UNIT V

5.1 Digital measurement of Electrical Quantities

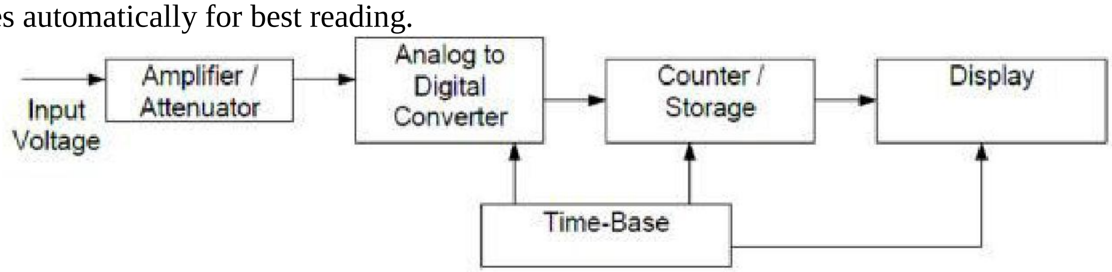
It is the measurement of analog electrical quantities by means of digital devices and display of measured result on a digital readout in numeric form as in the case of the counters.
It includes:

a) Digital voltmeter (DVM)
b) Digital frequency meter
c) Digital power meter
d) Digital phase meter.

Digital voltmeter (DVM):

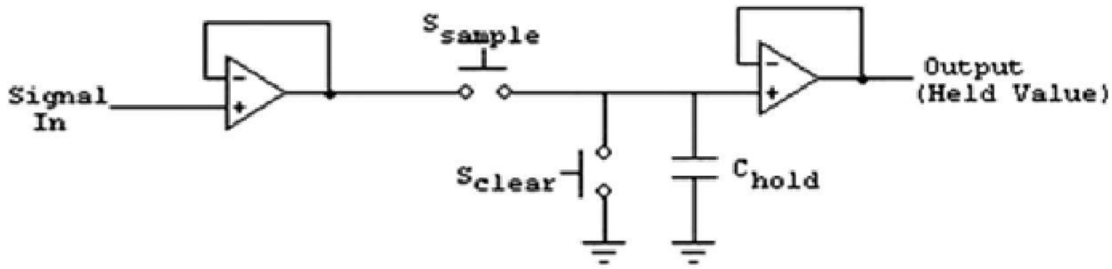
It is a device used for measuring the magnitude of DC voltages. AC voltages can be measured after rectification and conversion to DC forms. DC/AC currents can be measured by passing them through a known resistance (internally or externally connected) and determining the voltage developed across the resistance (*V*=*IR*). The result of the measurement is displayed on a digital readout in numeric form as in the case of the counters.

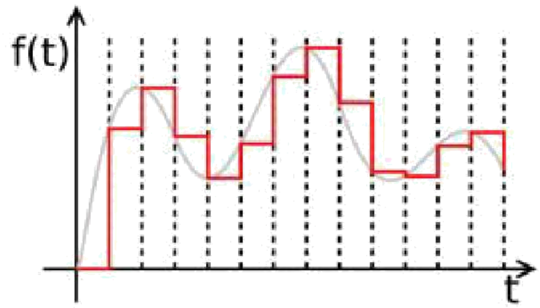
The block diagram in Figure below illustrates the principle of operation of a digital voltmeter. It is composed of an amplifier/attenuator, an analog to digital converter, storage, and display and timing circuits. There is also a power supply to provide the electrical power to run electronic components. The circuit components except the analog to digital converter circuits are similar to the ones used in electronic counters. The input range selection can be manually switched between ranges to get most accurate reading or it can be auto ranging that switches between ranges automatically for best reading.



The Analog to Digital Converter (ADC) – Sample and Hold

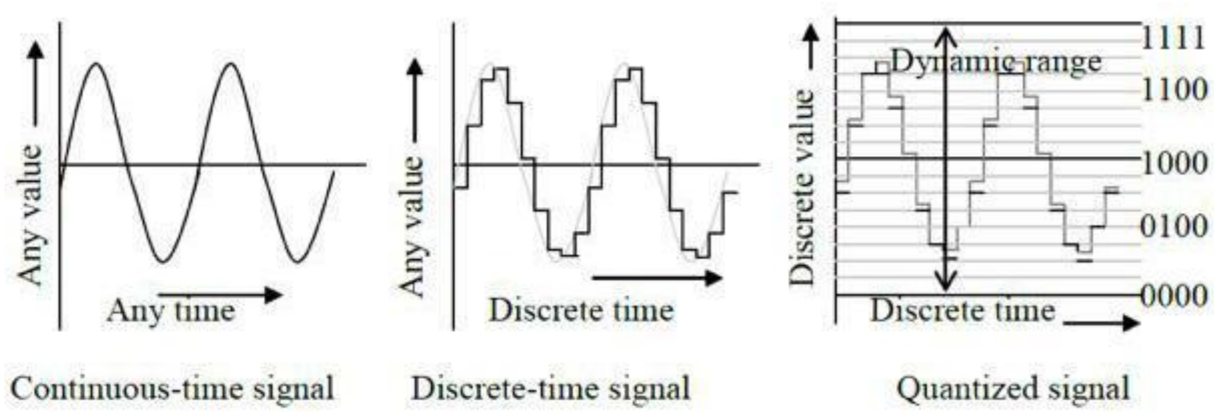
The analog to digital converter contains a sample and hold circuit, and conversion circuits. The sample and hold is composed of an electronic switch and a capacitor. The switch turns on and off at regular intervals. The capacitor charges and assumes the level of the input voltage as the switch is on. It holds the charge (hence the level of the input voltage) as the switch is off. The unity-gain buffer eliminates the loading of the capacitor by proceeding analog to digital converter circuitry. Figure below shows a simplified diagram with the input and output waveforms of the circuit.





