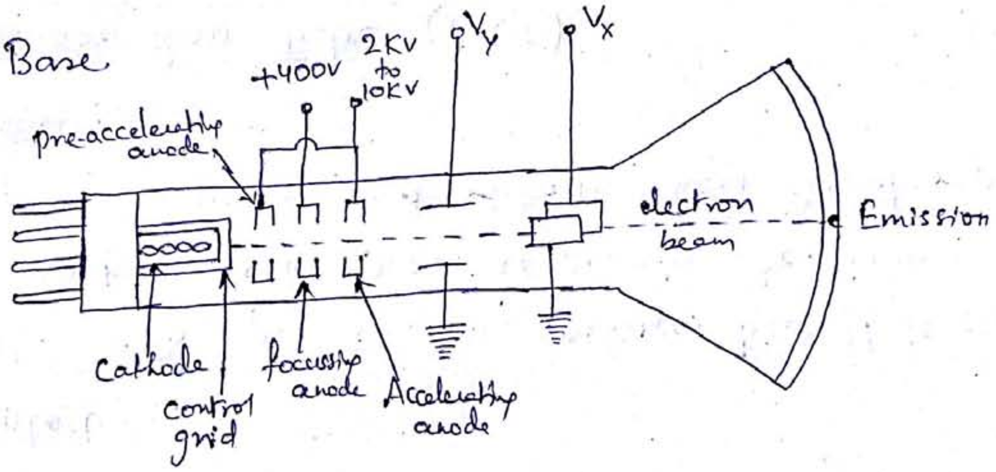
The CRO operates on voltages but it is possible to convert current, pressure, strain etc. into voltage using transducers and obtain their visual representation on CRO.

Cathode Ray Tube (CRT)

The CRT is the heart of the CRO. It generates the electron beam, accelerates the beam, deflects the beam and the beam appears as a spot on the screen.

Components of a CRT

1) Electron gun
2) Deflection system
3) Fluorescent screen
4) Glass tube or envelope
5) Base



Electron gun

The election gun section provides a sharply focussed electron beam directed towards the fluorescent coated screen. This section starts from thermally heated cathode, emitting the electrons. Control grid is given a negative potential w.r.t cathode. The control grid controls the number of electrons in the beam going to the screen.

The momentum of the electrons (their number x speed) determines the intensity or brightness of the light emitted from the fluorescent screen due to the election bombardment. As the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid

Voltages applied to various grids w.r.t cathode is taken as common point. This negative control voltage can be made variable. A more negative voltage results in less no. of electrons in the beam and hence decreased brightness of the spot.

Since the beam consists of many electrons, the beam tends to diverge because the similar (-ve) charges repel each other.

To compensate for such repulsive forces, an adjustable electrostatic field is created between two cylindrical anodes called focusing anodes. The variable positive voltage on the second anode is used to adjust the focus or sharpness of the bright beam spot.

The high positive potential is also given to the pre accelerating anodes and accelerating anodes which accelerates the electrons. The preaccelerating and accelerating anodes are connected to a common positive high voltage which varies between 2kV and 10kV. The focussing anode is connected to a lower positive voltage of about 400V to 500V.

Deflection System

When electron beam is accelerated it passes through the deflection system, with which the beam can be positioned anywhere on the screen

The deflection system consists of 2 pairs of parallel plates – vertical and horizontal deflection plates. One of the plates in each set is connected to ground. To the other plate of each set, external deflection voltage is applied to the Y-input terminal (V_y), which causes the beam to deflect vertically upward due to the attractive forces. A negative voltage applied to the Y-input terminal will cause the electron beam to deflect vertically downward due to the repulsion forces.

Similarly a positive voltage applied to the X-input terminal (V_x) will cause the electron beam to deflect horizontally towards the right. A negative voltage applied to the X-input terminal will cause the electron beam to deflect horizontally towards the left of the screen.

When voltages are applied simultaneously to vertical and horizontal deflecting plates, the electron beam is deflected due to the resultant of two voltages.

The horizontal deflection x produced is proportional to the horizontal deflecting voltage V_x applied to x-input.

$$x \propto V_x$$

$$x = K_x V_x$$

$$K_x = \frac{x}{V_x} \text{ cm/volt or division/volt.}$$

K_x is called the horizontal sensitivity of the oscilloscope.

The vertical deflection y produced is proportional to the vertical deflecting voltage V_y applied to y-input.

$$y \propto V_y$$

$$y = K_y V_y$$

$$K_y = \frac{y}{V_y} \text{ cm/volt or division/volt.}$$

called vertical sensitivity.

