CATHODE-RAY OSCILLOSCOPE (CRO)

INTRODUCTION:

- The cathode-ray oscilloscope (CRO) is a multipurpose display instrument used for the observation, measurement , and analysis of waveforms by plotting amplitude along y-axis and time along x-axis.
- CRO is generally an x-y plotter; on a single screen it can display different signals applied to different channels. It can measure amplitude, frequencies and phase shift of various signals. Many physical quantities like temperature, pressure
- and strain can be converted into electrical signals by the use of transducers, and the signals can be displayed on the CRO.
- A moving luminous spot over the screen displays the signal. CROs are used to study waveforms, and other time-varying phenomena from very low to very high frequencies.
- The central unit of the oscilloscope is the cathode-ray tube (CRT), and the remaining part of the CRO consists of the circuitry required to operate the cathode-ray tube.

Block diagram of a cathode-ray oscilloscope:

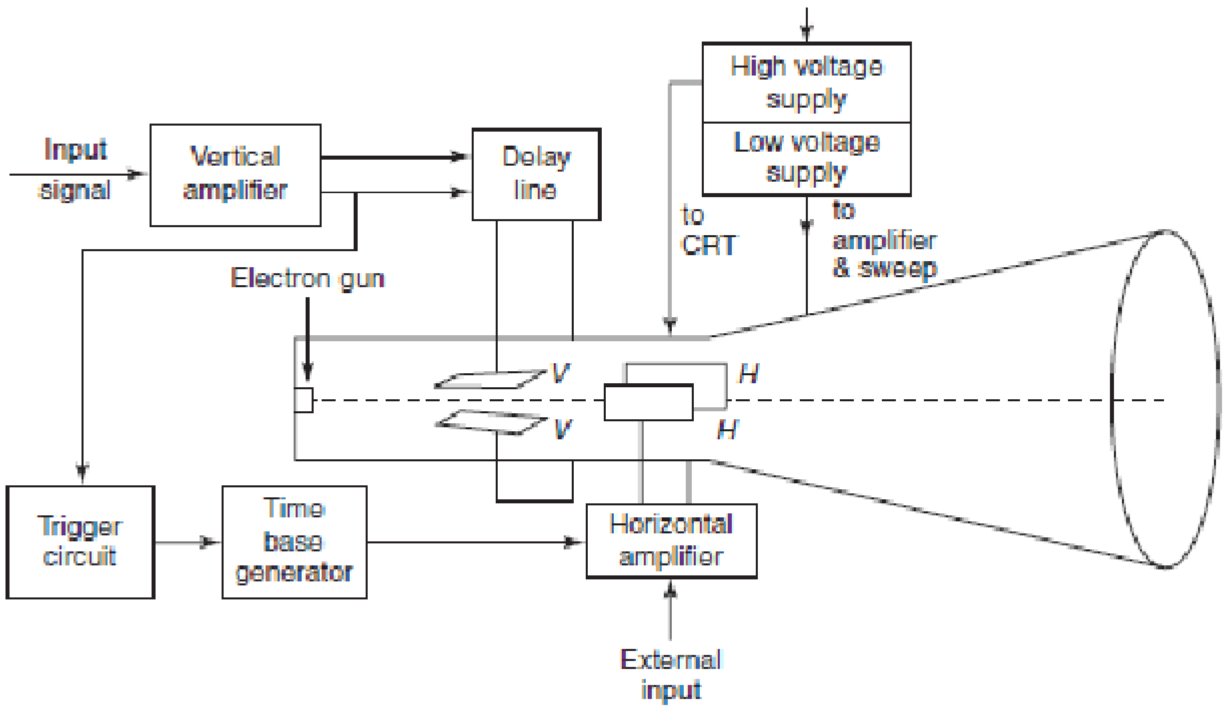


Figure 14-1 Block diagram of a cathode-ray oscilloscope

COMPONENTS OF THE CATHODE-RAY OSCILLOSCOPE:

The CRO consists of the following:

- (i) CRT
- (ii) Vertical amplifier
- (iii) Delay line
- (iv) Horizontal amplifier
- (v) Time-base generator
- (vi) Triggering circuit
- (vii) Power supply

Power supply

- It provides the voltages required by the cathode ray tube to generate and accelerate the electron beam.
- Cathode ray tube (CRT) requires high voltage for pre-accelerating and accelerating anode, low voltage required for heater, control grid, focusing anode and the other circuits of CRO.

<u>Vertical Amplifier</u>: The signal under the analysis is to be applied to vertical deflection plates through the vertical amplifier.

Delay line

- If both vertical and horizontal signals arrives at the same time to the corresponding deflection plates, then only we will get exact waveform.
- But vertical signal arrives much early compared to the horizontal signal. For this reason, the vertical signal at the output of the vertical amplifier should be delayed with the help of delay line. The delay time is almost equal to 200nsec.

