Unit-II

Cathode Ray oscilloscope

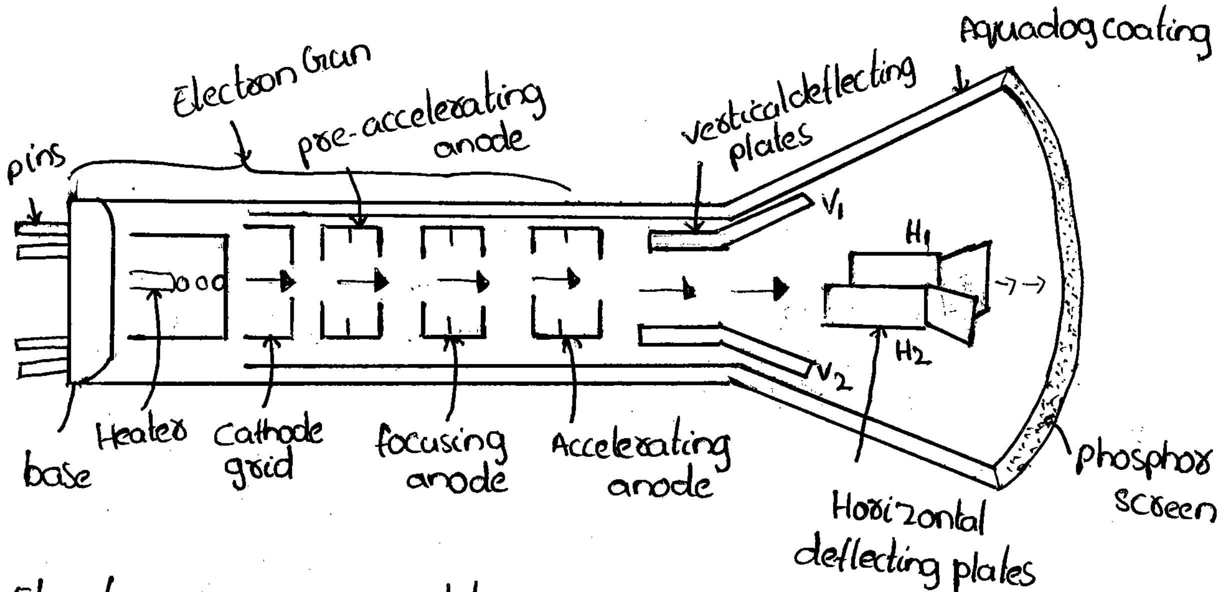
Introduction to CRT:

The cathode ray oscilloscope (CRO) is a very useful & versatile laboratory instrument used for display, measurement & analysis of waveforms & other phenomenon in electrical & electronic circuits.

A cathode ray oscilloscope consists of a cathode ray tube (CRT) which is the heart of the tube & some additional circuitry to operate the CRT.

The main parts of a CRT are

1. Electron Gun Assembly
2. Deflection plate Assembly
3. Flourescent screen
4. Glass envelope
5. Base through which connections are made to various parts.



Electron Gun Assembly: The electron gun emits electrons & forms them into a beam. This beam is focused on to screen to cause a luminous spot on the screen.

It consists of a

1. Heater 2. cathode 3. Grid 4. preaccelerating anode 5. Focusing anode 6. Accelerating anode

Heater & Cathode: Electrons are emitted from the indirectly heated cathode. A layer of barium & strontium oxide is deposited on the end of the cathode to obtain high emission of electrons at moderate temperature. The typical values of current & voltage required by an indirectly heated cathode are 600mA at 6.3V.

Grid: The control grid in the CRT is cylindrical, with a small aperture in line with cathode. The electrons emitted from the cathode emerge from this aperture as a slightly divergent beam. The negative bias is applied to the grid which controls the beam current. The intensity or brightness of the phosphorescent spot depends on this beam current. Hence, this control grid bias knob is labelled as intensity control in the CRO

Pre accelerating Anode & Accelerating anodes.

The electrons emitted from the cathode, pass through the hole in the control grid & are accelerated by a high positive potential which is applied to the preaccelerating & accelerating anodes.

These anodes are cylindrical in form, with small openings located in the centre of each electrode, coaxial with the tube axis.

The preaccelerating & accelerating anodes are connected to a common positive high voltage of about 1500V. The combination of two anodes produces an electric field that focuses the electron beam on the screen.

Focusing anode:

The focusing anode is connected to a lower adjustable voltage of 500V.

There are two method of focusing an electron beam

i. Electrostatic focusing

ii. Electromagnetic focusing

The CRO uses electrostatic method of focusing where as a TV picture tube employs electromagnetic focusing.

The advantage of using electrostatic deflection is, it permits high frequency operation & negligible power.