Fluorescent screen

The light produced by the screen does not disappear immediately when bombardment by electrons ceases. The time period for which the trace remains on the screen after the signal becomes zero is known as persistence.

The persistence may be as short as few μsec or as long as tens of seconds or minutes. Medium persistence traces are mostly used for general purpose applications. Long persistence traces are used in the study of transients. Short persistence is needed for extremely high speed phenomena.

Screen material

The screen is coated with a fluorescent material called phosphor which emits light when bombarded by electrons.

Ex:- Willemite (Zinc Orthosilicate)

$ZnO + SiO_2$ with traces of manganese.

This produces greenish trace.

Aluminizing

The kinetic energy of electron beam is converted into light and heat energy when it hits the screen. The heat so produced gives rise to phosphor burn. Thus, the phosphor must have high burn resistance to avoid damage to the screen.

The phosphor screen is provided with an aluminium layer called aluminizing the CRT.

The aluminium layer acts as a heat sink for the phosphor and thus reduces the chances of phosphor burning.

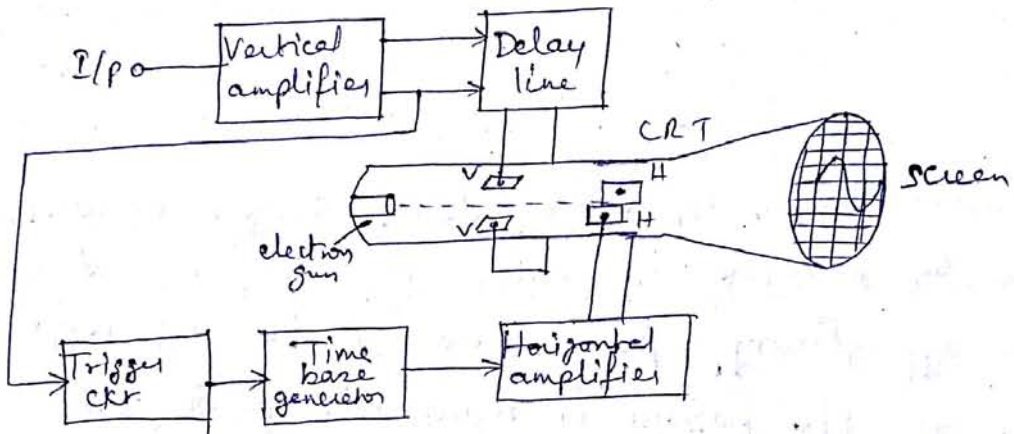
Glass tube or envelope

All components of the CRT are enclosed in an evacuated glass tube called envelope. This allows the emitted electrons to move about freely from one end of the tube to the other end.

Base

The base is provided to the CRT through which the connections are made to the various parts.

Block diagram of a CRO

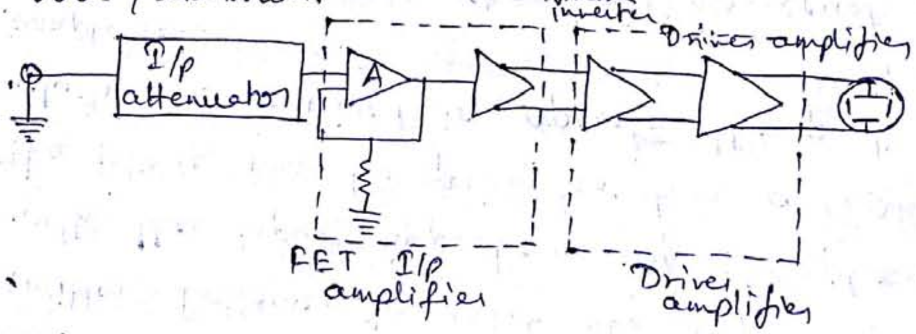


CRT :- The cathode ray tube is the heart of the CRO, used to emit the electrons required to strike the phosphor screen to produce the spot for display

Vertical amplifier

The input signals are generally not strong to provide the measurable deflection on the screen. The vertical amplifier is used to amplify the input signal.

The vertical amplifier consists of several stages with fixed overall sensitivity or gain expressed in volts / division.



The vertical amplifier is kept within its signal handling capability by proper selection of the I/p attenuator switch.

The first element of the preamplifier is the input stage, consisting of a FET source follower whose high input impedance isolates the amplifier from the attenuator.

This FET input stage is followed by a BJT emitter follower, to match the impedance of FET o/p with the input impedance of the phase inverter. The phase inverter provides two antiphase o/p signals which are required to operate the push pull output amplifier.