Trigger circuit

- This is triggered by the portion of the vertical amplifier output.
- This circuit initiates then time base generator. It is the link between the vertical input and horizontal time base.
- Trigger circuit is used to synchronize horizontal deflection with vertical deflection.

Horizontal Amplifier

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

CATHODE-RAY TUBE:

- The **electron gun or electron emitter, the deflecting system and the fluorescent screen** are the three major components of a general purpose CRT. A detailed diagram of the cathode-ray oscilloscope is given in Fig. 14-2

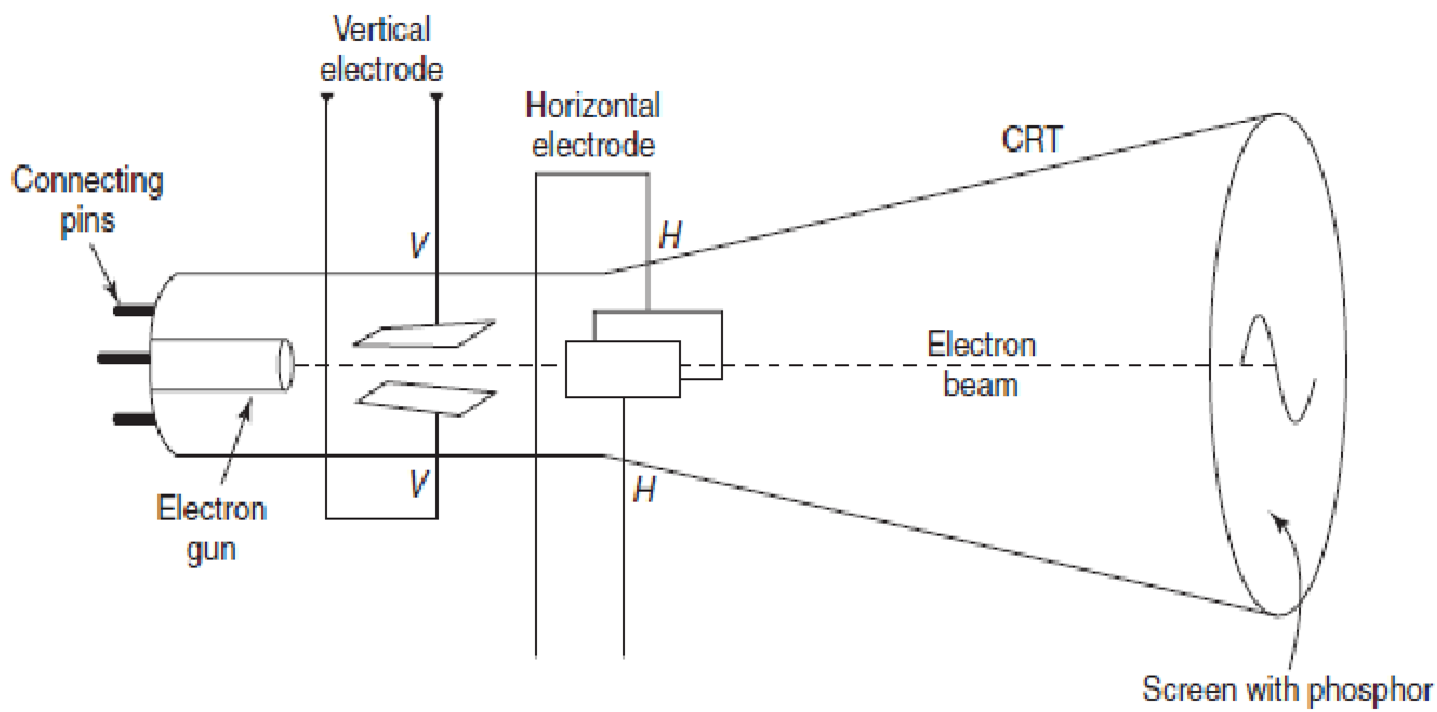


Figure 14-2 Components of a cathode-ray oscilloscope

Electron Gun:

- In the electron gun of the CRT, electrons are emitted, converted into a sharp beam and focused upon the fluorescent screen.
- The electron beam consists of an indirectly heated cathode, a control grid, an accelerating electrode and a focusing anode.
- The electrodes are connected to the base pins. The cathode emitting the electrons is surrounded by a control grid with a fine hole at its centre.
- The accelerated electron beam passes through the fine hole.
- The negative voltage at the control grid controls the flow of electrons in the electron beam, and consequently, the brightness of the spot on the CRO screen is controlled.