Digitization of Analog Signals:

The input of the sample and hold circuit is a continuous time analog signal that can take any value any time. The output is a discrete time signal that can take any value but only at certain times. This signal can't be processed by a digital circuit unless it is converted into a digital code. The figure below illustrates the digitization of analog signals. The analog input signal is continuous in time and it can take any value at any time. This is converted to a discrete-time signal that can accept any value but at certain times. The next stage is to divide the amplitude range into discrete steps as well by a process called the quantization.

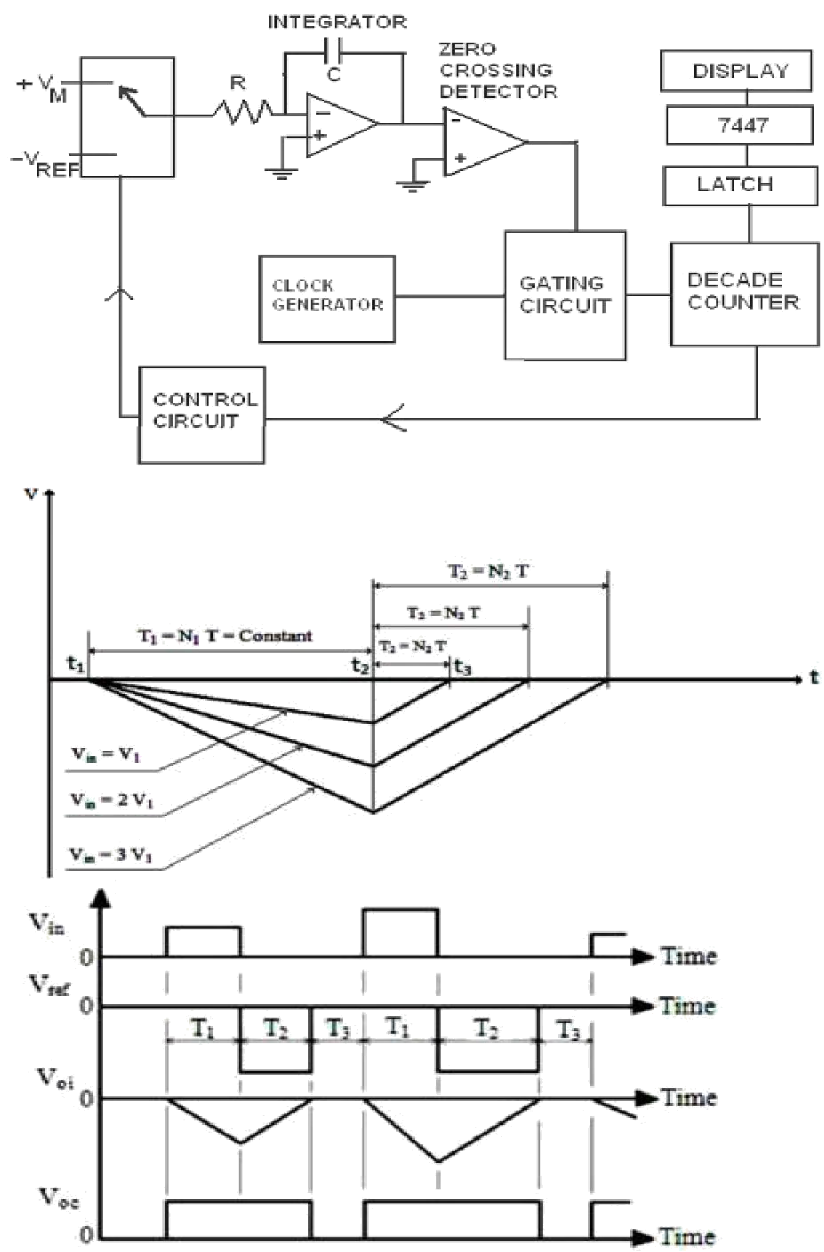


The figure exemplifies the principles for a 4-bit converter in which the dynamic range (the maximum peak to peak amplitude that the input signal can attain) is divided into 2^4-1 = 15 steps. A binary code (or binary coded decimal – BCD) is assigned for each level from 0000 to 1111 (1001 for BCD).

Dual slope Integrating Type Analog to Digital Converters:

The converter receives two signals, the analog input signal and the other one is a reference signal. These signals are accessed by a switching module. Then the analog signal (continuous in time) is sampled and the sample is integrated via an integrator module and after a certain time window, the reference signal, with a negative polarity, will be integrated. The basic principle of this operation is that the comparator module will determine the time to stop the integration process as shown in the figure below.

