# MODULE 3

# OSCILLOSCOPES

## Introduction:

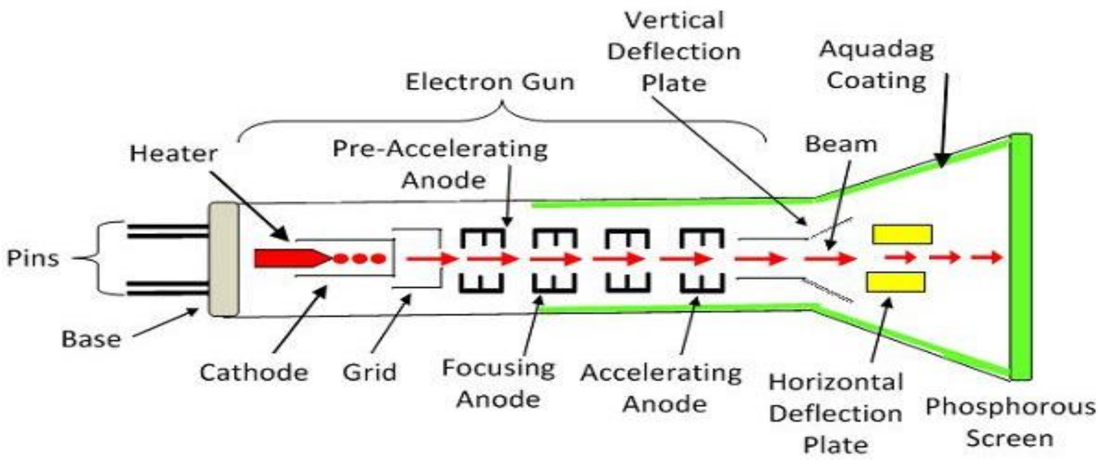
An oscilloscope is a test instrument which allows you to look at the 'shape' of electrical signals like current,voltage or power to be displayed against time on the screen. Oscilloscope also called as Cathode Ray Oscilloscope (CRO) is the most versatile tool for development of electronic circuits and systems. CRO uses electron beam which is bombarded on screen which is coated with fluorescent material to produce visible spot. When beam is deflected along X and Y axis a 2 – D display is generated.

Oscilloscope is basically an electron beam voltmeter and reproduces rapid variations, pulsations or transients and the user can observer waveform and measure amplitude at any instant of time.

It is completely electronic in nature and can reproduce high frequency waves which mechanical devices cannot follow. Thus oscilloscopes has simplified many tests and measurements.

## Basic Principle:

- The heart of the oscilloscope is CRT – Cathode Ray Tube
- It has electron gun which gives a narrow electron beam when focused on flat end of glass tube (screen), it glows at the point of collision generating a bright spot. The electron beam when deflected by means of electric or magnetic field, the spot moves accordingly and traces the pattern.
- The Fig. below shows the diagram of CRT




Cathode Ray Tube

- The electron gun is the source of the electron beams. The electron gun assembly has a heater, cathode, grid, pre-accelerating anode, focusing anode and accelerating anode.

- The control grid is cylindrical in shape and has small aperture which is in line with the cathode. The cathode emits electrons which emerges from this aperture as a divergent beam.
- A negative bias is applied to control grid which controls the beam current and this beam current in turn controls the intensity of spot.
- The diverging electron beam from cathode is made converged and focused onto the screen by anodes. These anodes acts as electronic lens.
- Ahead of control grid there are focusing anodes whose aperture is in line with cathode. The first anode is maintained at positive voltage with respect to cathode. (i.e., focusing anode are connected to the lower voltage of about 500V). The second anode which is pre-accelerating and accelerating anode are connected to the positive high voltage of about 1500V (at a higher positive potential). These anodes acts as accelerators and converges the beam of electron. The combination of anodes focuses the electron beam on the screen.
- After exiting the focusing anode, the beams passes through the vertical and horizontal deflecting plates which deflects the electron beam and helps in positioning the beam anywhere on the screen.
- In most oscilloscope electrostatic deflection is used rather than electromagnetic deflection as it is helpful in high frequency application and also consumes less power.
- The front of the CRT is called the face plate and it is made up of fiber optics. The internal surface of the faceplate is coated with the phosphor. The phosphorous converts the electrical energy into light energy. This produces the spots on the screen.
- The Aquadag is the aqueous solution of graphite which is connected to the secondary of the anode.The Aquadag collects the secondary emitted electrons which are necessary for keeping the CRT screen in the state of electrical equilibrium.

## CRT Features:

Electrostatic CRTs are available in a number of types and sizes to suit individual requirements. The important features of these tubes are as follows.

1. **Size**
   - It refers to the diameter of the screen. The CRTs for oscilloscopes are available in sizes of 1, 2, 3, 5, and 7 inches. 3 inches is most common for portable instruments.
   - If the number of CRT is - 5GP1, the first number 5 indicates that it is a 5 inch tube.Both round and rectangular CRTs are found in scopes today.

2. **Phosphor**
   - The fluorescent material used for coating the screen is phosphor. This material determines the colour and persistence of the trace.The trace colours in electrostatic CRTs for oscilloscopes are blue, green and blue green.
   - The time period for which the traces remains on the screen even after the signal becomes zero is called '**persistence**'. This persistence can be expressed as short, medium and long.
   - Medium persistence traces are mostly used for general purpose applications.
   - Long persistence traces are used for transients, since they keep the fast transient on the screen for observation after the transient has disappeared.

- Short persistence is needed for extremely high speed phenomena, to prevent smearing and interference caused when one image persists and overlaps with other.

The phosphor of the oscilloscope is designated as follows.
P1 – Green medium
P2 – Blue green medium
P5 – Blue very short
P11 – Blue short

- These designations are combined in the tube type number. Hence 5GP1 is a 5 inch tube with a medium persistence green trace.

**3. Operating Voltages**

The CRT requires a heater voltage of 6.3 volts ac or dc at 600 mA.The voltages vary with the type of tube used.
Negative grid (control) voltage – 14 V to – 200 V.
Positive anode no. 1 (focusing anode) – 100 V to – 1100 V
Positive anode no. 2 (accelerating anode) 600 V to 6000 V
Positive anode no. 3 (accelerating anode) 200 V to 20000 V in some cases

**4. Deflection Voltages**

To deflect the beam ac or dc voltage is required. The movement of spot on screen is proportional to the dc, or peak ac amplitude. The deflection sensitivity of the tube is usually stated as the dc voltage (or peak ac voltage) required for each cm of deflection of the spot on the screen.

**5. Viewing Screen**

The viewing screen is the glass plate, the inside wall of which is coated with phosphor. This screen is a rectangular screen having graticules marked on it and standard size used is 8 cm x 10 cm (8 cm on the vertical and 10 cm on horizontal). Each centimeter on the graticule corresponds to one division (div). The standard phosphor colour used is blue.

## Basic principle of Signal Display/ Function of Sweep Generator:

Principle of Sweep Generator:

- For dc voltage measurement gives a straight line trace representing the amplitude of the voltage.
- But for ac voltage, pulsating or transient, straight line trace does not give any information. Thus it is required to obtain a graph of amplitude versus time, where the voltage is traced on the screen by the spot.
- To obtain such a display the signal voltage is applied to the vertical plates (directly or through the vertical amplifier) and it moves the spot vertically corresponding to the instantaneous values of the signal.
- Simultaneously, to move the spot horizontally a sweep voltage applied to the horizontal plates. The combined action of these two voltages causes the spot to produce a trace on the screen.
- Thus sweep voltage produces the time base by moving the spot horizontally with time, while the signal moves the spot vertically in proportional to the voltage at a particular instant of time.

There are two important sweep generator requirements.

1. The sweep must be linear (the sweep voltage must rise linearly to the maximum value required for full screen horizontal deflection of the spot).
2. The sweep voltage must drop suddenly after reaching its maximum value so that the spot moves only in one direction i.e., from left to right.

These requirements call for a sweep voltage having a linear saw tooth waveform is shown in Fig below.