2. Deflection plate Assembly:

Electrons are negatively charged particles, they are attracted by a positive charge or field & repelled by a negative charge. Since the electron beam is a stream of electrons, a positive field will divert it in one direction & a negative field in the opposite direction.

To move the beam in this way in the CRT, the deflecting plates are mounted inside the tube & suitable deflecting voltages are applied to them.

These plates are arranged in two pairs H_1 & H_2 for deflecting the beam horizontally & V_1 & V_2 for deflecting the beam vertically. These beams moves between these four plates depending on the potentials.

3. Flourescent screen: The front of the CRT is called face plate. It is flat for screen sizes upto about 100mm x 100mm and is slightly curved for larger displays. The face plate is formed by pre molten glass in a mould & then annealing it

The inside surface of the face plate is coated with phosphor. this consists of very pure inorganic crystalline phosphor crystals ; about 2-3 microns in diameter, to which traces of activators such as silver, manganese, copper, chromium are added

A phosphor converts electrical energy to light energy when an electron beam strikes phosphor crystals it raises the energy level. This is known as cathadoluminescence. when light is emitted during phosphor excitation, it is called as flouresence

when the electron beam is switched off, the phosphor crystals return to their initial state & release a quantum of light energy. This is called as persistance or phosphorescence

persistance is expressed as short, medium & long this refers to the length of time the trace remains on the screen after the signal has ended.

The phosphor of the oscilloscope is designated as follows

P1 - Green medium

P2 - Blue green medium

P5 - Blue very short

P11 - Blue short

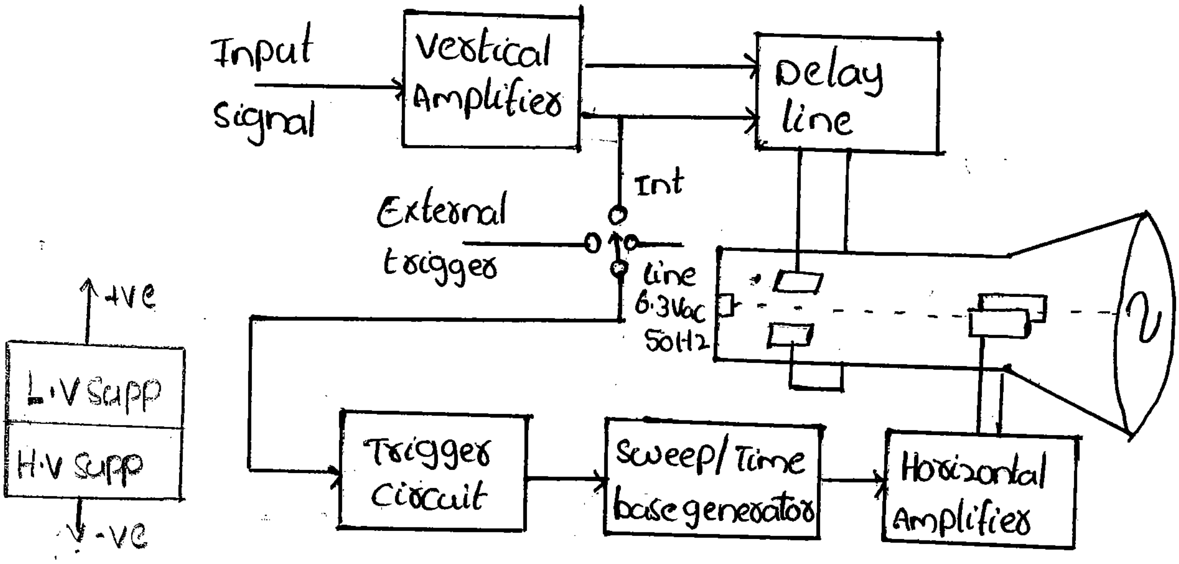
Ex: 5GP1 → 5 inch tube with a medium persistence green trace

Glass envelope: To the glass envelope graticules are attached. The graticules are a grid of lines which serve as a scale marking provided on the front of the CRT.

Aquadog: The bombarding electrons striking the screen, release secondary emission electrons. these secondary electrons are collected by a aqueous solution of graphite called Aquadog which is connected to accelerating anode.

collection of secondary electrons is necessary to keep the CRT screen in a state of electrical equilibrium.

Simple CRO:



The cathode ray oscilloscope is a very useful, general purpose electronic instrument for testing & developing electronic circuits, systems & instruments.

The electron beam generated in CRO is deflected by the given electrical signal & when the deflected electron beam strikes the screen of CRO, because of phosphorscence effect a visible trace is produced exactly in the same shape as the given electrical signal.

The function of various blocks are

Time base or sweep generator: CRO's are generally used to display a waveform that varies as a function of time. If the waveform is to be accurately reproduced, the beam must have a constant horizontal velocity. Since the beam velocity is a function of the deflecting voltage the deflection voltage must increase linearly with time. A voltage with this characteristic is called a Ramp voltage. If the voltage decreases rapidly to zero with the waveform repeatedly reproduced, the pattern called sawtooth waveform is produced.