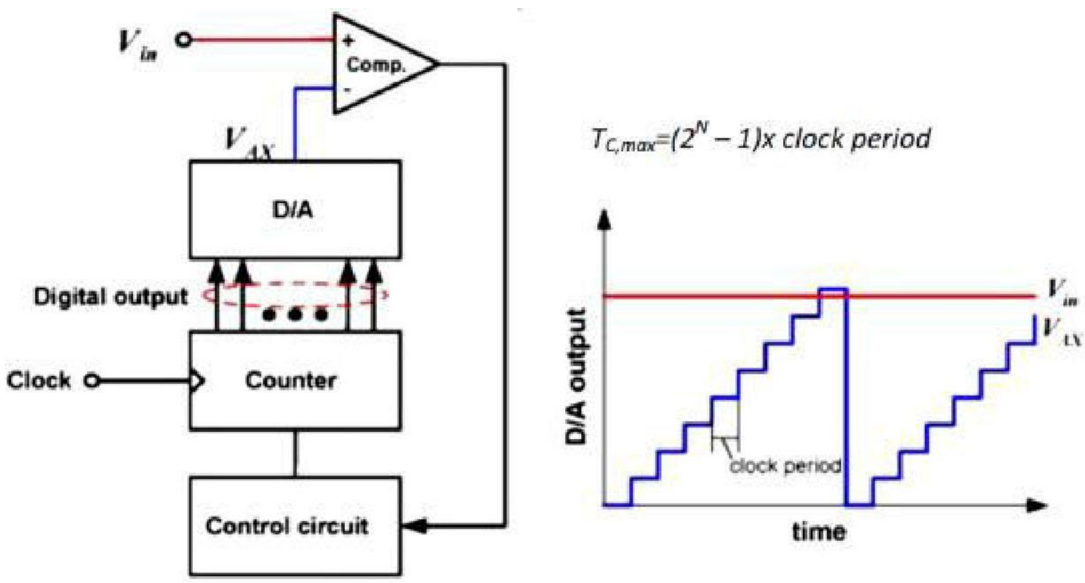
The time required for integrating the reference signal will be proportional to the value of the analog signal sample. Subsequently, the counter would contain binary digital representation of the input signal, which is converted into a decimal code. Finally, the decimal code representing the sample value is displayed on a seven-segment display



Staircase (Digital) Ramp Type DVM:

The figure below shows the block diagram of single ramp type of ADCs. The analog input signal is connected to the input terminal of a comparator that triggers a binary counter. The counter is connected to a DAC and the output of the DAC is connected to the other input terminal of the comparator. The output of the DAC will increase gradually as the counter is getting incremented.

This process will continue until the output of the DAC exceeds the unknown analog input signal, then the comparator output will change and cause the counter to stop and its value at that moment will represent the value of the input analog voltage.

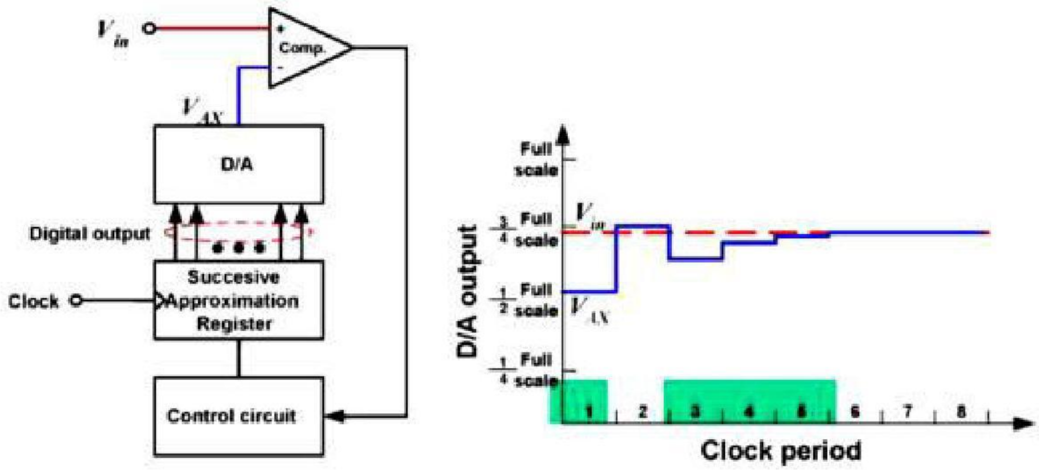


Successive Approximation Type DVM:

It is much faster than the digital-ramp ADC because it uses a digital logic that converges on the closest value to the input analog voltage. The figure below shows the block diagram of a Successive Approximation ADC. The successive approximation converter performs a binary search through all possible quantization levels before converging on the final digital value. The simplicity of the design allows for both high speed and high resolution while maintaining relatively small area.

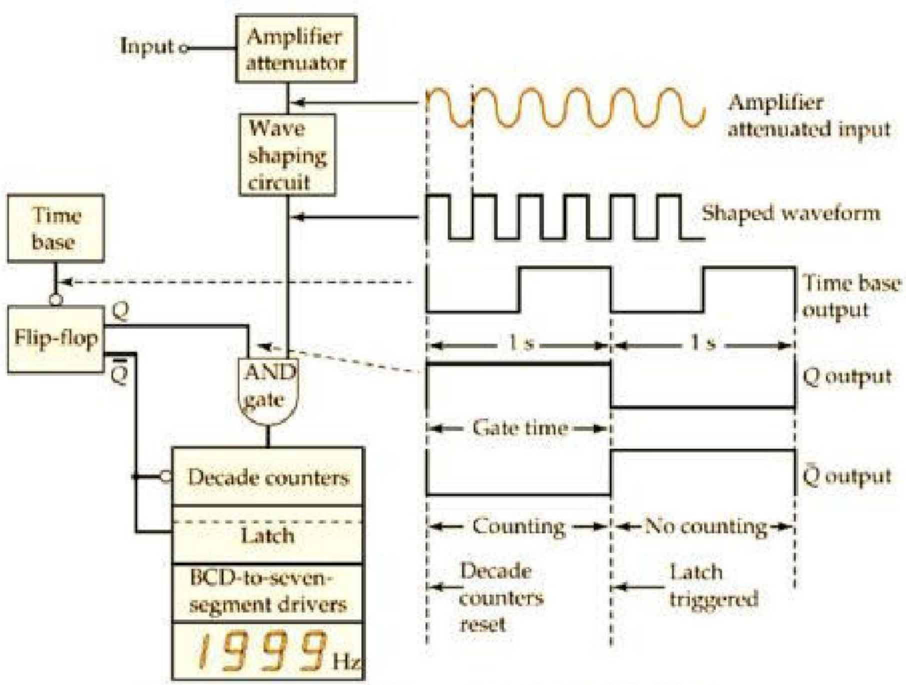
The binary search starts with the Most Significant Bit (MSB) and works towards the Least Significant Bit (LSB). The control logic initializes the MSB to a value 1. Then the content of Successive Approximation