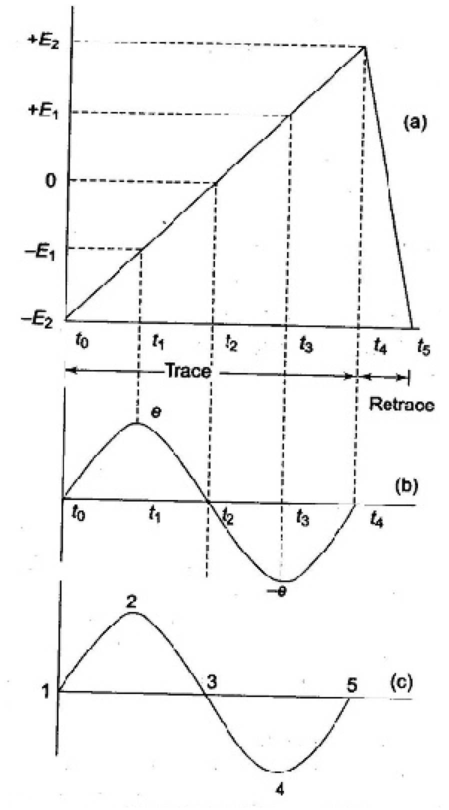



**Fig**. Waveform of sweep voltage

- Now at time t0, the sweep voltage is - E2, and this negative horizontal voltage moves the spot to point 1 on the screen. At this instant, the signal voltage is 0, so the spot rests at zero line on the screen.
- At time t1, the linearly increasing sweep voltage reaches - E1, this voltage moves the spot to point 2. At this instant, the signal voltage is e, the +ve peak value, so the point represents its maximum upward deflection of the spot.
- At time t2, the sweep voltage is 0, there is no horizontal deflection and the spot is at the centre, point 3. At this instant, the signal voltage is 0, so there is no vertical deflection either.
- At time t3, the sweep voltage is +E1 and this moves the spot to point 4. At this instant, the signal is -e, the -ve peak value, so point 4 is the maximum downward deflection of the spot.
- At time t4, the sweep voltage is +E2 and this moves the spot to point 5. Now the signal voltage is 0, so the spot is not vertically deflected.

- Between t4 and t5, the saw-tooth / sweep voltage falls quickly through 0 to its initial value of -E2, causing the spot back to point 1.
- This repeats for the next cycle of signal voltage. Thus due to effect of both voltages sinusoidal waveform appear on the screen.
- When sweep and signal frequencies are equal, a single cycle appears on the screen. When the sweep is lower than the signal, several cycles appear and when sweep is higher than signal, less than one cycle appears.
- The signal trace appears stationary only when the sweep and signal frequencies are either same or integral multiples of each other. For other frequencies the trace keeps on drifting horizontally.

The sweep voltage also known as sawtooth sweep voltage is generated by a multivibrator, relaxation oscillator or pulse generator. The different types of sweep voltage generated are as follows.

1. **Recurrent Sweep:** In this ac voltage alternates rapidly so that the display occurs repetitively and the image is seen by the eye. This is repeated operation is recurrent sweep.
2. **Single Sweep:** The signal under study produces a trigger signal, which in turn produces a single sweep.
3. **Driven Sweep:** There may be a chance that the sweep cycle may start after the signal cycle and this may result in missing a part of the signal. In driven sweep this problem is eliminated since the sweep and signal cycles start at the same time.
4. **Triggered Sweep:**In a recurrent mode, the voltage rises to a maximum and then suddenly falls to a minimum and it is repeated. This causes the electron beam to movefrom left to right, retraces rapidly to the left and the pattern is repeated. In this the horizontal sweep action takes place whether the input signal is applied to the oscilloscope or not, and a horizontal line is displayed on the screen continuously.

In case of triggered sweep, the sweep signal does not start unless initiated by a trigger voltage. This trigger is usually the incoming signal. If there is no signal then the sweep will be in hold mode and the screen will be blank.

The recurrent sweep uses a free running multivibrator. Butin triggered sweep it uses a monostable multivibrator which is in its off state until a trigger pulse arrives.

Thus in triggered sweep, when input signal is applied, a trigger pulse is generated and is applied to the multivibrator. This turns on sweep generator and produces a sweep signal and trace appears on the screen. For a specific period of time depending on voltage, the multivibratorwill be on after that it switches back to its off state. The process is repeated for next incoming signal.

5. **Intensity Modulation:**The ac signal is applied to the control electrode of the CRT and this causes the intensity of the beam itself to vary in step with signal alternations. This may result, the trace to be brightened during the +ve half cycles and diminished or darkened during -ve half cycles. This process, is called intensity modulation or Z-axis modulation.

## Block diagram of Oscilloscope:

The block diagram of general purpose CRO is shown below.The function of the various blocks are as follows.

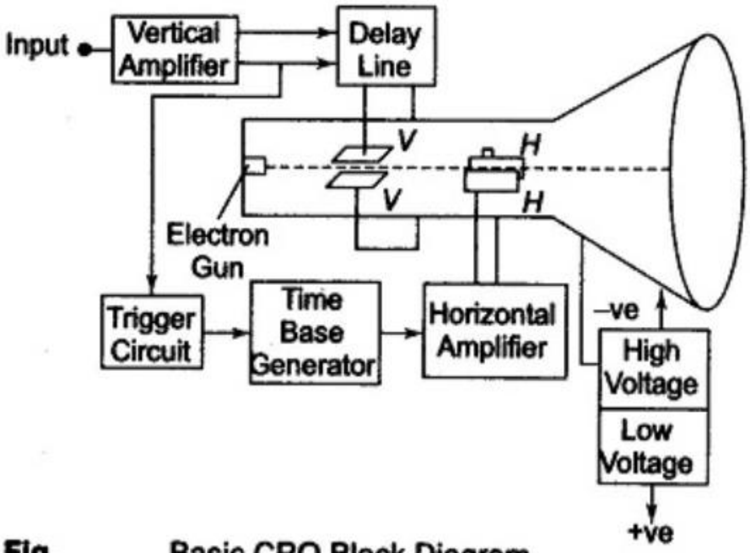



Fig. Basic CRO Block Diagram

1. **CRT:** This is the cathode ray tube which is used to emit electrons that strikes the phosphor screen to provide a visual display of signal.
2. **Vertical Amplifier:** The input signals to be measured are not strong to provide deflections, hence they are amplified using the vertical amplifier. The amplifier uses wide band so that it passes the entire band of frequencies.
3. **Delay Line:**It is used to delay the signal for some time in the vertical sections else part of the signal gets loss.
4. **Time Base:**It is used to generate the sawtooth voltage, required to deflect the beam in the horizontal section. This voltage deflects spots at a constant time dependent rate
5. **Horizontal Amplifier:**The sawtooth voltage generated by the time base generator may not be of sufficient strength. Thus before it is applied to horizontal deflection plates it is amplified using horizontal amplifier.
6. **Trigger Circuit:** trigger circuit converts the incoming signal into trigger pulses which can be used for synchronization. It is required that horizontal deflection starts at the same time as that of input vertical signal. Thus to synchronize the triggering circuit is used.
7. **Power Supply:**There are two power supplies, a -ve High Voltage (HV) supply and a +ve Low Voltage (LV) supply. Two voltages are generated in the CRO. The +ve volt supply is from + 300 to 400 V. The -ve high voltage supply is from -1000 to -1500 V. These voltages are required for controlling intensity, focus and positioning or accelerating the electrons.

**Advantages of using -ve HV Supply**:

- The accelerating anodes and the deflection plates are close to ground. This ground potential protects the operator from HV shocks.
- The deflection voltages are measured with respect to ground, therefore HV blocking or coupling capacitor are not needed.

- Less insulation is needed between positioning controls and chasis.

8. Graticules: this is the plastic/glass/fiber glass sheet screen in front of the CRO. This screen has grids similar to graph paper/sheet. This helps in measuring parameters on the oscilloscope. It is practically designed as 8×10 pattern i.e., 8 divisions vertical and 10 divisions horizontal.

## Simple CRO:

- The Basic block diagram of a simple CRO is shown in Fig.
- The ‘ac heater supply’ supplies power to the CRT heaters.
- CRT dc voltage is obtained from the ‘HV dc supply’ through voltage dividers R1-R5. It also includes potentiometer (R3) which varies the potential at the focusing electrode, known as focus control, and one which varies the control grid voltage, called the intensity control (R5).
- Capacitor C1 is used to ground the deflection plates and the second anode for the signal voltage, but dc voltage isolates these electrodes from the ground.
- S2 connects the sweep generator output to the horizontal input. The sweep voltage is amplified before being applied to the horizontal deflecting plates.
- When an externally generated sweep is used then, S2 is connected to its external position and the external generator is connected to the input. The sweep synchronizing voltage is applied to the internal sweep generator through switch S1, which selects the type of synchronization.