The push pull stage delivers equal signal voltages of opposite polarity to the vertical plates of the CRT.

Delay line

The delay line is used to delay the signal for some time in the vertical section. If delay line is not used, part of the input gets lost. Thus the I/p signal is not applied directly to the vertical plates but is delayed by sometime using a delay line ckt.

As the signal is delayed, the sweep generator output gets enough time to reach the horizontal plates before the signal reaches the vertical plates.

If the trigger pulse is picked off at time $t = t_0$ after the signal has passed through the main amplifier, then the signal is delayed by x_1 nano seconds, while sweep takes y_1 nano seconds.

The delay line is designed such that x_1 is higher than y_1. Generally $x_1 = 200$ ns and $y_1 = 80$ ns. Thus the sweep starts well in time and no part of the signal is lost.

Trigger circuit

It is necessary that horizontal deflection starts at the same point of the input vertical signal each time it sweeps. Hence to synchronize the horizontal deflection with vertical deflection, a synchronizing or triggering circuit is used. It converts the incoming signal into triggering pulses which are used for synchronization.

Time base generator

The time base generator is used to generate the saw tooth voltage required to deflect the beam in horizontal direction. This voltage deflects the spot at a constant rate. Thus the x-axis on the screen can be represented as time which helps to display and analyze the time varying signals

Horizontal amplifier

The saw tooth voltage produced by the time base generator may not be of sufficient strength. Hence before giving it to the horizontal deflection plates, it is amplified using the horizontal amplifier

Power Supply

The power supply block provides the voltages required by the CRT to generate and accelerate an electron beam and voltages required by other circuits of the CRO like horizontal amplifier, vertical amplifier.

There are two sections of a power supply block. High voltage section of 1000V to 1500V and low voltage of few hundred volts. High voltage is required by the CRT and low voltage for electron gun.

Time base generator

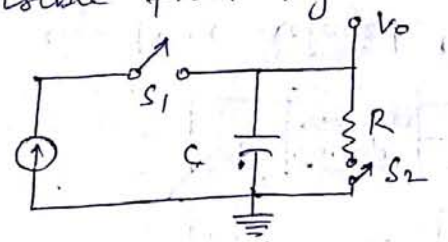
Time domain oscilloscopes require a sweep generator that is linear with time for the x-axis display. The motion of the spot on the screen from extreme left to extreme right is called sweep. The generator which generates a waveform which is responsible for the movement of spot on screen horizontally is called time base generator or sweep generator.

The sweep circuit along with the display gating function is called time base. The linear sweep moves the spot from left to right while the movement of spot from right to left is not visible.

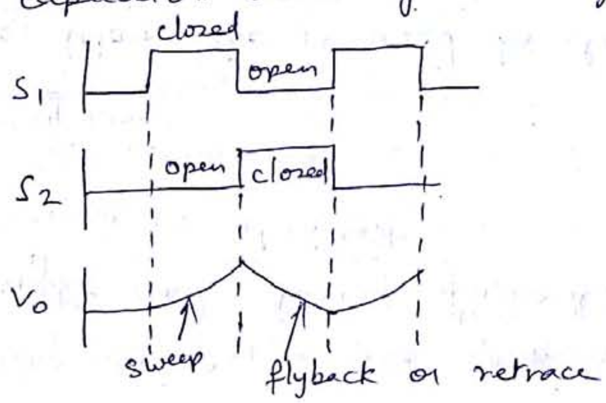
This portion of waveform generated by time base is called flyback or retrace. During this time the CRT is blocked. The time base generator also controls the rate at which the spot moves across the screen which can be adjusted from front panel control.

Basic Principle of time base generator

The basic sweep generator uses the charging characteristics of a capacitor to generate linear rise time voltage. Linearly increasing ramp which becomes zero within very short duration of time. ensures that the spot is visible from left to right and invisible from right to left.