Register (SAR) is fed into a DAC which outputs an equivalent analog voltage value needed to be compared with the unknown input voltage. If this value exceeds the input voltage then the comparator causes the control logic of the SAR to reset the MSB back to 0 and set the next bit to 1. If the output of the DAC is still lower than the input voltage then this bit will be kept at value 1 and the next lower bit will be set to 1. The binary search continues till every bit of the SAR is tested. The content of the SAR then will be the digital approximation value of the sampled input analog signal.



Digital Frequency Meter:

The digital frequency meter shown in the figure below consists of an accurate timing source (time-base), digital counting circuits, circuitry for shaping the input waveform, and a circuit for gating the shaped waveform to the counter.



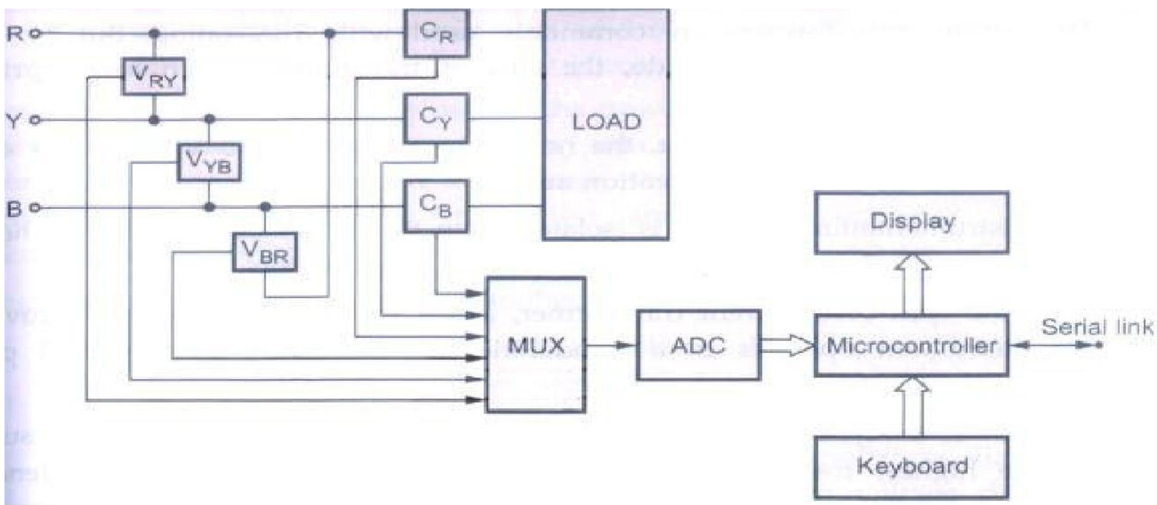
(a) Frequency meter system (b) System waveforms

The input is first amplified or attenuated, as necessary, and then fed to the wave shaping circuit, which converts it into a square or pulse waveform with the same frequency as the input. The presence of this wave shaping circuit means that the input waveform can be sinusoidal, square, triangular, or can have any other repetitive waveform.

The shaped waveform is fed to one input terminal of a two input AND gate, and the other AND gate input is controlled by the Q output from a flip-flop. Consequently, the pulses to be counted pass through the AND gate only when the flip-flop Q terminal is high. The flip-flop is controlled by the timing circuit, changing state each instant that the timer output waveform goes in a negative direction (negative edge). When the timing circuit output frequency is 1Hz, as illustrated, the flip-flop Q output terminal is alternately high for 1 second and low for one second.

Power Analyzer:

The power analyzer is the important device in a modern era. The schematic block diagram of a modern power analyzer is shown in figure given below.



Important Features of Power Analyzer:

1) The power analyzer can be used in either single phase circuit or three phase circuit.
2) The three phase circuit can use three wires or four wire power supply.
3) When power analyzer is used in a.c. circuits, the most commonly used current and voltage sensors are potential transformers and current transformers respectively.
4) The current transformers are commonly used with 5A rating. But by using multiple turns at primary side, the current transformers with lower primary current values can be used.
5) According to the requirement, the nominal voltages of 110V, 220V or 440V can be used in different application areas.

APPLICATION OF POWER ANALYSER:-

Basically the power analyzer identifies and characterizes a.c. line problems. Then it establishes cause and effect relationship between various events on the a.c. line and the problem occurrences so that it can take corrective action. Then the power analyzer compares the time at which is functioning of device takes place with the time of operation of the a.c. source. The power analyser can state if the problem is either source related or load related by observing the characteristics of the event.