Time base generator is used to generate a sawtooth voltage before it is applied to horizontal deflecting plates. usually a constant current, Miller sweep circuit is employed to generate a saw-tooth waveform & is used to deflect the electron beam linearly in X- direction.

Trigger circuit: To get a true representation of the input signal, the time base signal or x signal & the Y signal must be inicated at the same time.

The time base signal must be initiated by the vertical signal itself for proper triggering. This is acheived by the trigger circuit.

Horizontal Amplifier: The purpose of this amplifier circuit is to amplify an externally applied signal to the horizontal or x- plates. This also helps

Delay lines: the electron beam is deflected in the X-direction by a sawtooth waveform called the timebase signal. when the set magnitude of the sawtooth waveform is reached, it is to be reset & started again in order to get a true time variation of the given signal.

The attenuators, amplifiers, pulse shapers & circuit wiring introduce a certain time delay. To allow the operator to observe the leading edge of the signal waveform, the signal drive for the vertical CRT plates must be delayed by atleast the same amount. This is achieved by the vertical delay lines.

CRT: CRT is the heart of CRO. Here the electron beam is generated accelerated, deflected, post accelerated & made to strike flourescent screen to give the visual display of the electrical input signal given to the vertical or Y plates.

in adjusting the magnitude of the internal saw-tooth waveform being generated.

If the internal timebase waveform is not being used, an electron beam can be deflected horizontally by means of an external signal which is to be applied to this circuit. The externally applied x-signal can be amplified by adjusting the gain.

Vertical amplifier: This is also called Y-amplifier. The electron beam deflection in the y-direction or the vertical direction is proportional to the signal amplitude given to the Y input or vertical plates. Hence this is called a Y amplifier.

The gain can be varied externally with the help of amplitude control. The bandwidth of this amplifier ~~plate~~ puts a limit to the maximum frequency of the input signal that can be measured using the CRO. If the magnitude of the external signal is large, it can also be attenuated in the potential divider attenuator section.

High voltage HV & Low voltage LV supplies

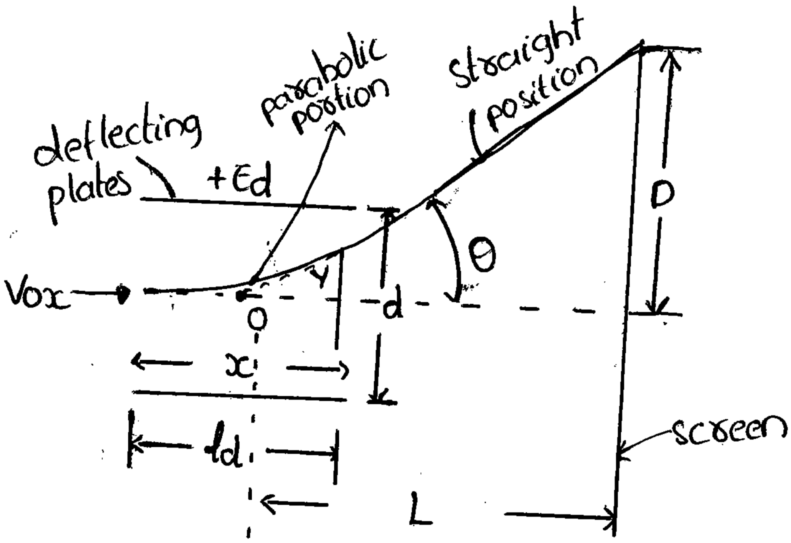
To accelerate, deflect & sweep the electron beam a large voltages in kilovolts is required for a CRT

This is generated by the HV power supply circuit

Vcc & other voltages which are required are generated in the low voltage power supply circuits.

usually a negative high voltage supply & a positive Low voltage supply are used. The positive volt supply is from +300 to 400V. The negative high volt supply is from -1000 to -1500V.

Electro static Deflection



There are two parallel plates with a potential applied between. These plates produce a uniform electrostatic field in the Y direction. Thus any electron entering the field will experience a force in the Y direction & will be accelerated in that direction.

There is no force either in x direction or z direction & hence there will be no acceleration of electrons in these directions.

Let E_0 = voltage of pre accelerating anode; V

e = charge of an electron; C,

m = mass of electron; kg

E_d = potential between deflecting plates; V

d = distance between deflecting plates; m

l_d = length of deflecting plate; m

L: distance between screen & the centre of the deflecting plates; m

D: deflection of electron beam on the screen in y direction; m

The loss of potential energy (P.E) when the electron moves from cathode to accelerating anode

$$P.E = e E_a \qquad E_a: \text{accelerating voltage}$$

the gain in kinetic energy (K.E) by an electron

$$K.E = (1/2) m V_{ox}^2 \qquad m = 9.109 \times 10^{-31} kg$$

Equating the two energies we have $V_{ox} = \sqrt{2eE_a/m}$

this is the velocity of the electron in the x direction when it enters the deflecting plates. The velocity in the x direction remains the same throughout the passage of electrons through the deflecting plates as there is no force acting in this direction.