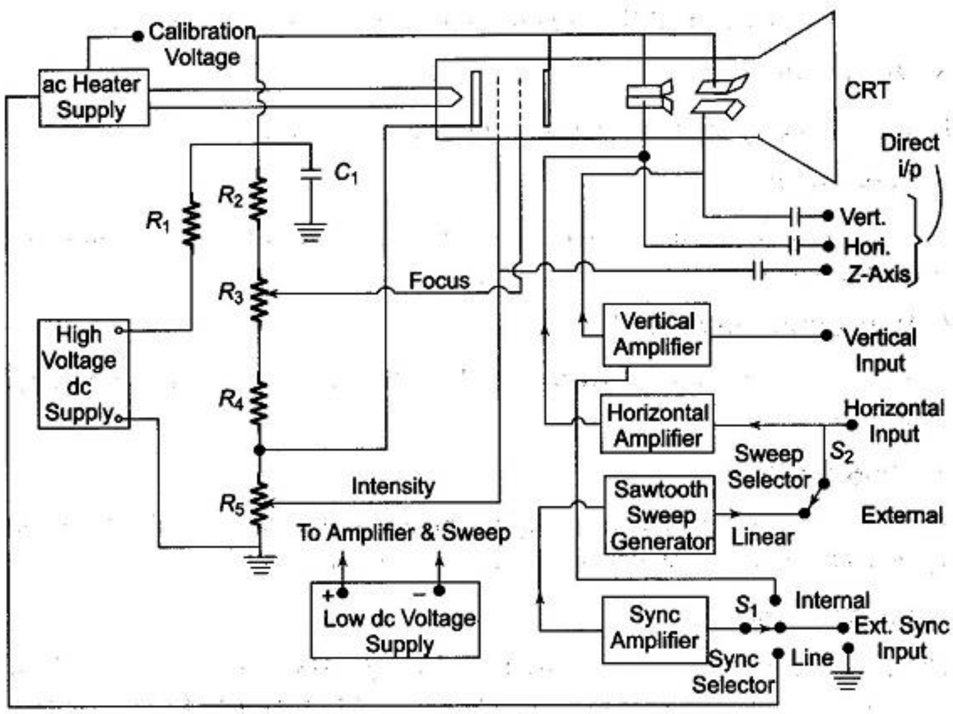



**Fig.** Simple CRO

## Vertical Amplifier:

The vertical amplifier in oscilloscope determines the sensitivity (gain) and frequency bandwidth (BW). The gain and B.W. product is constant. Thus to obtain a greater sensitivity the BW is narrowed or to get better/greater frequency sensitivity is reduced.

Some oscilloscopes provides two alternatives

- Switching to a wide bandwidth position
- Switching to a high sensitivity position.

The block diagram of a vertical amplifier is shown in below Fig.

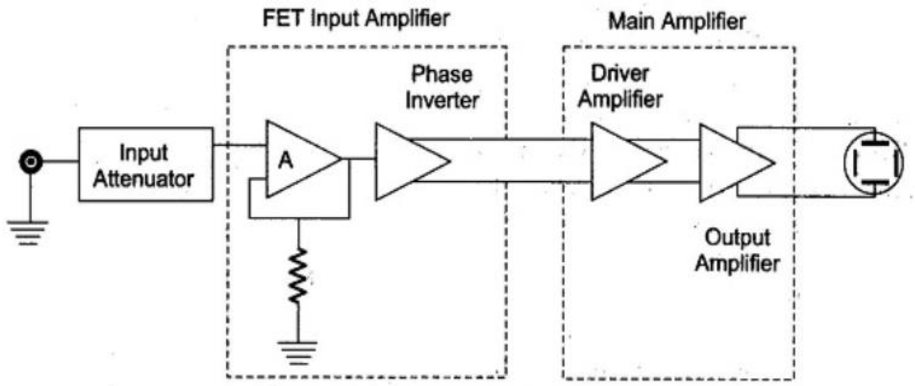



**Fig.** Vertical Amplifier

- The vertical amplifier stage is used to amplify the input signal as these signals are not strong enough to provide measurable deflection. Usually wide band amplifiers are used so that entire band of frequencies is passed faithfully.
- Similarly it also has a attenuator which brings down the signals within the measurable range. The attenuators are used when very high voltage signals are to be measured.
- The vertical amplifier consists of several stages, with sensitivity or gain fixed and expressed in V/divs. The advantage of fixed gain is that the amplifier can be more easily designed to meet the requirements of stability and B.W.
- The input stage has 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. The output of FET stage has medium impedance and it has to be connected to the phase inverter which has low impedance. Thus impedance matching is obtained with BJT emitter follower.
- 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, even harmonic suppression and greater power output per tube. In addition, a number of defocusing and non-linear effects are reduced.

## Horizontal Deflecting System

- The Horizontal Deflecting System consist of a Time Base Generator and an output amplifier

**Continuous or Time Base Generator:**A continuous sweep CRO using a UJT as a time base generator is shown in Fig. a.

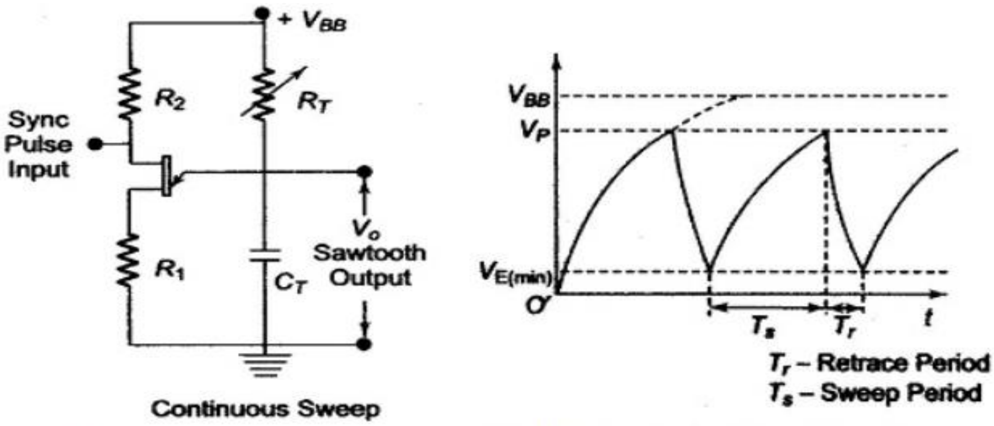



Fig. a Continuous Sweep Fig. b Sawtooth Output Waveform

- The UJT is used to produce the sweep. When the power is first applied, the UJT is off and the $C_T$ changes exponentially through $R_T$towards $V_{BB}$.
- At the same time the emitter voltage $V_E$of UJT rises towards $V_{BB}$. When capacitor charges to it max i.e., $V_P$, the emitter to base diode becomes forward biased and the UJT triggers ON.
- When UJT is ON it provides a low resistance path and the capacitor discharges rapidly.
- When the emitter voltage $V_E$ reaches the minimum value, the UJT goes OFF and the capacitor begins to recharges and the cycle repeats. This is shown in Fig. b
- From the output waveform we can see that sweep output is not linear. Thus to improve sweep linearity, two separate voltage supplies are used
    - A low voltage supply for UJT and
    - A high voltage supply for the $R_TC_T$ circuit.
- To control frequency, $R_T$ is varied and CT is varied or changed in steps for range changing.
- The sync pulse in Fig. a, provides the sweep frequency to be exactly equal to the input signal frequency, so that the signal is locked on the screen and does not drift.

## Storage Oscilloscope

- Conventional CRT has persistence ranging from few milliseconds to several seconds and sometimes it becomes necessary to retain the pattern for a longer period. In this case it becomes necessary to store the waveform for certain duration, which is independent of phosphor persistence.
- Two storage techniques are used in oscilloscope CRTs, mesh storage and phosphor storage.

**Mesh Storage:**

- Mesh storage CRT is used in displaying very low frequency (VLF) signals. It finds application in biomedical and mechanical fields.
- A mesh Storage Oscilloscope, shown in Fig. a. it has a dielectric material deposited on a storage mesh, a collector mesh, flood guns and a collimator, along with the elements of a standard CRT.
- In the storage mesh, the dielectric material deposited area is known as 'storage target'. It is deposited with material such as Magnesium Fluoride. It makes use of a property known as secondary emission.

- The writing gun or electron gun emits electrons, which etches a positively charged pattern on the storage mesh when focused on storage target. Because of the excellent insulating property of the Magnesium Fluoride coating, the positively charged pattern remains where it is deposited.