HARMONIC DISTORTION ANALYSER:-

The distortion caused due to non linear behavior of the circuit elements is called harmonic distortion. In case of sine wave which is harmonically distorted, it consists of a fundamental frequency 'f' and the harmonic multiples of fundamental frequency 2f, 3f....etc.

A measure of the distortion represented by a particular harmonic is simply the ratio of the amplitude of the harmonic to that of the fundamental frequency, expressed as percentage. It is represented as:

$D_2 = (B_2/B_1)$

$D_3 = (B_3/B_1)$ and so on

Where D_n (n =1, 2, 3....) represents the distortion of the n^{th} harmonic. B_n represents the amplitude of the n^{th} harmonic and B_1 represents the amplitude of the fundamental frequency component.

The total harmonic distortion or distortion factor is defined as:

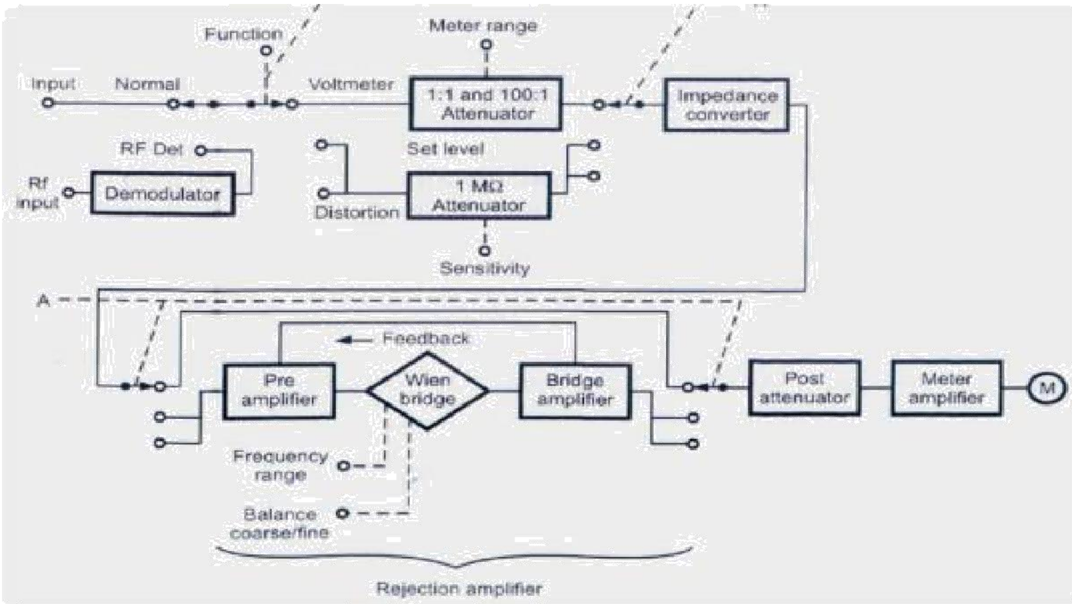
$$\mathrm{THD_F} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2 + \ldots}}{V_1}$$

Where V_2, V_3 and so on are the harmonic voltages and V_1 is the fundamental voltage.

Some of the methods used to measure the harmonic distortion factor are described below:

- **Fundamental Suppression Distortion Analyzer:-**

  This is used to measure the distortion factor rather than the contribution by each component. In this analyzer, the input is applied to such a network that suppresses or rejects the fundamental component but passes all the harmonic frequency components for the measurement.



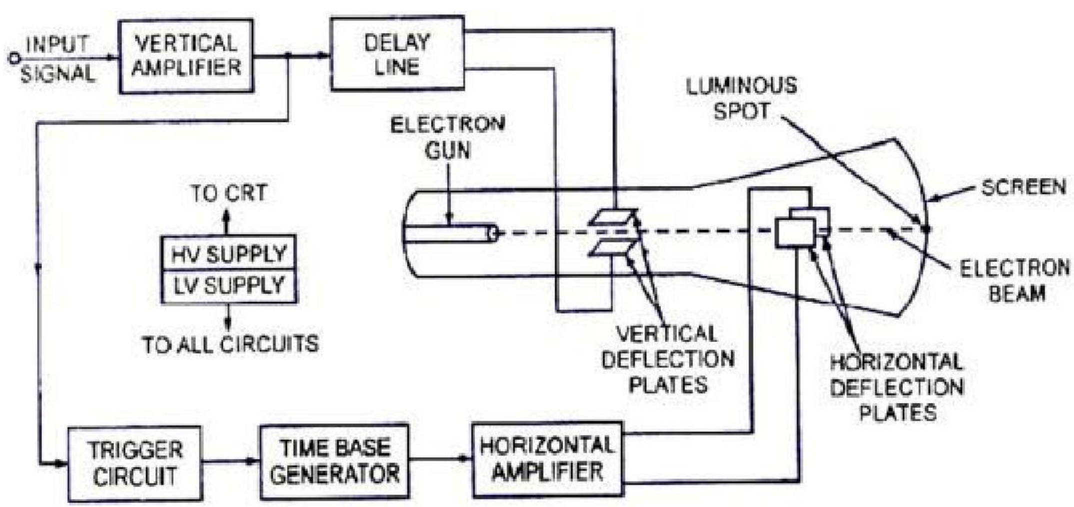
- **Heterodyne Harmonic Distortion Analyzer:-**

  In this type of analyzer, a highly selective, fixed frequency filter is used. The variable frequency oscillator output is mixed with each harmonic of the input signal, with the help of balanced mixer; either the sum or difference frequency is made equal to the frequency of the filter. The quartz crystal type highly selective filters can be used as each harmonic frequency signal related to a particular harmonic and pass it to the metering circuit.