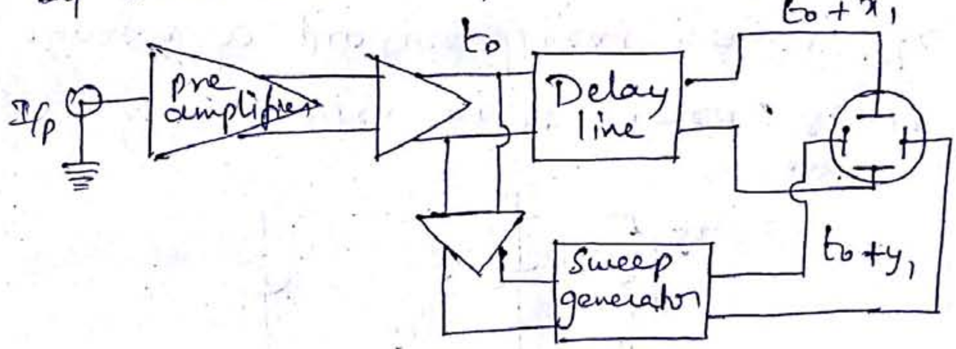
when switch S_1 is closed, S_2 is open, capacitor charges to produce linear ramp. The sweep rate can be controlled by changing the value of capacitor or charging current. when capacitor is charged upto the maximum current, S_2 is closed and S_1 open. The capacitor discharges through resistor R.



During sweep time the spot moves from left to right and during flyback or retrace time, the screen is blanked

Delay Line

The delay line is used to delay the signal for some time in vertical section. When delay line is not used, part of the signal gets lost. Thus the input signal is not applied directly to vertical plates, but is delayed by some time using the delay line.



As the signal is delayed, the sweep generator output gets enough time to reach the horizontal plates before reaching the vertical plates. If the trigger pulse is picked off at a time $t = t_0$ after passing through the main amplifier, the signal is delayed by x_1 nano seconds.

The sweep takes y_1 nano seconds to reach. The design of the delay line is such that the delay time x_1 is higher than time y_1.

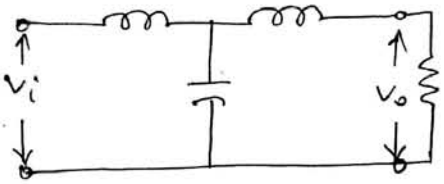
$x_1 = 200\,ns \quad y_1 = 80\,ns$

Types of delay line

1) Lumped parameter delay line
2) Distributed parameter delay line

Lumped parameter delay line

It consists of a number of cascaded symmetrical LC networks called T-sections. Each section is capable of delaying the signal by 3 to 6 nano seconds.



The T-section acts as a low pass filter having cut off frequency as

$$f_c = \frac{1}{\pi\sqrt{LC}}$$

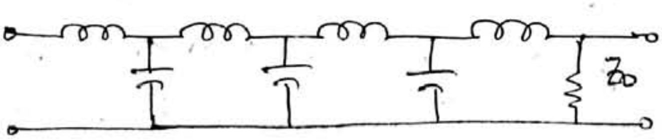
If V_i consists of frequencies much less than cut off frequency, o/p signal V_o will be a faithful reproduction of V_i but delayed in time t_s.

$$t_s = \frac{1}{\pi f_c} = \frac{1}{\pi \cdot \frac{1}{\pi\sqrt{LC}}} = \sqrt{LC}$$

t_s = delay for single T network

For n no. of T-sections, the total delay

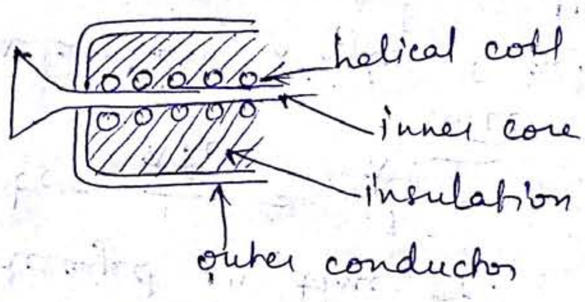
$t_d = n t_s$



Distributed Parameter delay line

It is basically a transmission line constructed with a wound helical coil on a mandrel with insulation. It is a specially manufactured coaxial cable with high inductance per unit length.

The inductance can be increased by winding the helical coil on ferromagnetic core. This increases the characteristic impedance Z_0 and delay time.



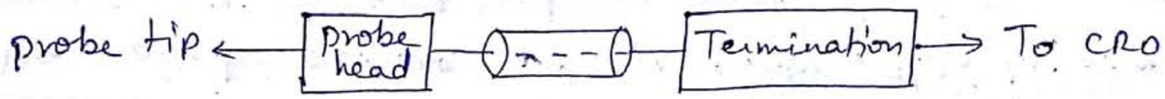
Advantages

1) It does not require precise adjustments as lumped parameter delay line

2) Requires less space

CRO probes

The probe is used with the oscilloscope to connect the circuit to the oscilloscope. while connecting the circuit, the probe does not alter, load or disturb the circuit and signal conditions to be analyzed. To achieve this, the probes should have high impedance and large bandwidth. (10 times the bandwidth of the oscilloscope)



The probe tip is the signal sensing circuitry which may be passive or active. The passive sensing circuitry consists of resistors and capacitors. Active circuitry consists of active components like FET source follower ckt. The coaxial cable is used to connect the probe head to the termination circuitry.