Deflection Systems:

- Electrostatic deflection of an electron beam is used in a general purpose oscilloscope. The deflecting system consists of a pair of horizontal and vertical deflecting plates.
- Let us consider two parallel vertical deflecting plates *P1 and P2. The beam is focused at point O on the screen in the absence of a deflecting plate voltage.*
- *If a* positive voltage is applied to plate *P1 with respect to plate P2, the negatively charged electrons are attracted towards* the positive plate *P1, and these electrons will come to focus at point Y1 on the fluorescent screen.*

Deflection Systems:

The deflection is proportional to the deflecting voltage between the plates. If the polarity of the deflecting voltage is reversed, the spot appears at the point *Y2, as shown in Fig. 14-3(a).*

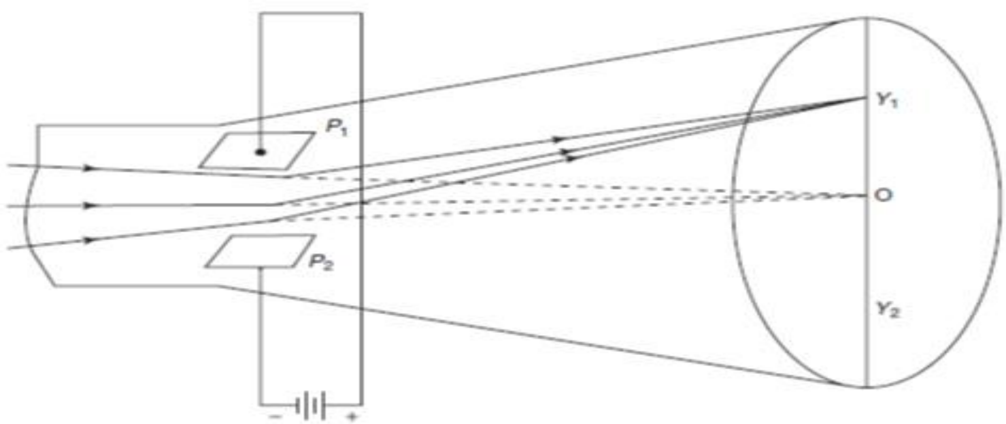


Figure 14-3(a) Deflecting system using parallel vertical plates

Deflection Systems:

- To deflect the beam horizontally, an alternating voltage is applied to the horizontal deflecting plates and the spot on the screen horizontally, as shown in Fig. 14-3(b).
- The electrons will focus at point *X2. By changing the polarity of voltage, the beam will focus at point X1. Thus, the* horizontal movement is controlled along *X1OX2 line.*

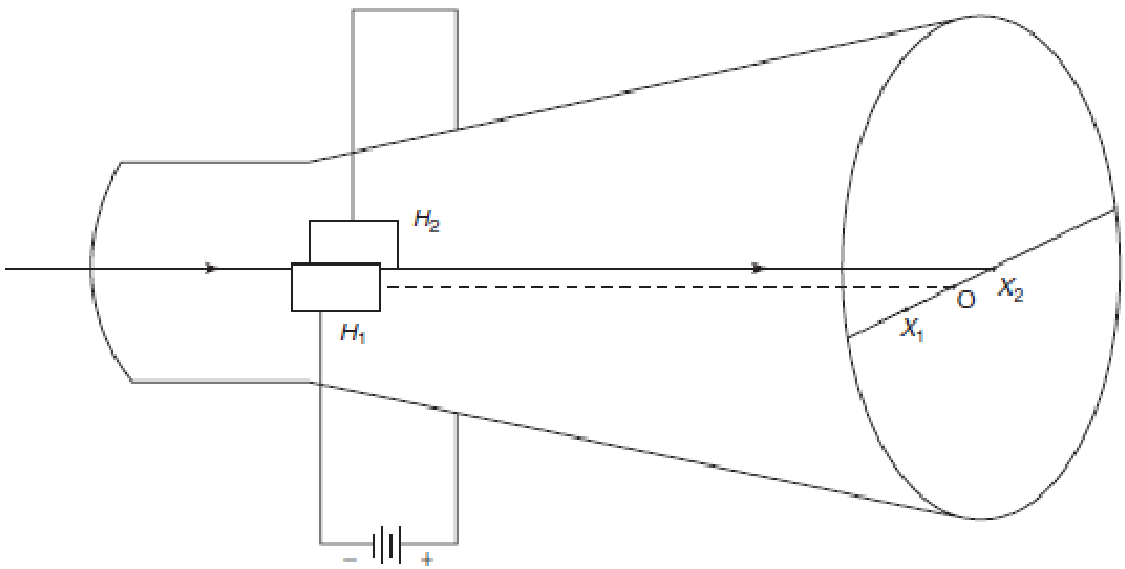


Figure 14-3(b) Deflecting system using parallel horizontal plate

Display waveform on the screen:

Figure 14-5(a) shows a sine wave applied to vertical deflecting plates and a repetitive ramp or saw-tooth applied to the horizontal plates.