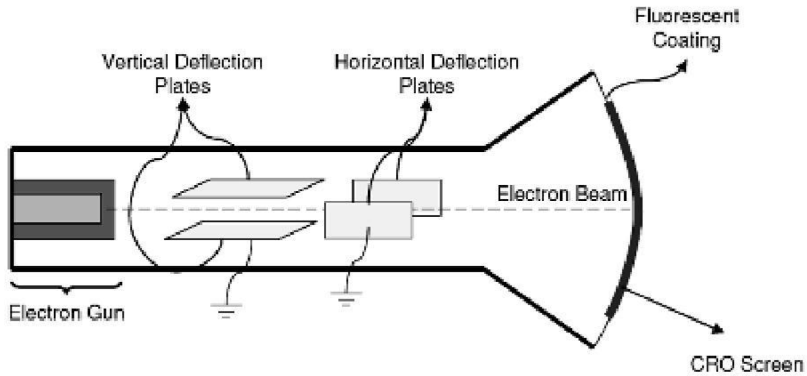
5.2 Cathode Ray Oscilloscope

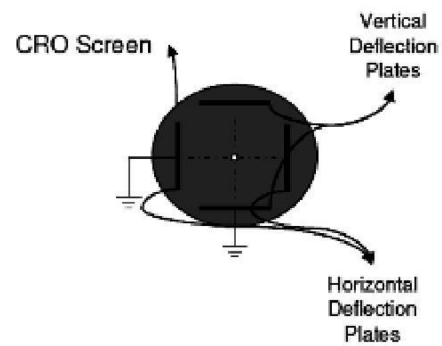
Oscilloscope: An oscilloscope (sometimes abbreviated as "scope") is a voltage sensing electronic instrument that is used to visualize certain voltage waveforms. An oscilloscope can display the variation of a voltage waveform in time on the oscilloscope's screen.

Cathode Ray Oscilloscope*:* Block diagram:



The structure and the main components of a cathode ray tube (CRT) are shown in the figure below.

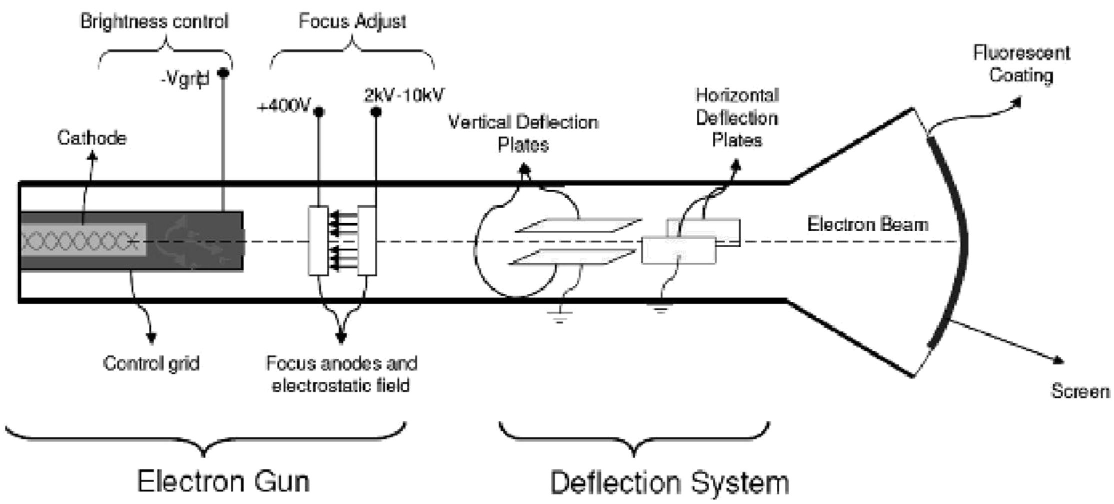




Electron beam generated by the electron gun first deflected by the deflection plates, and then directed onto the fluorescent coating of the CRO screen, which produces a visible light spot on the face plane of the oscilloscope screen.

Construction: The CRT is composed of two main parts:

1. Electron Gun
2. Deflection System



Electron Gun:

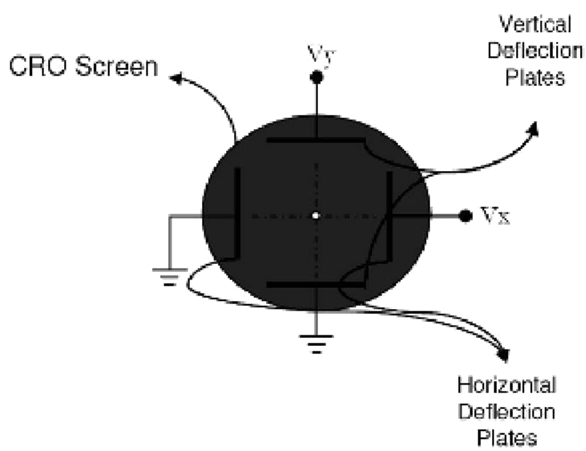
Electron gun provides a sharply focused electron beam directed toward the fluorescent-coated screen. The thermally heated cathode emits electrons in many directions. The control grid provides an axial direction for the electron beam and controls the number and speed of electrons in the beam.