Types of probes

① Direct probes

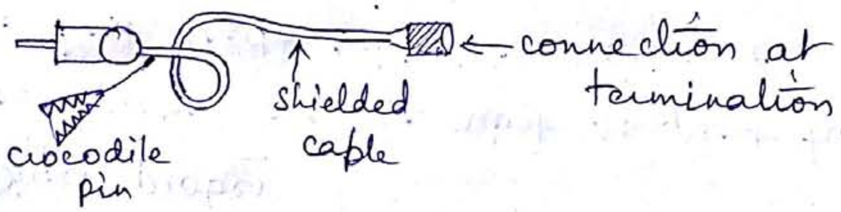
These probes are the most simplest type of probes. Simple test leads which are wires can also be used as direct probes. At the CRO end, such probes terminate with banana tips. At tip, crocodile clips are connected to the test circuit. These probes use a shielded coaxial cable.

These probes do not increase the impedance, hence called 1X probes.

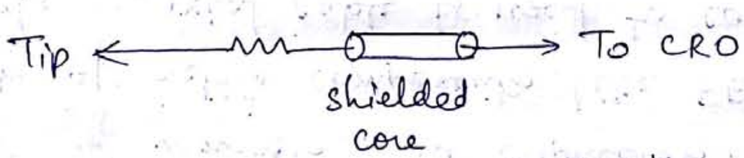
Disadvantage

the stray capacitance of the probe adds with the capacitance of the oscilloscope. At high frequencies, the total input reactance becomes very low, which decreases the input impedance.

This effect is dominant at high frequencies hence the use of such probes is limited to low frequencies only.



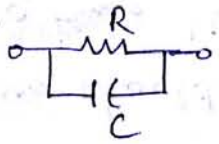
The shunt capacitance effect of such probe at high freq can be reduced by placing a carbon resistor in series with the test leads.



Such a probe is called isolation probe.

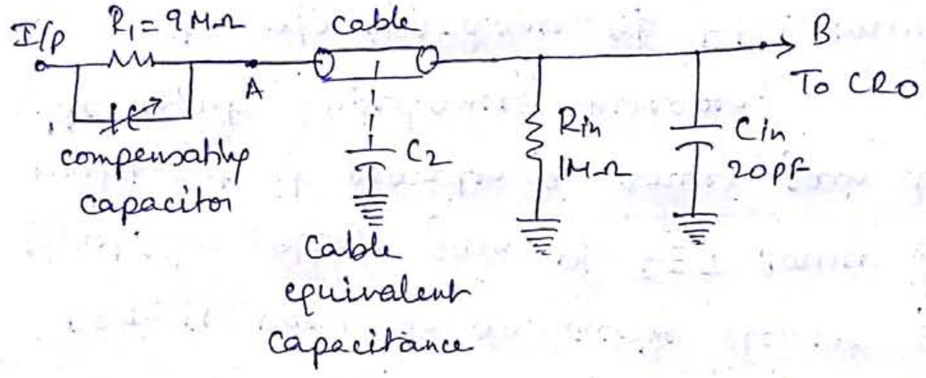
High Impedance Probes (10x)

Also called passive voltage probe. This increases input impedance and reduces input capacitance of oscilloscope. This probe head uses a resistor and capacitor combination

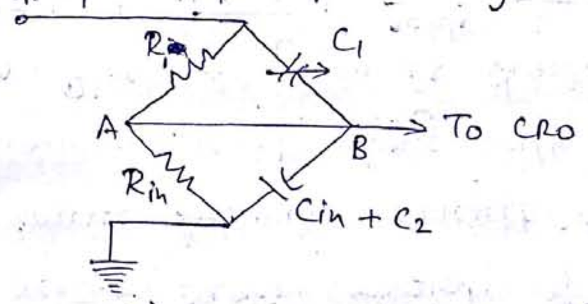


A coaxial cable connects probe head to CRO input. Let C_2 be the probe cable equivalent capacitance. Input resistance and capacitance of CRO can be referred as R_{in} and C_{in}.