The electric field intensity in the y direction

$$\mathcal{E}_y = E_d/d$$

Force acting on an electron in y direction =

$$F_y = e\mathcal{E}_y = e E_d/d$$

Suppose a_y is the acceleration of the electron in y direction. therefore $F = ma_y$

$$\Rightarrow a_y = e\varepsilon_y/m$$

As there is no initial velocity in the y direction the displacement y at any instant t in the y direction is

$$y = \frac{1}{2} a_y t^2 = \frac{1}{2} \frac{e\varepsilon_y}{m} t^2$$

As the velocity in x direction is constant; the displacement in x direction is given by

$$x = V_{ox} t$$

$$\therefore \quad t = x/V_{ox}$$

Substituting the value of t in '$y' = \frac{1}{2} e \frac{\varepsilon_y}{m} t^2$

$$y = \frac{1}{2} \frac{e\varepsilon_y}{mV_{ox}^2} x^2$$

This is the equation of a parabola

The slope at any point (x,y) is $\frac{dy}{dx} = \frac{e\varepsilon_y}{mV_{ox}^2} x$

putting $x = l_d$ in above equ we get value of $\tan\theta$

$$\text{slope} = \tan\theta = \frac{e\varepsilon_y}{mV_{ox}^2} l_d = \frac{eE_d l_d}{m d V_{ox}^2}$$

After leaving the deflecting plates, the electrons travel in a straight line. the straight line of travel of electrons is tangent to the parabola at $x = l_d$ & this tangent intersects the x-axis at point O'. The location of this point is given by

$$x = \frac{y}{\tan\theta} = \frac{e E_y l_d^2}{2 m V_{ox}^2} \Big/ \frac{e E_y}{m V_{ox}^2} l_d = \frac{l_d}{2}$$

The apparent origin is thus at the centre of deflecting plates. The deflection D on the screen is given by $D = L \tan\theta = \frac{L e E_d l_d}{m d V_{ox}^2}$

Substituting the value $V_{ox}^2 = \frac{2 e E_a}{m}$

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

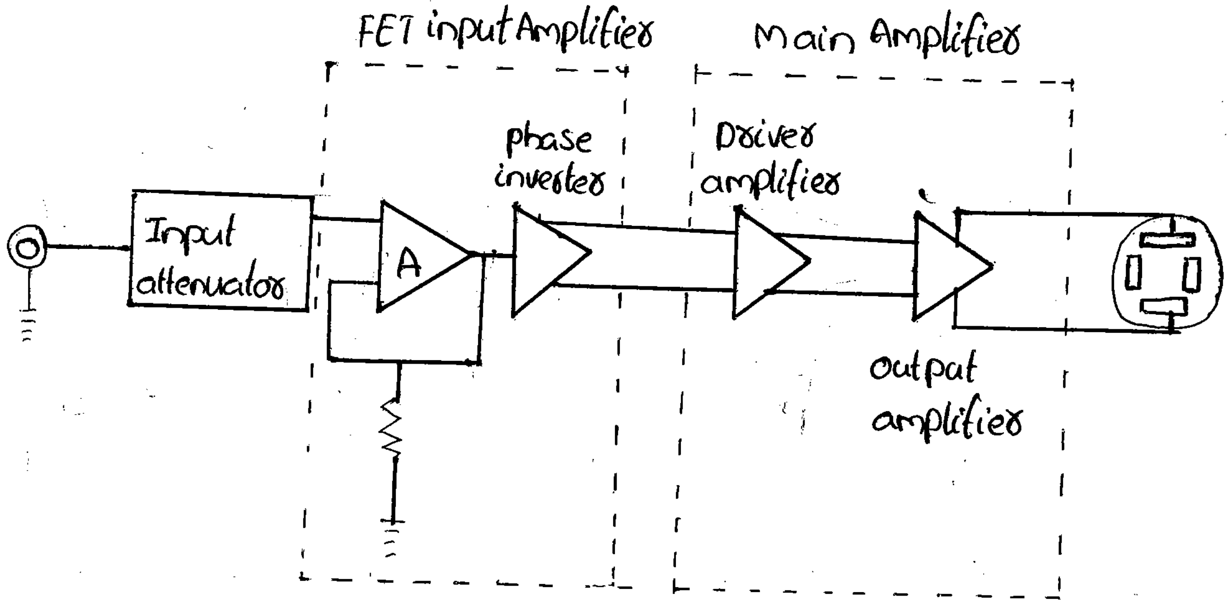
Deflection sensitivity: The deflection sensitivity of a CRT is defined as the deflection of the screen per unit deflection voltage

$\therefore$ Deflection Sensitivity $S = \frac{D}{E_d} = \frac{L l_d}{2 d E_a}$ m/V

The Deflection Factor of a CRT is defined as the reciprocal of sensitivity.