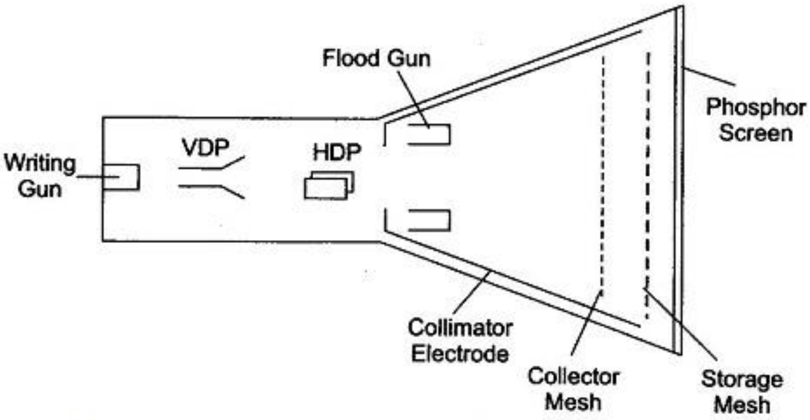



Fig. a Basic Elements of Storage Mesh CRT

- In order to make a pattern visible, a special electron gun, called the **flood gun**, is switched on.
- The flood gun emits low velocity electrons and these are bombarded on the storage mesh/target.
- The electrons from flood gun is adjusted by the collimator electrode, which forms a low voltage electrostatic lens system (to focus the electron beam), as shown in Fig. b.

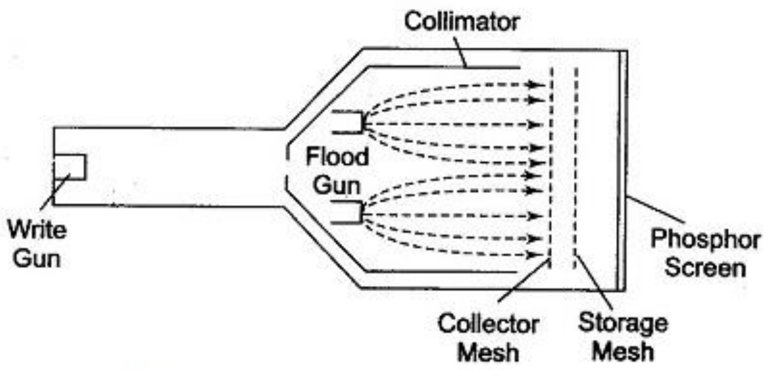



Fig. b Storage Mesh CRT

- Most of the electrons are stopped and collected by the collector mesh. Only electrons near the stored positive charge are pulled to the storage target with sufficient force to hit the phosphor screen.
- The CRT will now display the signal and it will remain visible as long as the flood guns operate.
- To erase the pattern on the storage mesh, a negative voltage is applied to neutralize the stored positive charge.
- To make the pattern visible flood guns and collimator electrodes are used, where the guns emits electrons and collimator electrodes focuses the electron path.

- Most of the electrons are stopped and collected by collector mesh. When the electrons penetrate beyond the collector mesh, they encounter either a positively charged region or negative charge region.
- The positive charge region has trace pattern while negatively charged region does not have any trace.
- The positivecharged areas allow the electrons to pass through to the post accelerator region and the display target phosphor. The negatively charged region repels the flood electrons back to the collector mesh.
- Thus the charge pattern on the storage surface appears and is reproduced on the CRT as though being traced with deflected beam.
- Figure c shows a display of the stored charge pattern on a mesh storage.

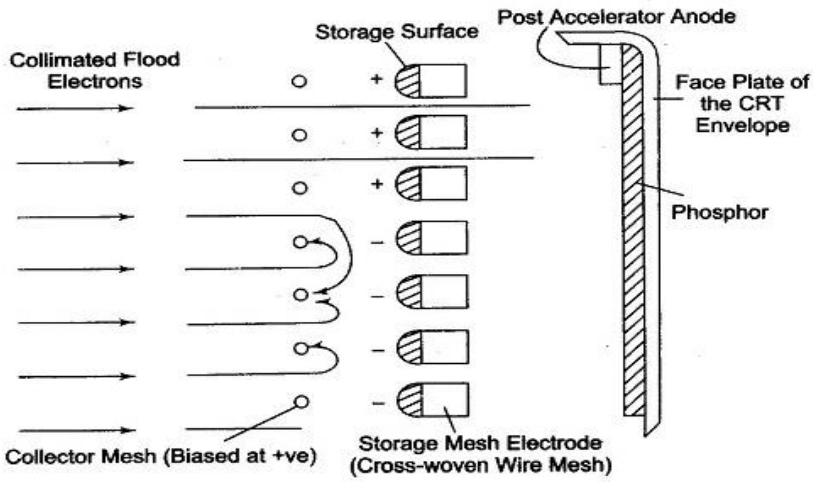



**Fig. c** Display of Stored Charged Pattern on a Mesh-storage

**Phosphor Storage:**
In this type of CRT, it uses a thin layer of phosphor to serve both storage and display element.

**Note:**
**Secondary emission:** the writing gun produces beam of electrons, which has the information of the signal. This beam hits the surface of the storage surface and this seperates other electrons from the surface of the target. This is known as secondary emission.

## Digital Readout Oscilloscope:

- The Digital Readout Oscilloscope instrument has a CRT display and a counter display. The Fig. d shows the block diagram of digital read out oscilloscope when measuring voltage.
- The input signal is sampled by a sampling circuit at regular interval of time and this process is called as '**strobing**'.
- The sweep time and input signal decides the equivalent time between 2 samples. Ex: if sweep time of 1 nano-sec/cm and a sampling rate/time of 100 samples/cm then it gives a time of 10 pico-sec/sample.

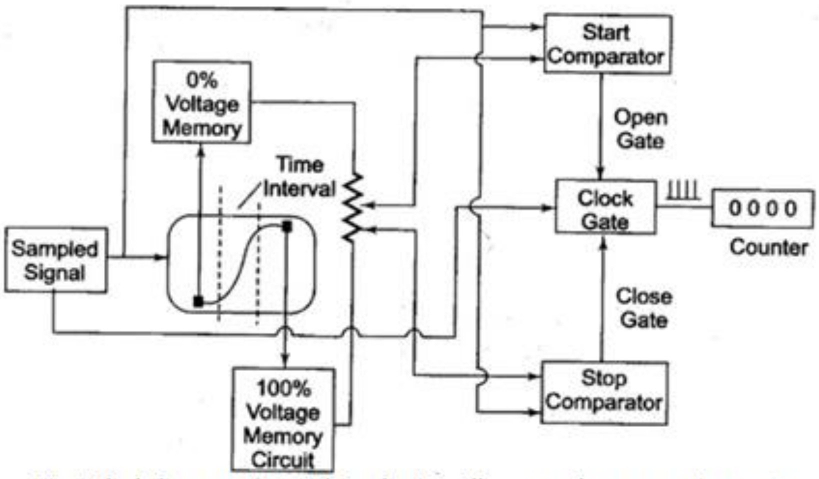



Fig. d Block diagram of Digital Readout Oscilloscope when measuring Voltage

- CRT trace is used to identify 0% and 100% zones position. This portion can be shifted to any part of the display.
- The potential/voltage divider taps voltage between the 0% and 100% level and these will be one of the signals for input to start and stop comparators respectively.
- Comparators are used for comparing the input waveform with selected % point.
- When the sampled signal is at 0% level is used to produce a pulse for opening gate. The output of comparator enables the clock gate andcounter starts counting the pulses.
- Similarly when 100% level is sensed, it gives a stop pulse and the clock gate is disabled and counter stops counting.
- The number of pulses counted by the counter is proportional to the actual sample taken and read out digitally in ns, µs, ms or seconds.
- Fig e (below) shows the block diagram of digital read out oscilloscope used for measuring time.
- In this a linear ramp generator is used which produces a voltage and this is one of the input to start and stop comparator respectively.

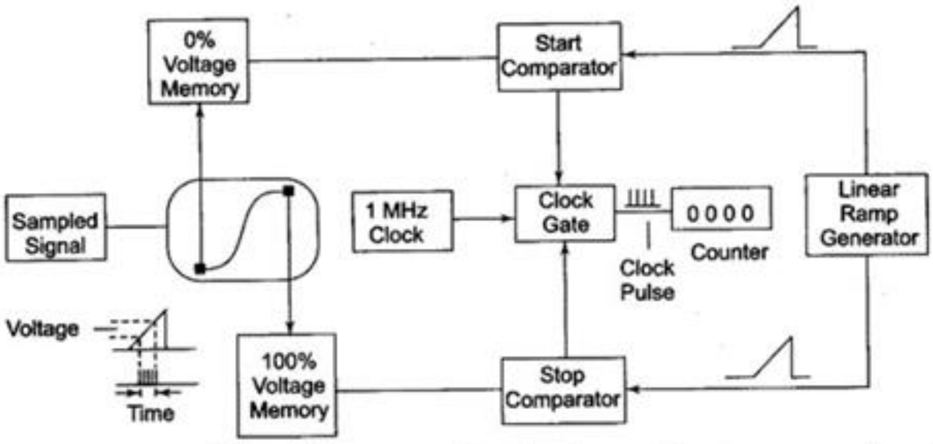



Fig. e Block Doagram of Digital Readout Oscilloscope to measure the voltage to time conversion

- When the linear ramp voltage equals the 0% reference the clock gate gets enabled/opens. When the ramp equals 100% reference the clock gate disables/closes.