The momentum of the electrons determines the intensity, or brightness, of the light emitted from the fluorescent coating due to the electron bombardment. Because electrons are negatively charged, a repulsion force is created by applying a negative voltage to the control grid, to adjust their number and speed. A more negative voltage results in less number of electrons in the beam and hence decreased brightness of the beam spot.

The Deflection System:

The deflection system consists of two pairs of parallel plates, referred to as the vertical and horizontal deflection plates. One of the plates in each set is permanently connected to the ground (zero volt), whereas the other plate of each set is connected to input signals or triggering signal of the CRO.

As shown in Figure above, the electron beam passes through the deflection plates. In reference to the schematic diagram in Figure 8, a positive voltage applied to the Y input terminal causes the electron beam to deflect vertically upward, due to attraction forces, while a negative voltage applied to the Y input terminal causes the electron beam to deflect vertically downward, due to repulsion forces. Similarly, a positive voltage applied to the X input terminal will cause the electron beam to deflect horizontally toward the right, while a negative voltage applied to the X input terminal will cause the electron beam to deflect horizontally toward the left of the screen.



The amount of vertical or horizontal deflection is directly proportional to the corresponding applied voltage. When the electrons hit the screen, the phosphor emits light and a visible light spot is seen on the screen. Since the amount of deflection is proportional to the applied voltage, actually the voltages Vy and Vx determine the coordinates of the bright spot created by the electron beam.

Application of CRO in measurement:

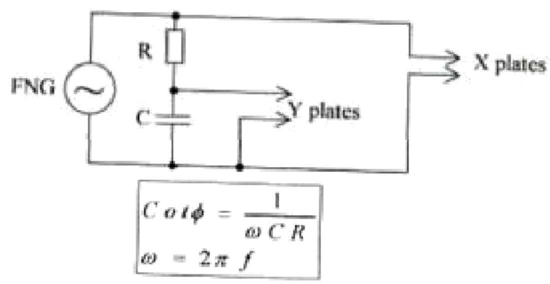
1. To measure AC/DC voltages: When the DC input to be measure is fed to the Y-input of the CRO in the DC mode, then vertical shift of the trace gives the measure of the magnitude of the DC voltage.

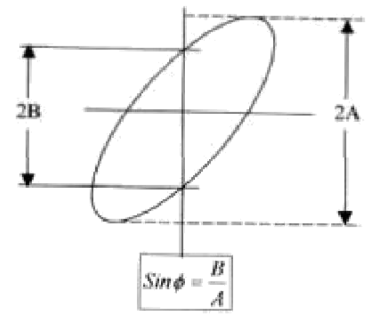
   When the ac signal from a signal generator is fed to the Y-input of the CRO in the ac mode, then, the peak to peak voltage of the signal is measured by noting the height of the signal on the screen and the vertical gain position of the Y input.

2. To measure frequency of a sinusoidal signal: If the signal from the function generator (FG) is connected to the Y-input and the horizontal sweep speed selector (time/div) is adjusted to get a steady pattern of the signal on the CRO screen. Then, the time interval

between two consecutive peaks can be measured and hence, the frequency of the signal is given by f=1/t.

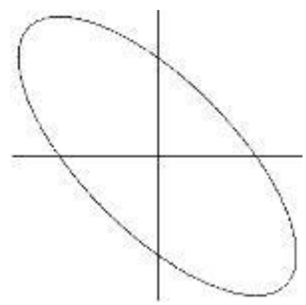
3. To measure the phase difference between two signals: *Using Dual trace (channels Y_1 and Y_2):* One can approximately measure the phase difference θ between two signals (same frequency) by feeding the signal to two inputs Y_1 and Y_2 of a dual trace CRO and noting the shift in the peak positions. The shift is measured on the time scale (div/sec) and then converted into the phase difference assuming one period T= 2π radians or 360^o. A simple way of producing a difference between two signals is to pass one of the signals through a capacitor C, an inductance L or a combination of R and C. The pattern obtained is known as Lissajous Pattern.