Typical values $R_{in} = 1M\Omega$
$C_{in} = 20pF$



The arrangement of various elements can be further simplified by representing it in a bridge fashion



The compensating capacitor is adjusted so as to get balanced bridge condition.

$$R_1 X_{(C_{in}+C_2)} = R_{in} X_{C_1}$$

$$\frac{R_1}{\omega(C_{in}+C_2)} = \frac{R_{in}}{\omega C_1}$$

Thus the points A and B will be equipotential. The probe acts as a potential divider consisting of R_1 and R_{in} across the input.

Thus the attenuator factor is

$$\frac{R_1 + R_{in}}{R_{in}} = 10$$

Hence the probe is called 10x probe.
The effective input resistance increases by a factor 10 while the input capacitance decreases by a factor of 10.

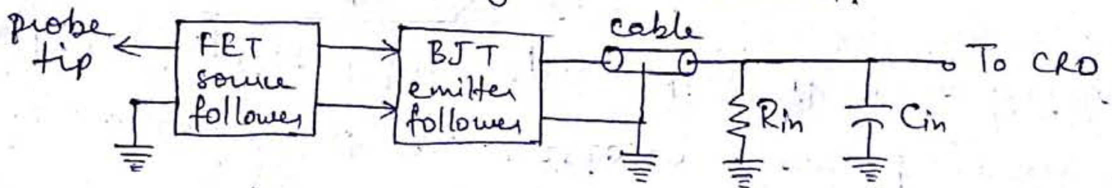
disadvantage

the signal is attenuated.

Active Probes

For connecting fast rising and high frequency signals, active probes are used. These are 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 as emitter follower circuit along with a coaxial cable termination. Block diagram is shown.



FET is used as an active element to amplify the signal. The voltage gain of FET source follower is unity but it provides a power gain due to which the input impedance increases.

The o/p impedance of FET source follower is very low which eliminates the loading effect

Instead of connecting the cable directly to the CRO, from FET stage, one more stage of BJT emitter follower is introduced. This emitter follower drives the cable and helps in solving the problems of improper impedance matching.

Advantages

1) No signal attenuation, hence small signals can be measured.
2) Provides high input impedance reducing the loading effect.
3) Capacitance of probes is very low 2 to 3 pF.
4) HF signals and fast rise time signals can be measured.

disadvantages

1) bulky
2) expensive
3) They can handle signals less than few volts only.

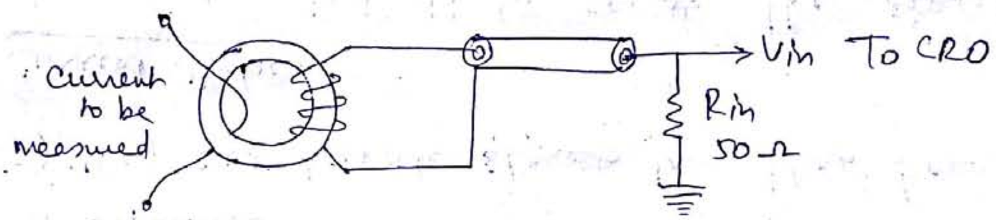
Current Probes

These probes inductively couple the signal to the CRO input, thus the direct electrical connection to the test circuit is not necessary. This probe can be clamped around a wire carrying an electrical current without any physical contact to the probe.

A magnetic core with a removable piece is used as coupling element for the current probe.

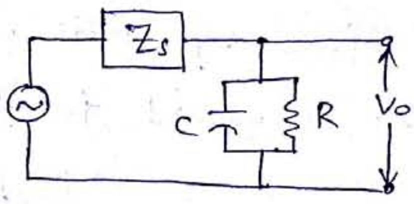
The wire carrying the current to be measured is inserted in the centre of the magnetic core and acts as a primary of transformer. The core is a ferrite U shaped core and multi turn coil of approximately 25 turns is wound on one leg of this core. This works as secondary of the transformer.

Because of electromagnetic induction principle, whenever current flows through primary, the emf gets induced in the secondary. This is fed to CRO input via termination circuitry.



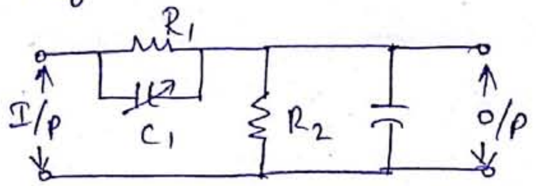
High voltage Probe

It is a cathode follower type which provides high input impedances and unity gain, hence no attenuation.



The resistance and capacitance of a CRO is high, hence a shielded cable is necessary. If shielded cables are not used, the stray fields produce interference on the pattern on the CRO. The shielded cable provides high input impedance with a low capacitance.