- The number of clock pulses that activate the counter is directly proportional to the voltage between the selected references and is read out in mV or volts by the Nixie tube display.

## Lissajous Method for frequency measurement:

- The phase and frequency measurement can be done using the oscilloscope.
- One of the fastest method to determine frequency is by using Lissajous patterns.
- These patterns results when sine waves aresimultaneously applied to both the deflection plates pairs. If one frequency is an integral multiple (harmonic) of the other, the pattern will be stationary, and is called a Lissajous figure.
- The measurement method involves applying known frequency (standard frequency) to the horizontal plates and unknown frequency (of approximately the same amplitude) is simultaneously applied to the vertical deflection plates.
- TheLissajous figures depends on (i)Amplitude of two waves, (ii)Phase difference between 2 waves and (iii)Ratio of frequencies of two waves
- The horizontal signal is designated as fh and the vertical signal as fv.
- Now if 2 signals of having same amplitude, frequency and phase difference of ϕ between them and if this is applied to the deflecting beams. Then difference in phase produces various patterns which varies from straight diagonal line to ellipse of different tilts
- Figure below shows the basic circuit for frequency measurement.

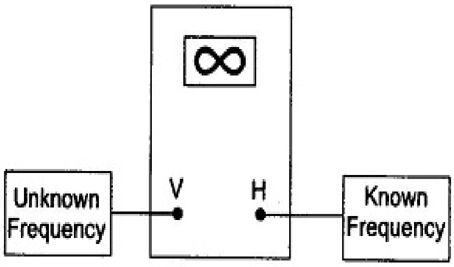



Fig. Basic Circuit for Frequency Measurements with Lissajous Figures

**Measurement of frequency:**

- The oscilloscope is set up and the internal sweep is switched off (or change to Ext). The signal source are connected as in above Fig.
- Keep frequency fv (unknown frequency) constant and vary frequency fh (known frequency), when observed the pattern spins in alternate directions and shape is changed.
- The pattern becomes stationary when fv and fh are in an integral ratio (either even or odd). The fv = fh pattern is still and is a single circle or ellipse. When fv = 2 fh, a two loop horizontal pattern is obtained as shown in below Fig.

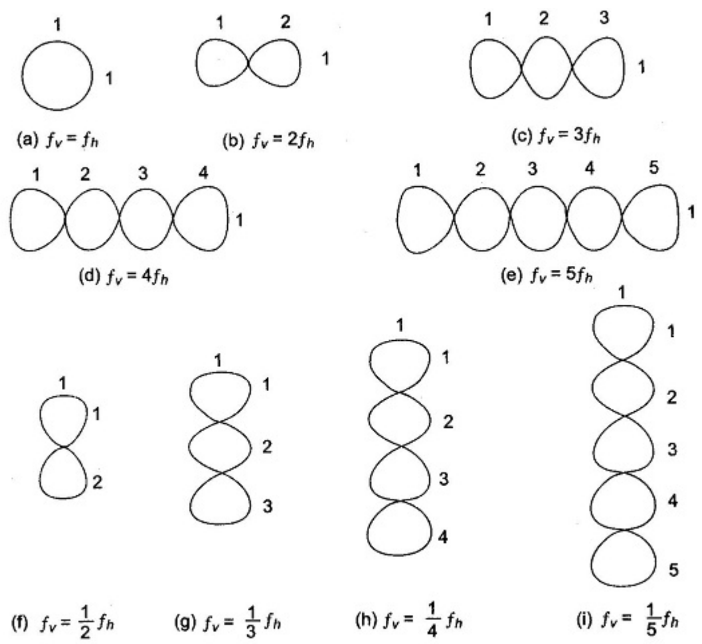



**Fig.** Lissajous Patterns for Integral Frequencies

- The frequency from Lissajous figure can be determined by, counting the number of horizontal loops in the pattern and divide it by the number of vertical loops and multiply this quantity by fh (known or standard frequency).
- In fig (h), the number of horizontal loop is 1 and vertical loop is 4. This gives a fraction of ¼. Thus the unknown frequency fv is equal to ¼ of fh.
- When the two frequencies are equal and in phase, the pattern appears as a straight line at an angle of 45° with the horizontal. If the phase between the two alternating signals changes, the pattern changes cyclically.
    - An ellipse pattern (at 45° with the horizontal) is seen when the phase difference is π/4
    - A circle pattern is seen when the phase difference is π/2
    - An ellipse (at 135° with horizontal) when the phase difference is 3π/4
    - A straight line pattern (at 135° with the horizontal) when the phase difference is π radians.
    - Thus as the phase angle between the two signals (fh and fv) changes from π to 2π radians, the pattern changes correspondingly through the ellipse-circle-ellipse cycle to a straight line.
- Now if the two frequencies being compared are not equal and if they are fractionally related, then a more complex stationary pattern appears. In this the patterns depends on the frequency ratio and the relative phase between the two signals.
- This is shown below in fig.

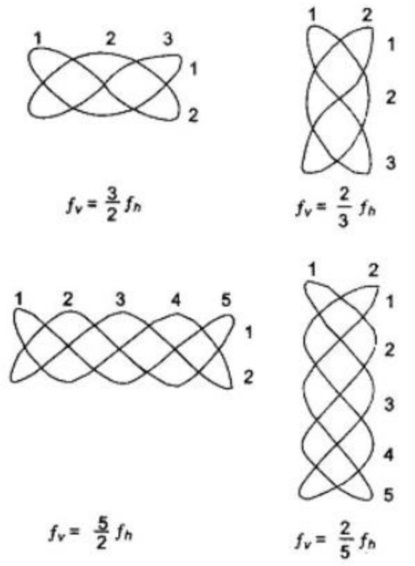



**Fig. 1** Lissajous Patterns for Non-Integral Frequencies

- The fractional relationship between the two frequencies is determined by counting the number of cycles in the vertical and horizontal and is given below.

$$f_v = (\text{fraction}) \times f_h$$

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

## Digital Storage Oscilloscope (DSO):

DSO are available in processing and non-processing types. In Processingequipment it includes interfacing and a microprocessor which provides a complete system for information acquisition, analysis and output. Processing capability ranges from simple functions (such as average, area, rms, etc.) to complex Fast Fourier Transform (FFT) spectrum analysis capability.

Non–processing digital scopes are designed such that they can be replacements for analog instruments for both storage and non-storage types. They include many desirable features which may lead to replace the analog scopes entirely.

The block diagram of DSO is shown below in the figure.

- These oscilloscope uses same type of amplifier and attenuator circuitry as used in the conventional oscilloscopes.
- The attenuated signal is applied to the vertical amplifier.
- From the amplifier the input signal is sampled through sample and hold circuit and to digitize the analog signal, it is fed to analog to digital (A/D) converter.
- The successive approximation type of A/D converter is most often used in the digital storage oscilloscopes.
- The sampling rate and memory size are selected based on the duration & the waveform to be recorded.
- Once the input signal is sampled, the A/D converter digitizes it.The signal is then captured/stored in the memory.

- Once it is stored in the memory, many manipulations are possible as memory can be readout without being erased.
- The input signal is also used for trigger circuit (sweep generator) to generate the signal for horizontal deflecting plates.
- To the deflecting plates the digital data is again converted to analog and is amplified and fed.