$\therefore$ Deflection Factor $G = 1/S = \frac{2 d E_a}{L l_d}$ V/m.

Vertical Amplifier: the vertical amplifier is the principle factor in determining the sensitivity & bandwidth of an oscilloscope. the gain of the vertical amplifier determines the smallest signal that the oscilloscope can satisfactorily reproduce on the CRT screen. The sensitivity of an oscilloscope is directly proportional to gain of the vertical amplifier that is, as gain increases sensitivity increases, which allows us to observe smaller-amplitude signal.



The vertical amplifier consists of several stages with fixed overall sensitivity or gain expressed in V/div. the advantage of fixed gain is that the amplifier can be more easily designed to meet the requirements of

Bandwidth & Stability. The vertical amplifier is kept within its signal handling capability by proper selection of the input attenuator switch. The first element of the pre-amplifier is the input stage, often consisting of 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 medium impedance of FET output with the low impedance input of the phase inverter.

This phase inverter provides two antiphase output signals which are required to operate the push-pull output amplifier. The push-pull output stage delivers equal signal voltages of opposite polarity to the vertical plates of the CRT.

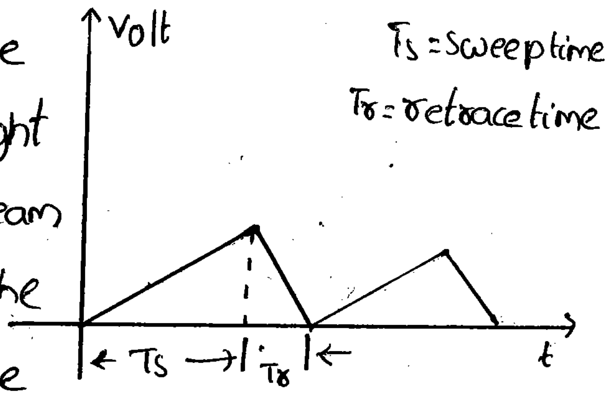
The advantages of push-pull operation in CRO are better hum voltage cancellation from the source, even harmonic suppression, especially the large 2nd harmonic is cancelled out, & greater power output per tube as a result of even harmonic cancellation. In addition; a number of defocusing & nonlinear effects are reduced because neither plate is at ground potential.

Horizontal Deflecting System

The horizontal deflecting system consists of time base generator & an output amplifier.

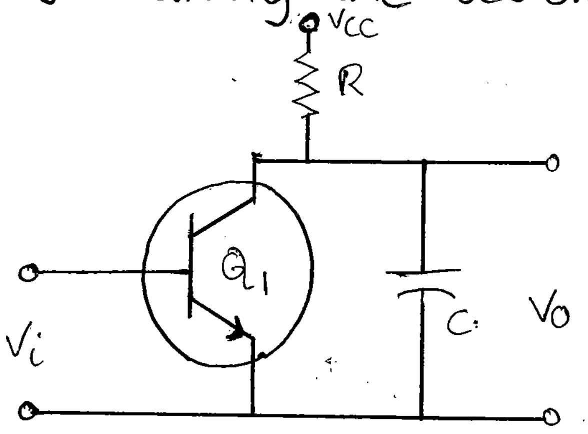
Time base generator or sweep generator

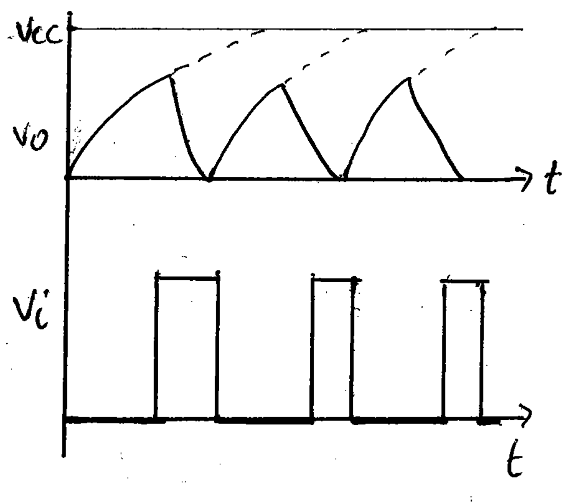
Oscilloscopes are generally used to display a waveform that varies as function of time. If the waveform is to be accurately reproduced, the beam must have a constant horizontal velocity. Since the beam velocity is a function of the deflecting voltage, the deflecting voltage must increase linearly with time. A voltage with this characteristic is called a ramp voltage. If the voltage decreases rapidly to zero with the waveform repeatedly reproduced a shown in fig, the pattern is generally called a sawtooth waveform.