- The ramp waveform at the horizontal plates causes the electron beam to be deflected horizontally across the screen.
- If the waveforms are perfectly synchronized then the exact sine wave applied to the vertical display appears on the CRO display screen.

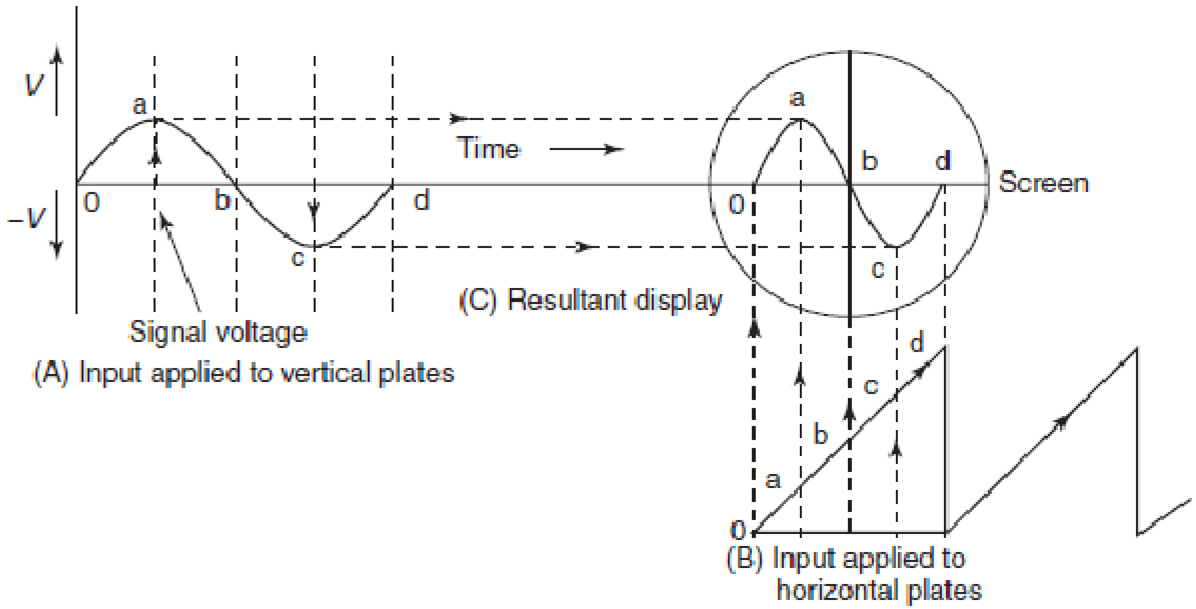


Figure 14-5(a) A typical display waveform on the screen

Fluorescent Screen:

- Phosphor is used as screen material on the inner surface of a CRT. Phosphor absorbs the energy of the incident electrons. The spot of light is produced on the screen where the electron beam hits.
- The bombarding electrons striking the screen, release secondary emission electrons. These electrons are collected or trapped by an aqueous solution of graphite called “Aquadag” which is connected to the second anode.
- Collection of the secondary electrons is necessary to keep the screen in a state of electrical equilibrium.
- The type of phosphor used, determines the color of the light spot. The brightest available phosphor isotope, P31, produces yellow–green light with relative luminance of 99.99%.

TIME-BASE GENERATORS:

- The CRO is used to display a waveform that varies as a function of time. If the wave form is to be accurately reproduced, the beam should have a constant horizontal velocity.
- As the beam velocity is a function of the deflecting voltage, the deflecting voltage must increase linearly with time.
- A voltage with such characteristics is called a ramp voltage. If the voltage decreases rapidly to zero—with the waveform repeatedly produced, as shown in Fig. 14-6—we observe a pattern which is generally called a saw-tooth waveform.
- The time taken to return to its initial value is known as flyback or return time.

Time base generator is used to generate saw tooth voltage, required to deflect the beam in horizontal section.
In saw tooth wave form, the deflecting voltage increases slowly and linearly with respect to time and reduces to zero quickly (fast) i.e. raise time is high and fall time is less.

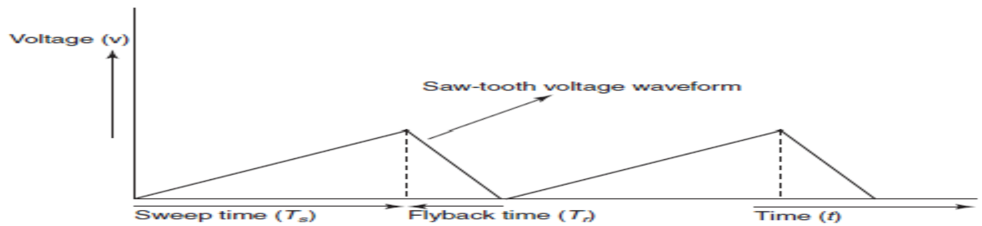


Figure 14-6 Typical saw-tooth waveform applied to the horizontal deflection plates