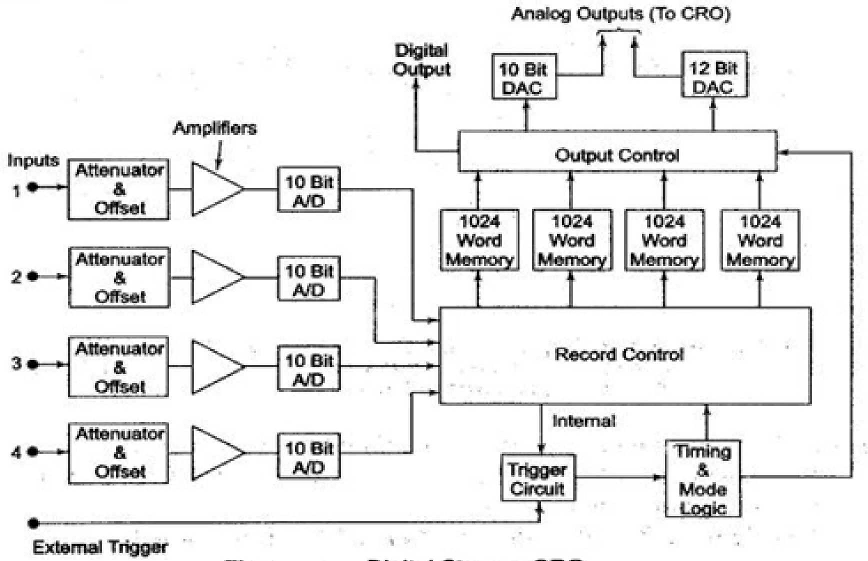



Fig. Digital Storage CRO

Advantages of digital storage oscilloscope:

1. It is easier to operate and has more capability.
2. The storage time is infinite.
3. The voltage and time scales of display can be changed after the waveform has been recorded, which allows expansion (typically to 64 times) of selected portions, to observe greater details.
4. A cross-hair cursor (◎)can be positioned at any desired point on the waveform and the voltage/time values displayed digitally on the screen, and/or readout electrically.
5. Some scopes use 12 bit converters, giving 0.025% resolution and 0.1% accuracy on voltage and time readings.
6. Split screen capabilities (simultaneously displaying live analog traces and replayed stored ones) enable easy comparison of the two signals.
7. The display flexibility is available. The number of traces that can be stored and recalled depends on the size of the memory.
8. The characters can be displayed on screen along with the waveform which can indicate waveform information such as minimum, maximum, frequency, amplitude etc.
9. The X-Y plots, B-H curve, P-V diagrams can be displayed.
10. The pre-trigger viewing feature allows to display the waveform before trigger pulse.
11. Keeping the records is possible by transmitting the data to computer system where the further processing is possible
12. Signal processing is possible which includes translating the raw data into finished information e.g. computing parameters of a captured signal like r.m.s. value, energy stored etc.

# SIGNAL GENERATORS

Signal generator is a vital component in test set up. It provides variety of waveforms for testing electronic circuits at low power.

Oscillator → provides sine wave

Generator → provides several output waveforms

Energy is not created in generators; it is simply converted from dc source to ac energy at some specified frequency.

Requirements of signal generators are

*The amplitude should be controllable from very small to relatively large values

*The signal should be distortion free

In some cases a particular signal required by the instrument is internally generated by a self-contained oscillator.

Classes of generators that are available as separate instruments to provide signals for general test purpose are called signal generators.

AF → Audio frequency- 20 Hz to 20 KHz

RF → Radio frequency- above 30 KHz

## 5.1: Fixed frequency AF oscillator

Some Instruments has self contained oscillator is an integral part of the instrument circuitry and is used to generate a signal at some specified audio frequency. Such a fixed frequency might be a 400 Hz signal used for audio testing or a 1000 Hz signal for exiting a bridge circuit.

Oscillations at specified audio frequency are generated by the use of an iron core transformer to obtain positive feedback through inductive coupling between the primary and secondary windings.

## 5.2: Variable AF oscillator

A variable AF oscillator for general purpose use in a laboratory should cover at least the full range of audibility (20 Hz to 20 KHz) and should have a pure sinusoidal wave output over the entire frequency range. These oscillators are of RC feedback oscillator type or beat frequency oscillator type.

## 5.3: Basic standard signal generator (sine wave)

In most of the measurement and instrumentation systems, the input signal required is sinusoidal signal. Such a periodic, sinusoidal signal is generated using an oscillator. An oscillator is a circuit which generates a –sinusoidal signal with constant amplitude and constant desired frequency using positive feedback. It generates an output waveform at a desired frequency in a range from few hertz to several giga hertz.

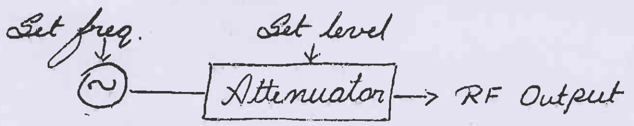



Fig: Basic Sine Wave Generator

A simple sine wave generator consists of two basic blocks,
(i) Oscillator
(ii) Attenuator

The oscillator uses an active device such as an op-amp. The output of an op-amp is fed back in phase with input. This positive feedback causes regenerative action resulting in oscillation.

The attenuator provides amplitude control. Basically the attenuator is a device which reduces or attenuates the power level of the signal by fixed amount. The proper functioning of a signal generator depends on the performance of an oscillator and attenuator.

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## 5.4: Conventional standard signal generators

Standard signal generator is basically a radio frequency (RF) signal generator. It produces known and controllable voltages.

This instrument is provided with a means of modulating the carrier frequency. The modulation is indicated by a meter. The output signal can be amplitude modulated (AM) or frequency modulated (FM). Modulation may be done by a sine wave, square wave, triangular wave or a pulse.

The block diagram of conventional standard signal generator is shown below

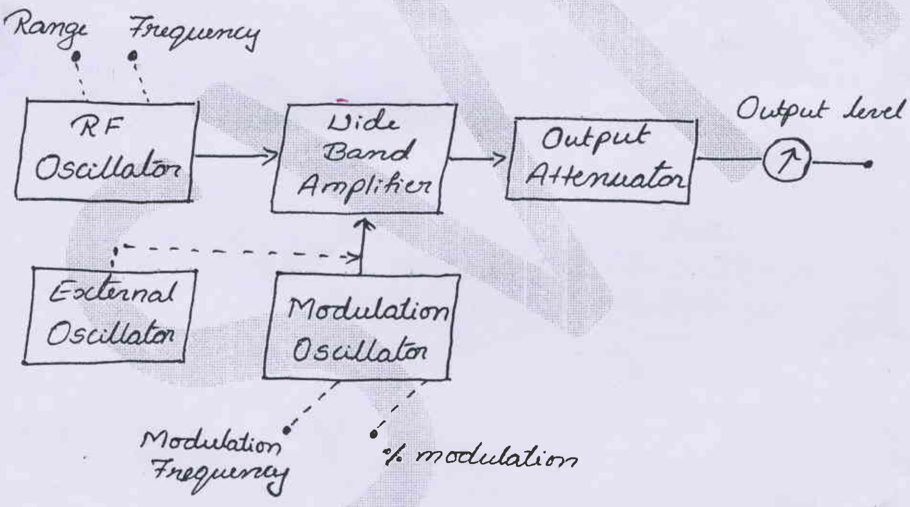


Fig: Conventional Standard Signal Generator

The carrier frequency is generated by a very stable RF oscillator which has constant output over any frequency range. Modulation is done in the output amplifier circuit. The output of amplifier is modulated carrier and is given to an attenuator. This attenuator helps in selecting proper range of attenuation and thus the output signal level is controlled.

In LC tank circuit design of master oscillator, frequency stability is limited. The switching of frequency in various ranges is achieved by selecting appropriate capacitor. This upsets circuit design and requires some time to stabilize at new resonant frequency.

In high frequency oscillators, it is essential to isolate the master oscillator from output circuit. Because of this isolation, changes in output circuit do not reflect on the oscillator frequency, amplitude characteristics. For isolation buffer amplifiers are used.

ADVANTAGES

*The output is stable

*The output voltage can be controlled according to the requirement

DISADVANTAGES

*Due to LC tank circuit, the frequency stability is limited.

*It takes some time to stabilize at new freq when the range is changed

*In high frequency oscillators, isolation of master oscillator from output is necessary

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## 5.5: Modern laboratory type signal generator

In modern laboratory type signal generator, the frequency stability is increased by using single master oscillator. With this single master oscillator we can get the highest frequency range with good stability as compared to conventional signal generator.

The master oscillator is made insensitive to temperature variations. Temperature compensation devices are used which can work properly for any temperature changes. The influence of the succeeding stages is also overcome by using buffer amplifiers.