During the sweep time Ts the beam moves from left to right across the CRT screen. The beam is deflected to the right by the increasing amplitude of the ramp voltage & the fact that the positive voltage attracts the negative electrons. During the retrace time or fly back time t_r, the beam returns quickly to the left side of the screen. The control grid is generally "gated off" which blanks out the beam during retrace time & prevents an undesirable retrace pattern from appearing on the screen.

Since signals of many different frequencies will be observed with the oscilloscope, the sweep rate must be adjustable. We can change the sweep rate in steps by switching different capacitors into the circuit. The front panel control for this adjustment is marked time/div. The sweep rate can be adjusted in minor ways by making the resistor 'R', a variable resistor.





The circuit shown in figure is a simple sweep circuit in which the capacitor c charges through the resistor R. The capacitor discharges periodically through the transistor Q_1 which causes the waveform shown in figure to appear across the capacitor. the signal V_i which must be applied to the base of the transistor to turn it on for short short intervals is also shown. when the transistor is turned completely 'on', it presents a low-resistance discharge path through which the capacitor discharges quickly

If the transistor is not turned on, the capacitor will charge exponentially to the supply voltage Vcc according to the equation

$$V_o = V_{cc}\left[1 - \exp\left(-t/RC\right)\right]$$

where V_o = instantaneous voltage across capacitor at time t ; V,

V_{cc} = supply voltage, V

t = time of interest, sec

R = Value of series resistor, Ω

C = value of capacitor ; F

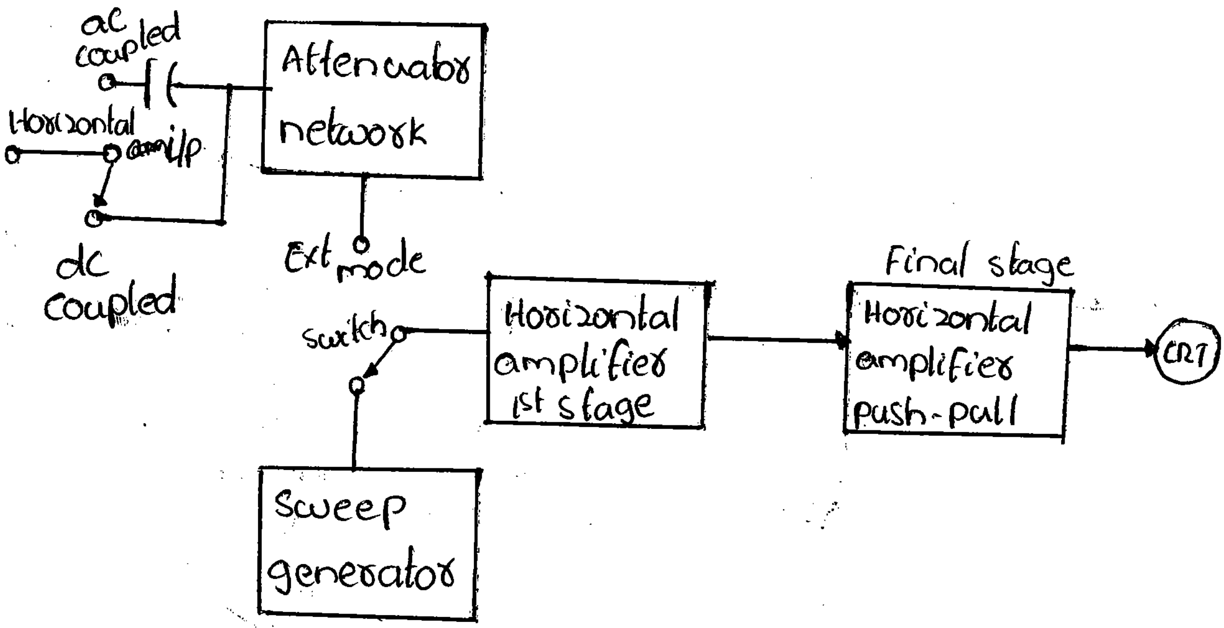
Horizontal Amplifier: The horizontal amplifier basically serves two purposes

1. when the oscilloscope is being used in the ordinary mode of operation to display a signal applied to the vertical input, the horizontal amplifier will amplify the sweep generator output.

2. when the oscilloscope is being used in the X-Y mode the signal applied to the horizontal input terminal will be amplified by the horizontal amplifier.

When the oscilloscope is being used in its ordinary mode of operation ; the gain & bandwidth requirements for the horizontal amplifier are not as stringent as those for the vertical amplifier. Although the vertical amplifier must be able to reproduce faithfully low-amplitude ; high frequency signal with fast rise time, the horizontal amplifier is required to provide only a faithful reproduction of the sweep signal, which has a relatively high amplitude & a slow rise time.