Because of high impedance of the cable, the input signal will be attenuated.



If the time constant R_1C_1 of the probe is equal to R_2C_2 of the CRO, the complex waveform will be passed through the probe without distortion.

If $R_1C_1 = R_2C_2$, the low capacitance probe acts as a simple resistance voltage divider independent of frequency.

High frequency CRO considerations

If a high freq signal is applied to the vertical amplifier, the rate of change of deflecting voltage increases, since freq is large. Due to this, the intensity on the CRT screen decreases.

Therefore to get a pattern of reasonable intensity, the electron beam must be accelerated to a high velocity. A higher electron beam velocity is achieved by increasing the voltage on the accelerating anodes.

Deflection sensitivity

$$S = \frac{D}{E_D}$$

where D = deflection produced in mm or cm on the screen

E_D = deflecting voltage applied to Y or vertical deflecting plates.

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

where L = distance between the screen and deflecting plates

l_d = length of the deflecting plates

E_d = deflection voltage

d = distance between the deflecting plates

E_a = accelerating voltage in the range 2000V to 10KV

If E_a is more, to get the same deflection, E_d also should be increased to get the same deflection sensitivity. Hence the gain in vertical amplifiers should be large.

Lissajous Figures

The lissajous pattern method is the quickest method of measuring frequency. In this method, the standard known freq signal is applied to horizontal plates and unknown frequency to the vertical plates.

Such patterns obtained by applying two different sine waves to horizontal and vertical deflection plates are called Lissajous figures or lissajous patterns.

The shape of lissajous figures depends on

a) amplitudes of two waves

b) phase difference between two waves

c) ratio of frequencies of two waves

Let the two signals of same amplitude and frequency with phase difference of ϕ

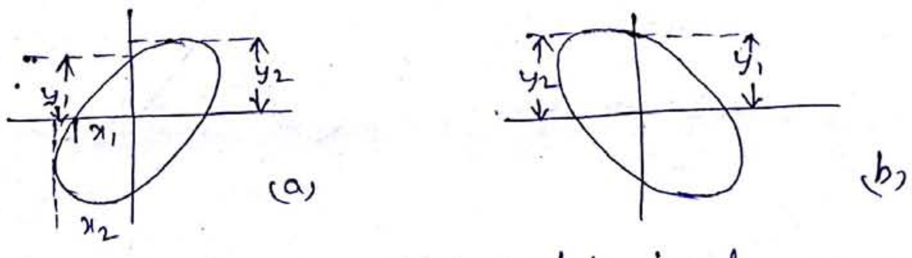
$$e_1 = E_m \sin \omega t$$

$$e_2 = E_m \sin(\omega t + \phi)$$

The phase difference ϕ produces various patterns which vary from straight diagonal lines to ellipses of different eccentricities.

Measurement of phase difference

Consider the lissajous figure with unknown phase difference ϕ, frequency and phase is the same.



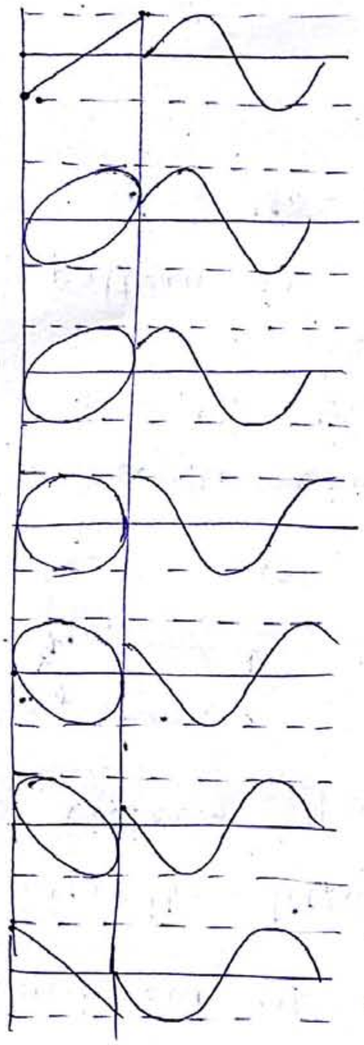
phase angle can be obtained as

$$\phi = \sin^{-1}\frac{y_1}{y_2} \quad \text{or} \quad \sin^{-1}\frac{x_1}{x_2}$$

For pattern in fig (b)

$$\phi = 180^\circ - \sin^{-1}\frac{y_1}{y_2}$$

Lissajous patterns for same frequency and different phase shifts



0° or 360°

30° or 330°

60° or 300°

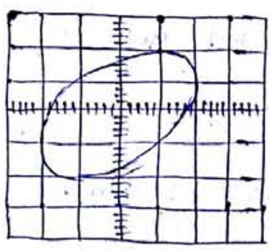
90° or 270°

120° or 240°

150° or 210°

180°

<u>problem</u> :- the Lissajous figure is obtained on the CRO as shown. find the phase difference between the two waves applied.