TYPES OF THE CATHODE-RAY OSCILLOSCOPE:

- The categorization of CROs is done on the basis of whether they are digital or analog. Digital CROs can be further classified as storage oscilloscopes.
- **1. Analog CRO:** In an analog CRO, the amplitude, phase and frequency are measured from the displayed waveform, through direct manual reading.
- **2. Digital CRO:** A digital CRO offers digital read-out of signal information, i.e., the time, voltage or frequency along with signal display. It consists of an electronic counter along with the main body of the CRO.
- **3. Storage CRO:** A storage CRO retains the display up to a substantial amount of time after the first trace has appeared on the screen. The storage CRO is also useful for the display of waveforms of low-frequency signals.
- **4. Dual-Beam CRO:** In the dual-beam CRO two electron beams fall on a single CRT. The dual-gun CRT generates two different beams.
- These two beams produce two spots of light on the CRT screen which make the simultaneous observation of two different signal waveforms possible. The comparison of input and its corresponding output becomes easier using
  the dual-beam CRO.

IMPORTANT FORMULAE:

1. The deflection sensitivity of the CRT is:

$$S = \frac{l_{\text{total}}}{V_d} = \frac{lL}{2sV_a} \text{ m/V}$$

2. The deflection factor of the CRT is:

$$G = \frac{1}{S} = \frac{2sV_a}{lL} \text{ V/m}$$

ELECTROSTATIC DEFLECTION AND ITS DEFLECTION SENSITIVITY

- The electro static deflection system uses a pair of deflection plates as shown in fig.
- The hot cathode K emits electrons which are accelerated towards the anode by the potential V_a.
- Those electrons which are not collected by the anode pass through the tiny anode hole and strike the end of the glass envelope.
- The glass envelope has been coated with a material that fluoresces when bom-barded by electrons. Thus the position where the electrons strike the screen are made visible to the eye.