As with the vertical amplifier, the final stage of the horizontal amplifier is a push-pull amplifier



The attenuator network given in the figure reduces; by voltage division, the amplitude of the horizontal input signal to a level equal to the sensitivity of the horizontal amplifier.

Types of sweeps: There are four basic types of sweeps.

Free Runing or Recurrent Sweep: In the free running or recurrent sweep the sawtooth waveform is repetitive. A new sweep is started immediately after the previous sweep is terminated & the circuit is not initiated by any external signal.

2. Triggered sweep: A waveform to be observed on the CRO may not be periodic but may perhaps occur at irregular intervals. In this case it is desirable that the sweep circuit remain inoperative and the sweep be iniated by the waveform under examination. In some cases the waveform may be periodic, but it may be that the interesting part of the waveform is of a very short duration compared to the period of the waveform. under such cases a triggered sweep is used.

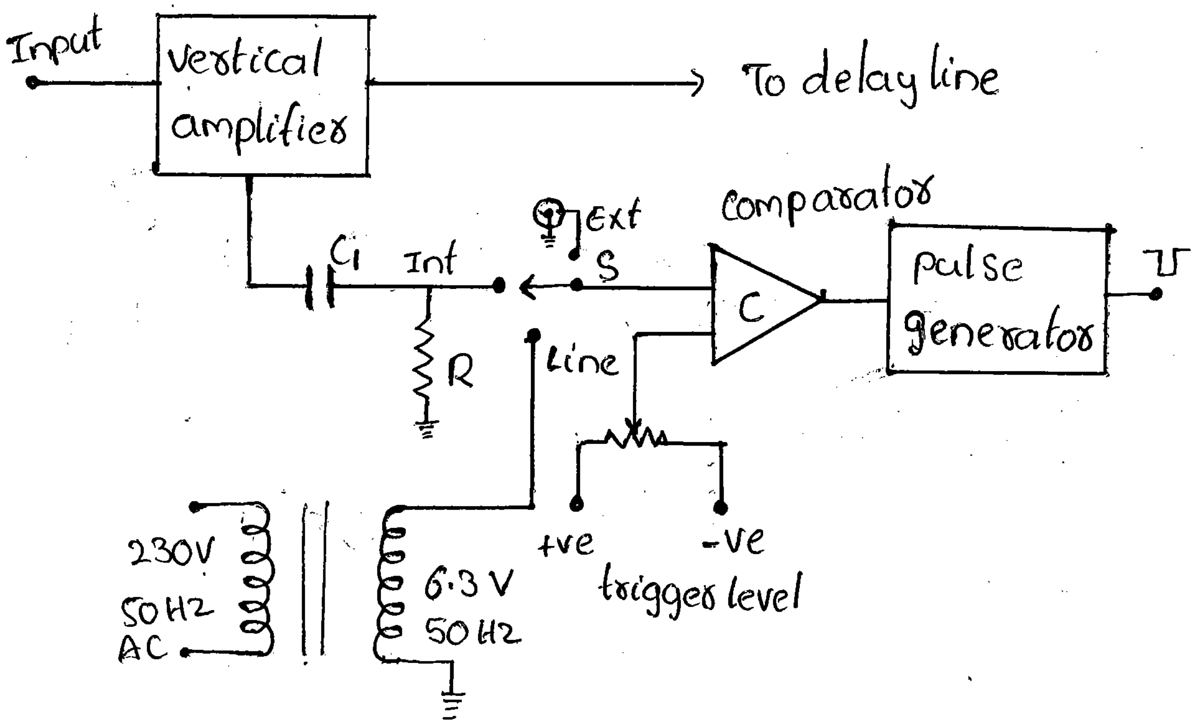
In triggered sweep or single sweep the spot is swept once across the screen in response to a trigger signal. the trigger sweep is used for examination of transients or one time signals & the waveform is photographed or recorded. The trigger can be obtained from the signal under investigation or by an external source.

3. Driven Sweep: In most cases, a driven sweep is used where the sweep is recurrent but triggered by the signal under test.

4. Non-SawTooth Sweep: For some applications like comparison of two frequencies or for finding phase shift between two voltages, non sawtooth sweep voltages are utilized for the sweep circuit. Sweep frequencies vary with the type of oscilloscope. A laboratory oscilloscope may have sweep frequencies upto several MHz; a simple oscilloscope for audio work has an upper limit of 100 kHz

Trigger pulse circuit

The trigger circuit is activated by signals of a variety of shapes & amplitudes which are converted to trigger pulses of uniform amplitude for the precision sweep operations. If the trigger level is set too low, the trigger generator will not operate. on the other hand, if the level is too high, the UJT may conduct for too long & part of the leading edge of the input signal may be lost.