$y_1 = 8$ units

$y_2 = 10$ units

$$\phi = \sin^{-1}\frac{y_1}{y_2} = \sin^{-1}\frac{8}{10}$$

$$= 53.13^\circ$$

Measurement of frequency

To measure the unknown frequency, the signal with unknown frequency is applied to vertical plates called f_V. the signal applied to horizontal deflection plates is obtained from a variable freq oscillator of known frequency f_H.

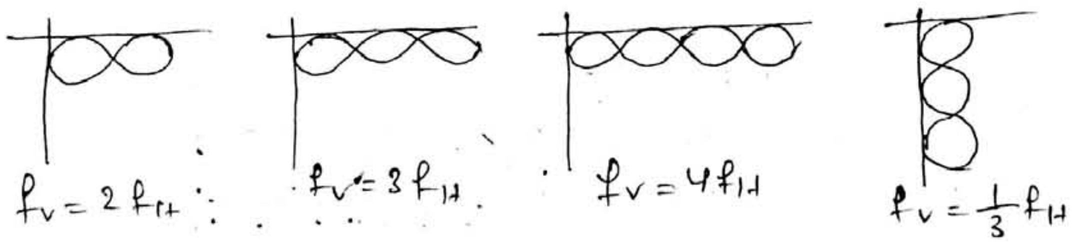
f_H = Known freq signal to horizontal plates

f_V = unknown freq signal to vertical plates

Using the shift control, stationary lissajous figures are obtained on the screen such that the figure is tangential to the vertical and horizontal axes. The patterns depend on the ratio of two frequencies f_H and f_V.

ratio of two frequencies

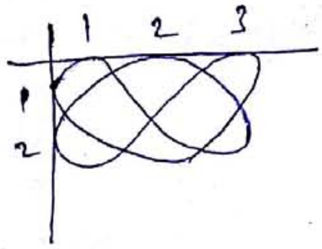
$$\frac{f_V}{f_H} = \frac{\text{No. of horizontal tangencies}}{\text{No. of vertical tangencies}}$$



From the ratio of two frequencies, the pattern is obtained and unknown frequency is calculated.

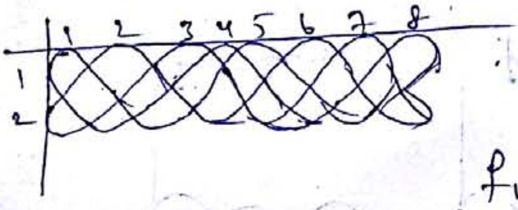
For non integer values

If the ratio of two frequencies is not an integer, the lissajous patterns are as follows



$$\frac{f_V}{f_H} = \frac{3}{2} = 1.5$$

Example :- Determine the unknown frequency of vertical signal.



$$\frac{f_V}{f_H} = \frac{8}{2} = 4$$

$$f_V = 4 f_H$$

Limitations of CRO

1) Low intensity of the waveform. Since T is small (f is large) the phosphorescence effect is limited and intensity is small.
2) Bandwidth of vertical amplifiers should be large
3) Since gain bandwidth product is constant for a given amplifier, multistage coupling is to be done
4) Deflection sensitivity is less.

Applications of CRO

1) It is used to measure ac as well as dc voltages and currents, peak to peak values, rms values, duty cycle etc.
2) In laboratory to measure the frequency, period, phase relationships between the signals, to study periodic and non periodic signals.
3) In radar; for giving the visual representation of targets such as aeroplane, ship etc.
4) In radio applications, it is used to trace and measure a signal throughout RF, IF and AF channels of radio and television receivers.
5) In medical applications, it is used to display cardiogram for diagnosis of heart of the patient and electromyograms for studying muscle conditions.
6) In industry for many purposes such as BH curves P-V diagrams, response of transducers (measuring strain, pressure, temperature), radiation pattern of antennas.
7) To determine modulation characteristics and to detect the standing waves in transmission lines.
8) Testing of active devices such as vaccum tubes, transistors, diodes and integrated circuits.
9) To measure capacitance and inductance.