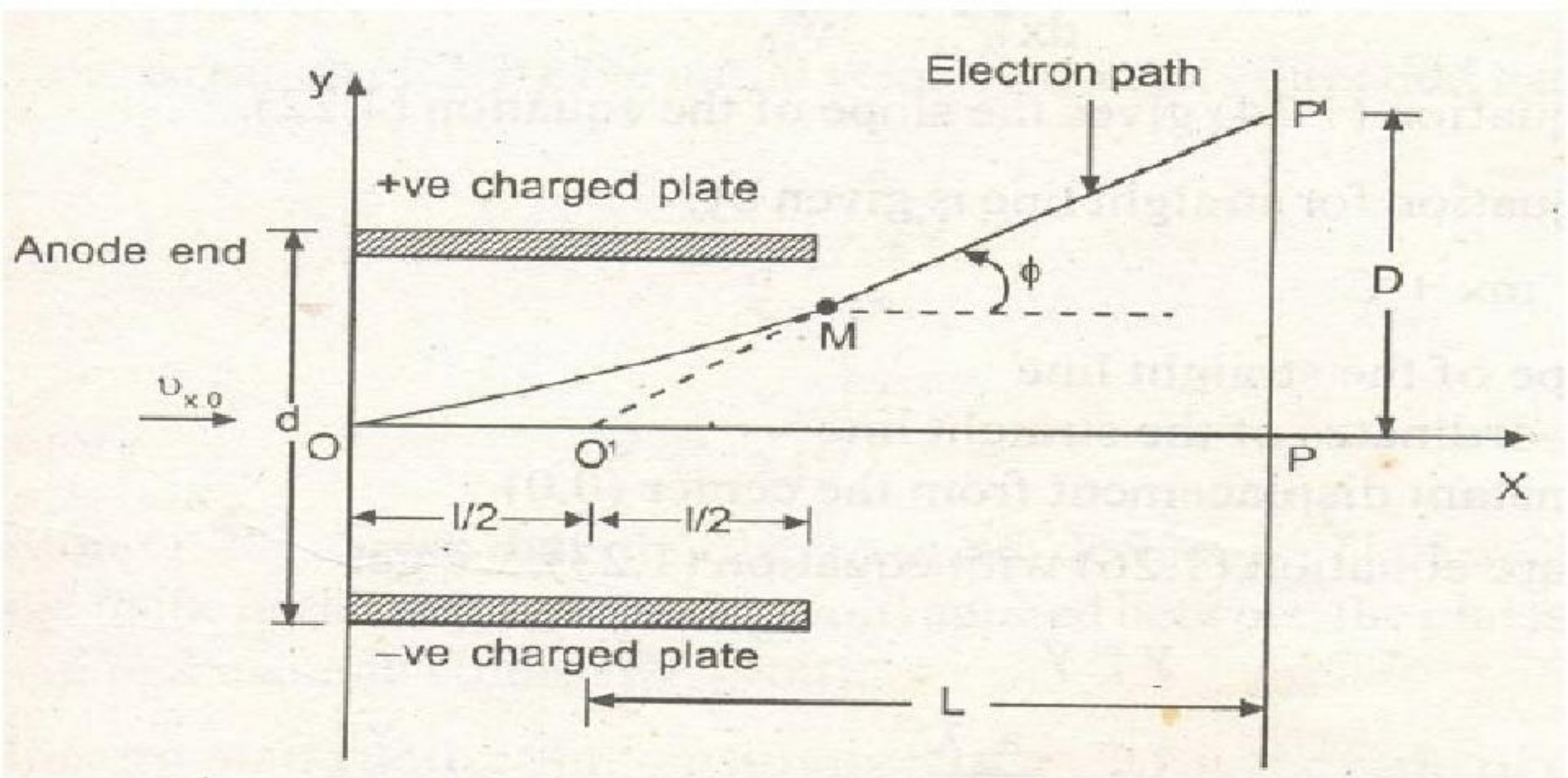


Fig: Electrostatic deflection in a cathode – ray Tube

$$D = Ll V_d / 2dVa$$

- This result shows that the deflection on the screen of a cathode – ray tube is directly proportional to the deflecting voltage V_d applied between the plates.
- CRT may be used as a linear – voltage indicating device.

Deflection Sensitivity:

- The electrostatic – deflection sensitivity of a cathode – ray tube is defined as the deflection (in meters) on the screen per volt of deflecting voltage.

Spot Beam Deflection Sensitivity:

The deflection sensitivity of a CRT is defined as the distance of the spot-beam deflection on the screen per unit voltage. If l_{total} is the total amount of deflection of the spot beam on the screen for the deflecting voltage V_d, as shown in Fig.14-4, the sensitivity can be expressed as:

$$S = \frac{l_{total}}{V_d} \quad (14\text{-}1)$$

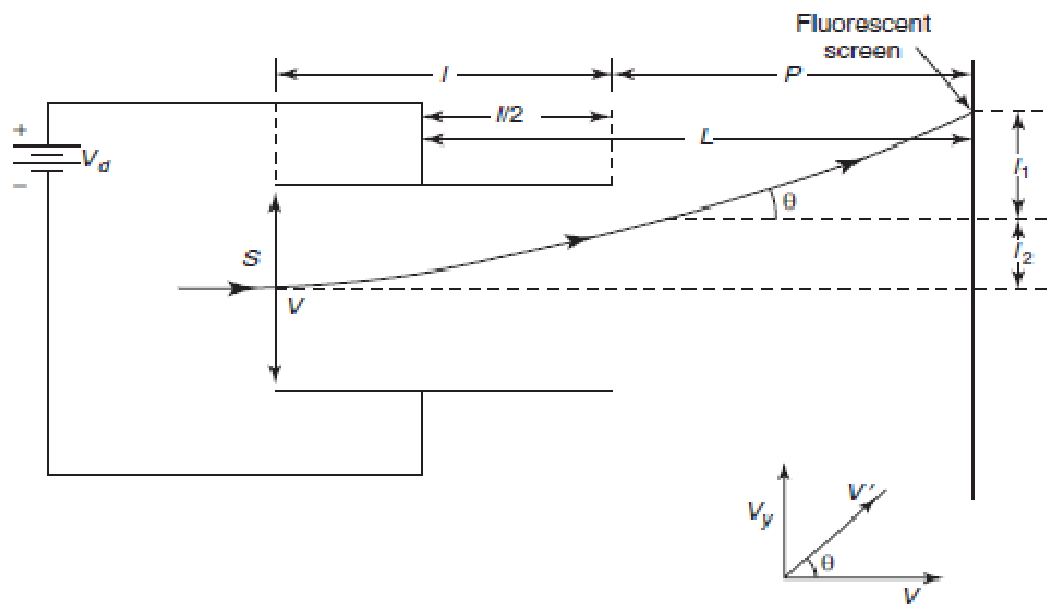


Figure 14-4 Schematic diagram of electrostatic deflection systems

MAGNETIC DEFLECTION SYSTEM

- Here the magnetic field is perpendicular to direction of electron beam i.e., it directs towards the reader.
- The electron beam is deflected upwards. The electron moves in a straight line to point ‘0’ from cathode with initial velocity V_0 .
- Now the force acts on the electron and the resultant direction is perpendicular to both ‘B’ and ‘v’ is so resultant path is circular one.
- Path taken by the electron with in this uniform magnetic field is an arc of circle with radius ‘R’.
- The path OM is an arc of the circle whose center is at "θ