The block diagram of modern laboratory type signal generator is shown below

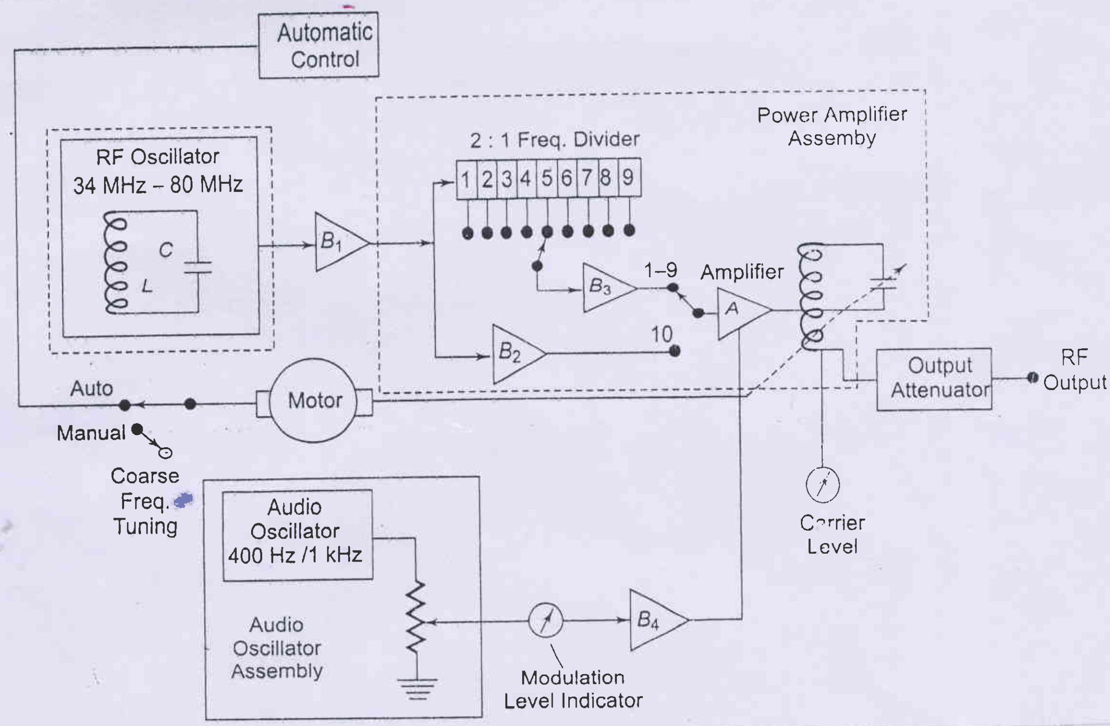


Fig: Modern Signal Generator

The RF oscillator consists of LC tank circuit. It gives frequency range from 34 MHz to 80 MHz. This signal is connected to untuned buffer amplifier $B_1$. The output of this amplifier is given to frequency divider circuit. The circuit shown above consists of 9 frequency dividers. The frequency division can be done by using flip-flops to get ratio of 2:1.

The lowest frequency range obtained by using frequency divider is the highest frequency range divided $2^9$ or 512. The master oscillator has both automatic and manual controllers. Availability of motor driven frequency control is employed for programmable automatic frequency control devices.

The LC tank circuit and frequency divider provides a carrier signal. The buffer amplifiers B2 and B3 are used for isolation. The use of buffer amplifiers provides very high degree of isolation between master oscillation stage and power amplifier stage. This eliminates all frequency distortions caused by loading between input and output circuits.

The modulation is done at the power amplifier stage.Signal for modulation is provided by an audio oscillator (400 Hz and 1 kHz). The modulation takes place in main amplifier, in power amplifier stage. The level of modulation can be adjusted up to 95% by using control devices.

ADVANTAGES

*As same master oscillator is used to get various frequency ranges, the stability is improved even at the highest frequency range.

*The use of buffer amplifiers provides good isolation between the master oscillator and main power amplifier eliminating loading effect completely.

*The change in the output due to temperature variations is compensated by compensation devices for all frequency ranges.

*The power consumption of the instrument is very low.

*Good regulation and crystal stability, with low ripple, is obtained.

*Range switching effects are eliminated as the same oscillator is used on all the bands.

*Excellent Q stability with very low ripple.

*Due to high degree of isolation, distortion get eliminated between the input and output circuits.

DISADVANTAGES

*The circuit is complex, so cost is increased as compared to conventional signal generator.

DIFERENCE BETWEEN STANDARD AND MODERN SIGNAL GENERATOR

| | Standard signal generator | Modern signal generator |
|---|---|---|
| 1 | It has limited frequency stability. | Frequency stability over entire frequency range is maintained |
| 2 | Temperature compensation is not provided | Temperature compensation is provided |
| 3 | The frequency range is small | Wide frequency range is possible |
| 4 | Loading and distortion effects are more | Loading and distortion effects are less |
| 5 | It takes time to stabilize at new frequency | It gets stabilized to new frequency very quickly |
| 6 | Regulation is poor | Regulation is excellent |
| 7 | Less Q stability with high ripple | Good Q stability with low ripple |
| 8 | Automatic tuning with motor is not available | Motorized automatic tuning is possible |
| 9 | Construction is simple | Construction is complicated |
| 10 | Cost is low | Cost is high |

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## 5.6: AF sine and square wave generator

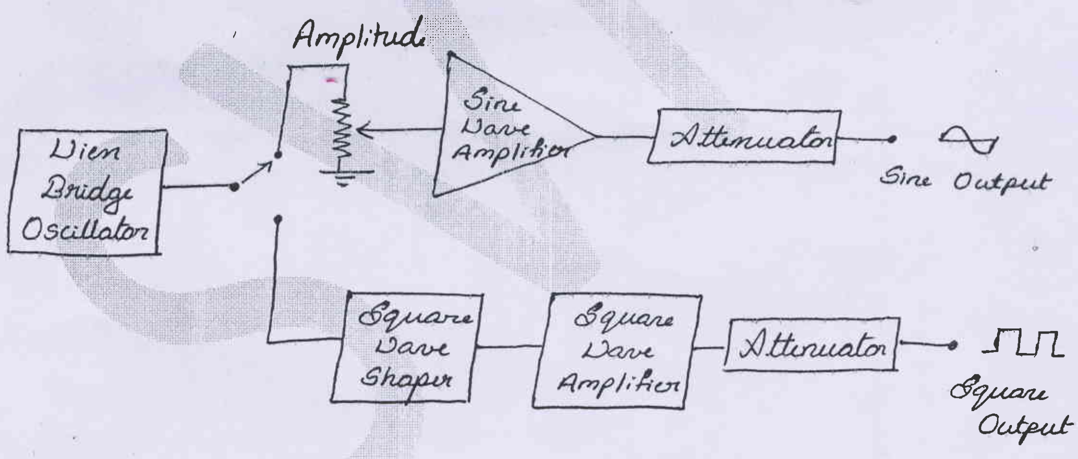


Fig: Sine and Square Wave Generator

The block diagram of AF sine and square wave generator is shown above. A Wien bridge oscillator is used in this generator. The Wien bridge oscillator is the best for audio frequency range. The frequency of oscillations can be changed by varying the capacitance in the oscillator. The frequency can also be changed in steps by switching in resistors of different values.

The output of the Wien bridge oscillator goes to the function switch. The function switch directs the oscillator output either to the sine wave amplifier or to the square wave shaper. At the output, we get either a square wave or sine wave. The output is varied by means of an attenuator.

The front panel of a signal generator consists of the following

1. *Frequency selector*: It selects the frequency in different ranges and varies it continuously in a ratio of 1:11. The scale is non-linear.
2. *Frequency multiplier*: It selects the frequency range over 5 decades, from 10 Hz to 1 MHz
3. *Amplitude multiplier*: It attenuates the sine wave in 3 decades, ×1, ×0.1 and × 0.01.
4. *Variable amplitude*: It attenuates the sine wave amplitude continuously
5. *Symmetry control*: It varies the symmetry of the square wave from 30% to 70%
6. *Amplitude*: It attenuates the square wave output continuously
7. *Function switch*: It selects either sine wave or square wave output.
8. *Output available*: This provides sine wave or square wave output.
9. *Sync*: This terminal is used to provide synchronization of the internal signal with an external signal.
10. *ON*-OFF Switch

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## 5.7: Function generator

A function generator produces different waveforms of adjustable frequency. The output waveforms are sine, square and triangular. Frequency can be adjusted from 0.01 Hz to 100 kHz. Various outputs can be used at the same time. The function generator can be phase locked to an external source. One function generator can be used to lock a second function generator, and thus the two output signals can be displayed in phase.

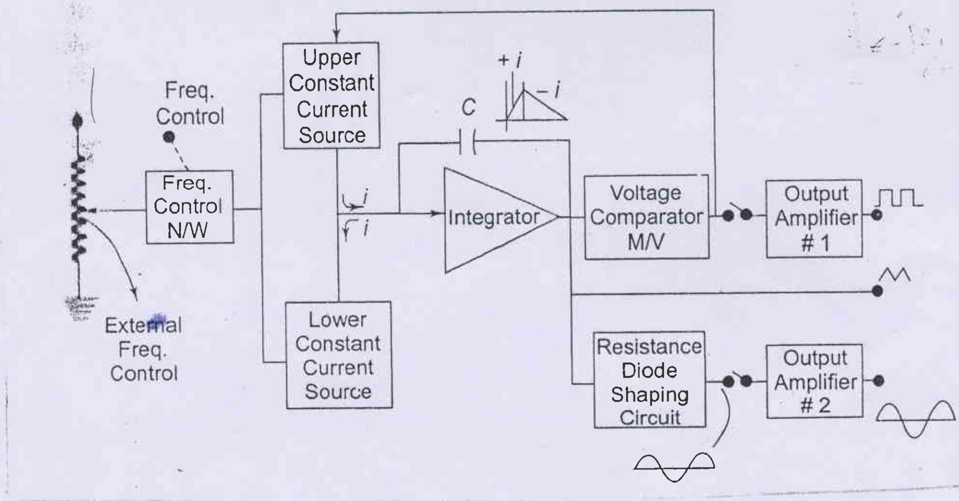


Fig: Block diagram of Function Generator

The block diagram of the function generator is shown above. The frequency is controlled by varying the magnitude of current which drives the integrator.