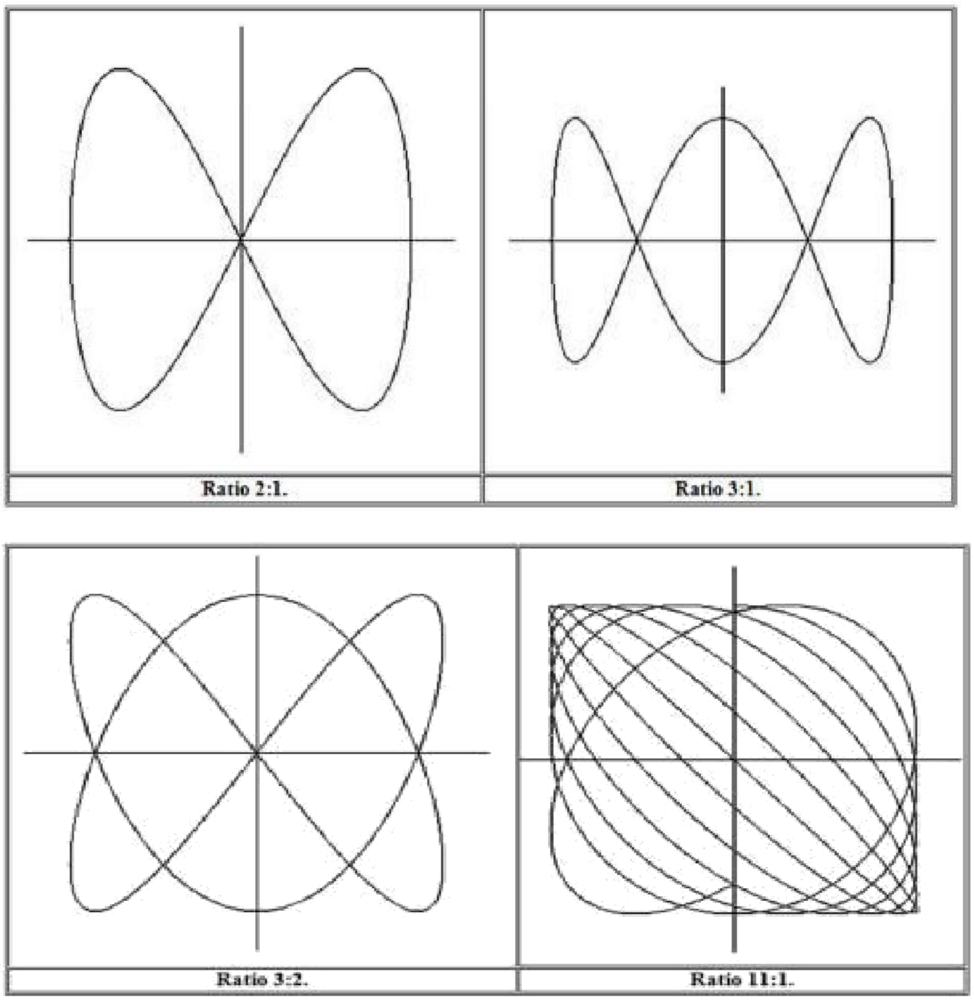
Lissajous pattern*:* This is used for measurement of phase and frequency of sinusoidal wave.If two signals are given, one to the X input and another to the Y input, X-Y pattern is obtained depending on frequency, amplitude and the phase difference of the two signals.

Case1: For same frequency and amplitude, the oscilloscope's beam should orbit around a perfect circle or ellipse on the screen.



If the two frequencies are slightly different, the pattern will not 'stand still.

Case2: If the frequencies are in exactly integral ratio, you'll get stable, pretty patterns called Lissajous figures. The ratio of frequencies can be 'read off' the screen by counting `loops' of the pattern on the vertical and horizontal axes.



Ratio 2:1. Ratio 3:1.

Ratio 3:2. Ratio 11:1.

Dual Trace Oscilloscopes: Fig. below shows the construction of a typical dual trace oscilloscope. There are two separate vertical input channels, A and B, and these use separate attenuator and preamplifier stages. Therefore the amplitude of each input, as viewed on the oscilloscope, can be individually controlled.

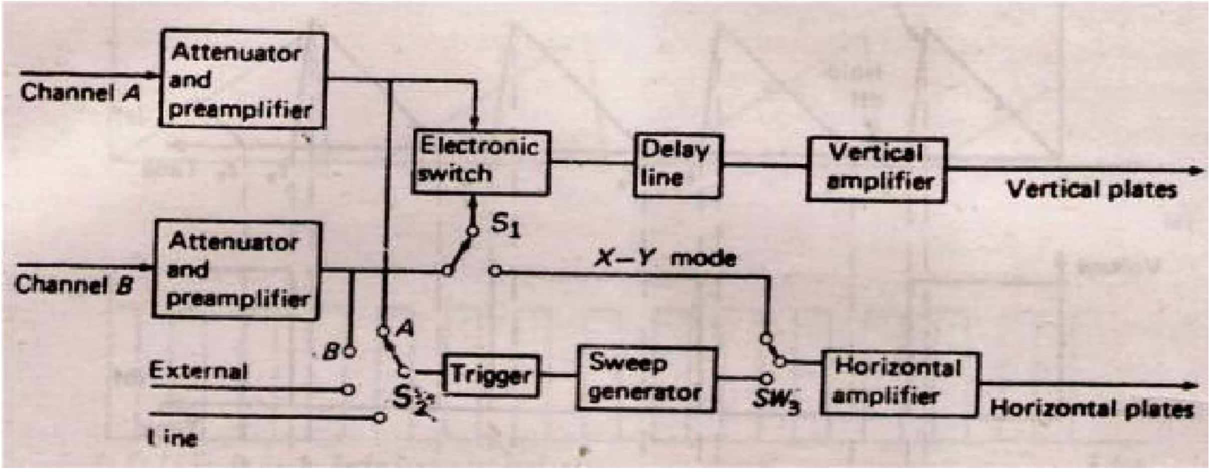


Figure 5 Block Diagram of a Dual Trace Oscilloscope

After pre-amplification the two channels meet at an electronic switch. This has the ability to pass one channel at a time into the vertical amplifier, via the delay line. There are two common operating modes for the electronic switch, called alternate and chop, and these are selected from the instrument's front panel.

Dual beam oscilloscope: The dual trace oscilloscope cannot capture two fast transient events, as it cannot switch quickly enough between traces. The dual beam oscilloscope has two separate electron beams, and therefore two completely separate vertical channels. The two channels may have a common time base system, or they may have independent time base circuits. An independent time base allows different sweep rates for the two channels but increases the size and weight of the oscilloscope.