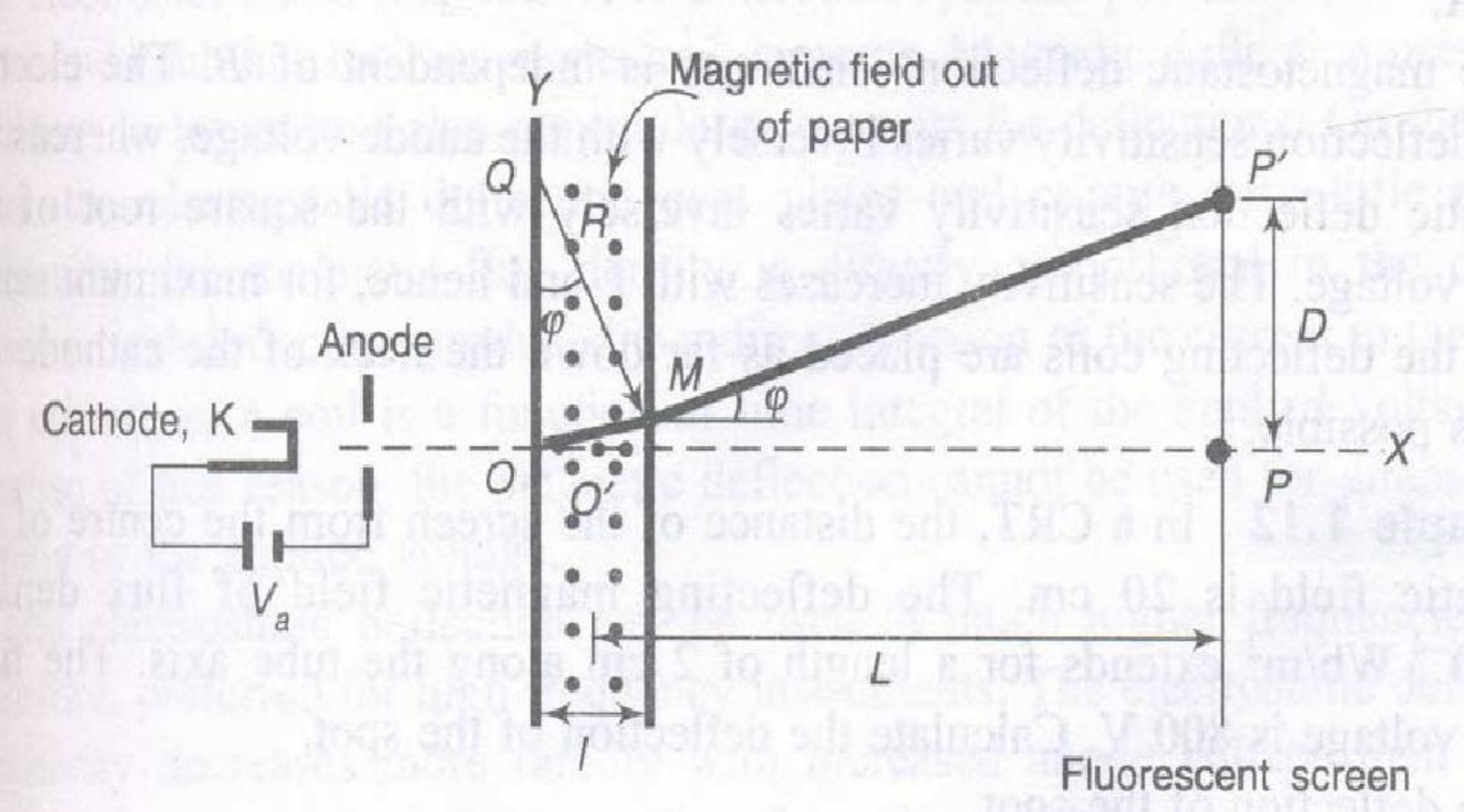


Fig: Magnetostatic deflection in a cathode – ray Tube

$$D = \frac{\square LB}{\sqrt{V_a}} \cdot \sqrt{\frac{e}{2m}}$$

Magnetic Deflection Sensitivity:

The Deflection per unit magnetic field intensity D/B is given by is called the magnetic – deflection Sensitivity of the tube

$$\frac{D}{B} = \frac{lL}{\sqrt{V_a}}\sqrt{\frac{e}{2m}}$$

Which is independent of magnetic flux density 'B'.