The frequency controlled voltage regulates two current sources. The upper current source supplies constant current to the integrator whose output voltage increases linearly with time, according to the equation of the output signal voltage,

$$e_{out} = -\frac{1}{C}\int_0^t i\,dt$$

An increase or decrease in the current increases or decreases the slope of the output voltage and hence control the frequency. The voltage comparator multi-vibrator changes states at a pre-determined maximum level of the integrator output voltage. This change cuts off the upper current supply and switches on the lower current supply. The lower current source supplies a reverse current to the integrator, so that its output decreases linearly with time. When the output reaches pre-determined maximum level, the voltage comparator again changes state and switches on the upper current source.

The output of the integrator is a triangular waveform whose frequency is determined by the magnitude of the current supplied by the constant current sources.

The comparator output delivers a square wave voltage of the same frequency. The resistance diode network alters the slope of the triangular wave as its amplitude changes and produces a sine wave with less than 1% distortion.

## 5.8: Square and pulse generator (laboratory type)

The fundamental difference between a pulse generator and a square wave generator is in the duty cycle. A pulse with 50% duty cycle is called a square wave.

$$Duty\ cycle = \frac{pulse\ width}{pulse\ period}$$

**Requirements of a pulse:**

1. Pulse should have minimum distortion
2. Basic characteristics of the pulse are rise time, overshoot, ringing, sag and undershoot.
3. Pulse should have sufficient maximum amplitude and also the attenuation range should be adequate to produce small amplitude pulses.
4. The range of frequency control of the pulse repetition rate (PRR) should meet the needs of the experiment.
5. Pulse generators can be triggered by an external trigger signal and also pulse generators can be used to produce trigger signals
6. Output impedance of pulse generator is important consideration. Generator should be matched to cable and cable to test circuit.
7. DC coupling of the output circuit is needed when dc bias level is to be maintained.

*Overshoot:* The maximum height immediately following the leading edge
*Ringing:* It is the positive and negative peak distortion, excluding overshoot
*Sag (pulse drop):* It is the fall in pulse amplitude with time.

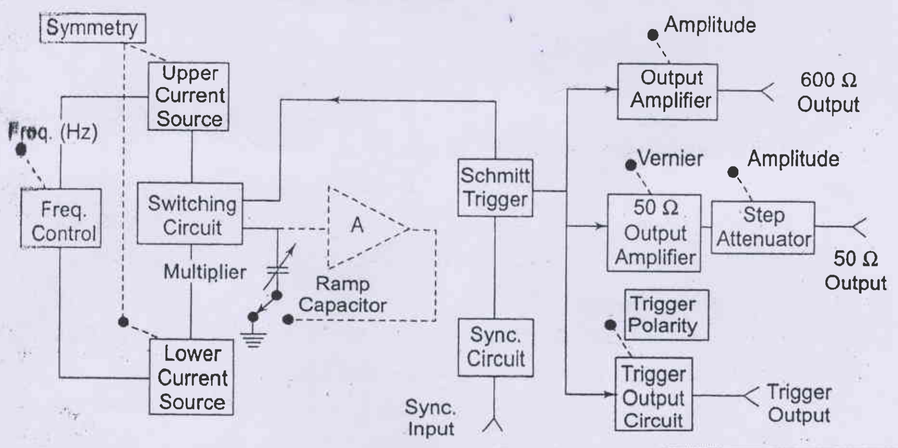


Fig: Block diagram of Pulse Generator

A laboratory type square wave and pulse generator is shown above. The frequency range of the instrument is from1 Hz to 10 MHz. The duty cycle can be varied from 25-75%. Two independent outputs are available, a 50Ω source that supplies pulses with rise and fall time of 5 ns at 5V peak amplitude and 600 Ω source which supplies pulses with a rise and fall time of 70 ns at 30 V peak amplitude. This instrument can be operated as a free running generator or it can be synchronized with external signals.

The basic generating loop consists of the current sources, the ramp capacitor, the Schmitt trigger and the current switching circuit as shown below.

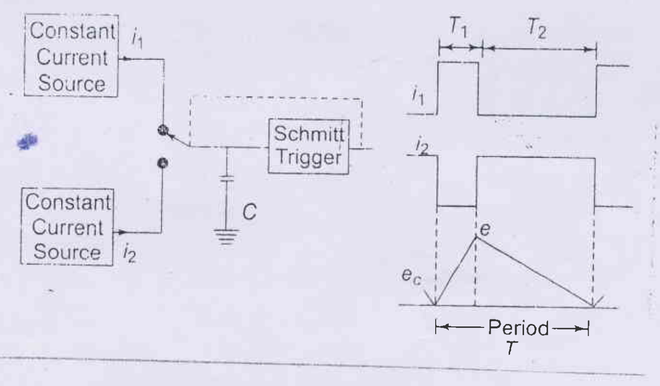


Fig: Basic Generating Loop

The upper current source supplies a constant current to the capacitor and the capacitor voltage increases linearly. When the positive slope of the ramp voltage reaches the upper limit set by the internal circuit components, the Schmitt trigger changes state. The trigger circuit output becomes negative and reverses the condition of the current switch. The capacitor discharges linearly, controlled by lower current source. When the negative ramp reaches a predetermined lower level, the Schmitt trigger switches back to its original state. The entire process is then repeated.

The ratio $i_1/i_2$ determines the duty cycle and the sum $i_1+i_2$ determines the frequency.

## SWEEP FREQUENCY GENERATOR:

The process of testing frequency response of amplifiers and filters can be simplified and speed up using signal generator that automatically varies its frequency over a pre-determined range. Such an instrument is called as sweep generator.

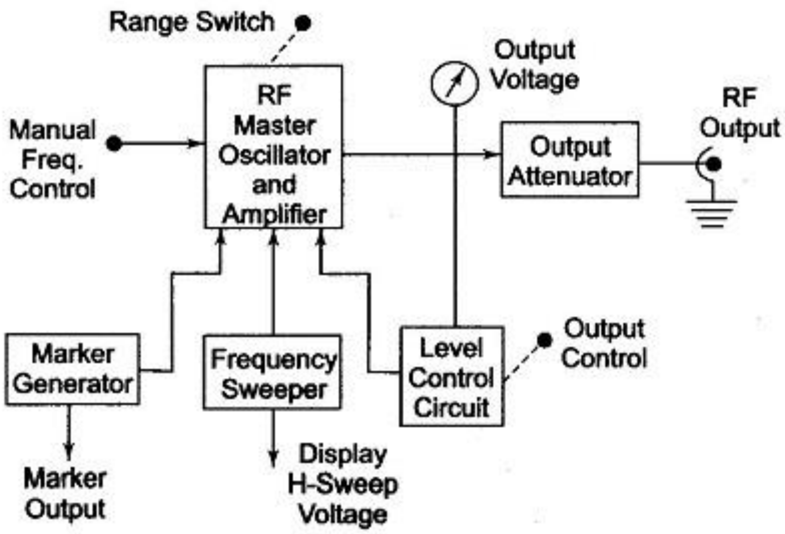


**Fig. 8.10** Sweep Generator

- Sweep generator provides a sinusoidal output voltage whose frequency varies smoothly and continuously over an entire frequency band.
- The process of frequency modulation may be accomplished electronically or mechanically.
- It is done electronically by varying reactance of the oscillator tank circuit component and mechanically by means of a motor driven capacitor.
- **Frequency sweeper**: provides a variable modulating voltage which causes the capacitance of the master oscillator to vary and used for synchronization to drive the horizontal deflection plates of the CRO. The amplitude of the response of a test device will be locked and displayed on the screen.
- **Manual control:** allows independent adjustment of the oscillator resonant frequency.

- In **automatic level control circuit** has closed loop feedback system which provide constant power delivery to test circuit which monitors the RF level at some point in the measurement system. Thus constant power level prevents any source mismatch and also provides a constant readout calibration with frequency.
- **Marker generator** provides half sinusoidal waveforms at any frequency within the sweep range. The marker voltage is added to the sweep voltage of the CRO during alternate cycles of the sweep voltage, and appears superimposed on the response curve.