The trigger secation is a 3-position switch. Internal. External - Line. The trigger input signal is applied to a voltage comparator whose referencelevel is set by the Trigger Level control on the CRO front panel.

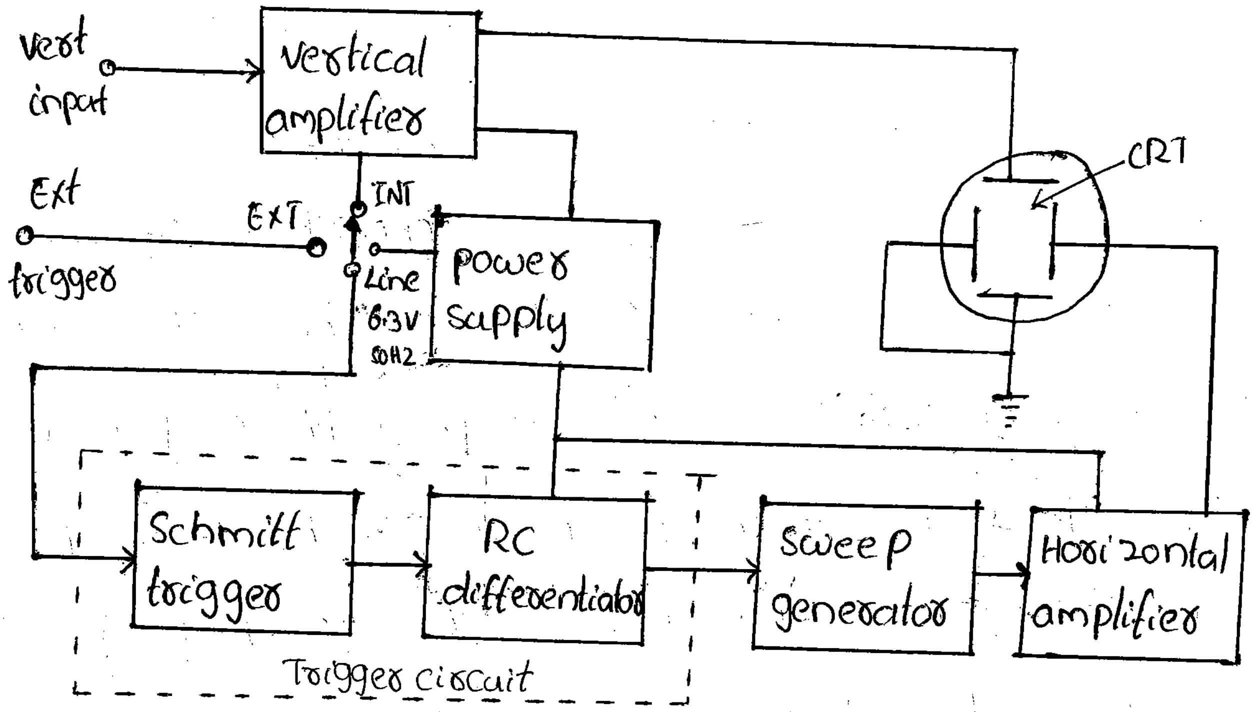
The comparator circuit C produces a change in the output whenever the trigger input exceeds the present trigger levels. The pulse generator that follows the comparator produces -ve trigger pulses each time the comparator output crosses it quiescent level, which in turn triggers the sweep generator to start the next sweep. The trigger sweep generator contains the stability or sync control, which prevents the display from jittering or running on the screen. Stability is secured by proper adjustments of the sweep speeded. Sweep speed is adjustable by means of a sweep rate control & its multiplier i.e range control. The timing resistance is used for sweep rate control & timing capacitor is changed to in steps for sweep rate control.

Triggered sweep CRO: (for sync of ver & hor - triggered Sweep gene)

In very basic oscilloscopes the sweep generator is continuously charging & discharging a capacitor. One ramp voltage is followed immediately by another hence the sawtooth pattern appears. A sweep generator operating in this manner is said to be 'free running'. In order to present a stationary display on the screen, the sweep generator signal must be forced to run in synchronization with the vertical input signal. In basic oscilloscope this is accomplished by carefully adjusting the sweep frequency to a value very close to the frequency of the vertical input signal or a submultiple of this frequency.

With both signals at the same frequency, an internal synchronizing pulse will lock the sweep generator into the vertical input signal. This method of synchronization has some serious limitations when an attempt is made to observe low amplitude signals. However the most serious limitation is probably the inability of the instrument to maintain synchronization when the amplitude or frequency of the vertical signal is not constant, such as voice or music signals.

The above limitations are overcome by incorporating a trigger circuit into the oscilloscope.



The trigger circuit may receive an input from one of three sources depending on the setting of the trigger selector switch. The input signal may come from an external source when the trigger selector switch is set to EXT, from a low amplitude