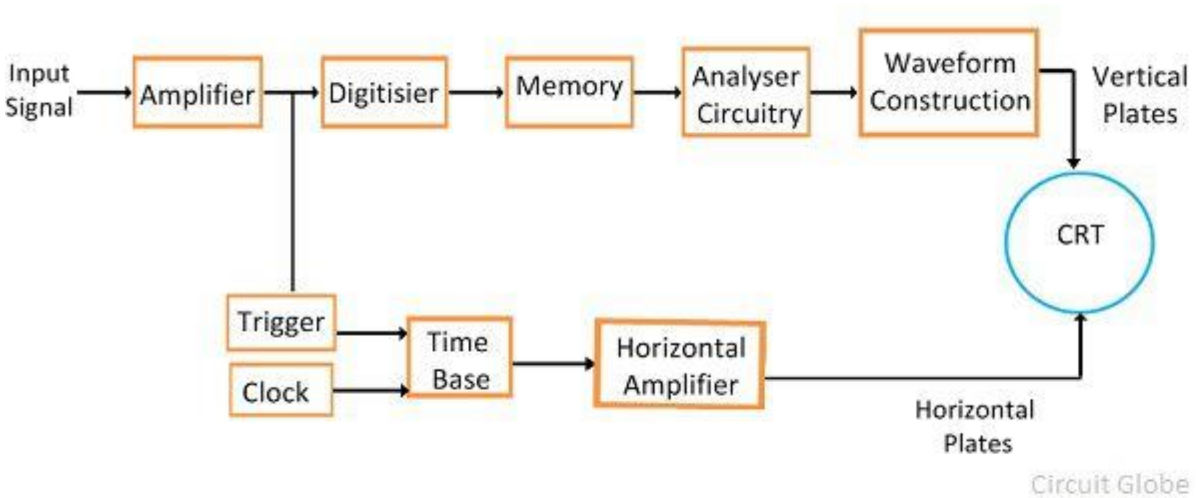
$$S = \frac{lL}{\sqrt{V_a}}\sqrt{\frac{e}{2m}}$$

Digital Storage Oscilloscope

Definition: The **digital storage oscilloscope** is defined as the oscilloscope which **stores and analysis the signal digitally**, i.e. in the form of 1 or 0 preferably storing them as **analogue signals**. The digital oscilloscope takes an input signal, store them and then display it on the screen. The digital oscilloscope has advanced features of storage, triggering and measurement. Also, it **displays** the signal **visually** as well as **numerically.**

Working Principle of Digital Storage Oscilloscope

The digital oscilloscope digitises and stores the input signal. This can be done by the use of **CRT** (Cathode ray tube) and **digital memory**. The block diagram of the basic digital oscilloscope is shown in the figure below. The digitisation can be done by taking the sample input signals at periodic waveforms.



The maximum frequency of the signal which is measured by the digital oscilloscope depends on the two factors. Theses factors are the

1. Sampling rate
2. Nature of converter.

Sampling Rate – For safe analysis of input signal the sampling theory is used. The sampling theory states that the sampling rate of the signal must be twice as fast as the highest frequency of the input signal. The sampling rate means analogue to digital converter has a high fast conversion rate.

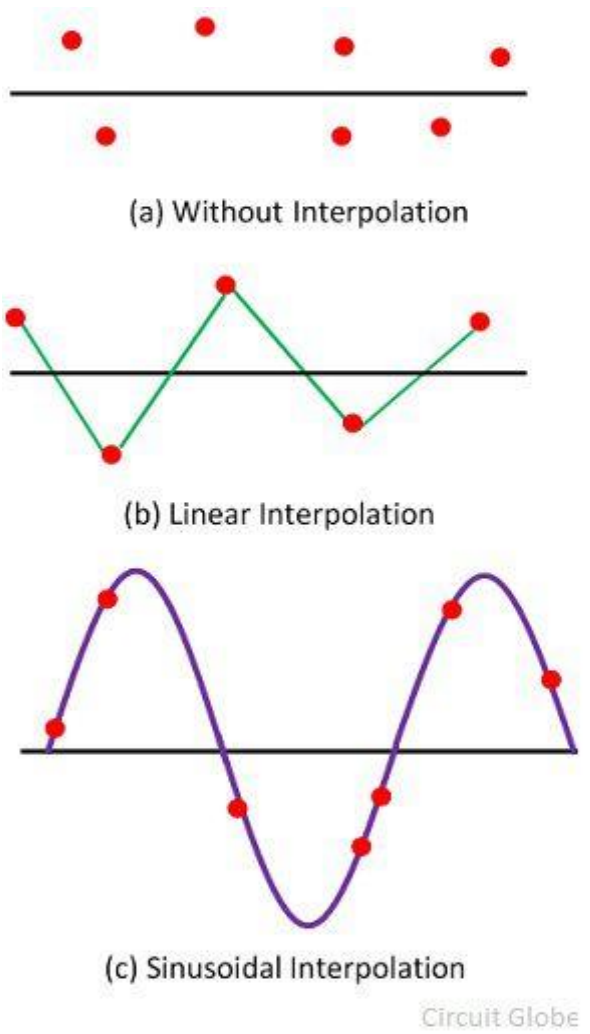
Converter – The converter uses the expensive flash whose resolution decreases with the increases of a sampling rate. Because of the sampling rate, the bandwidth and resolution of the oscilloscope are limited.

The need of the analogue to digital signal converters can also be overcome by using the shift register. The input signal is sampled and stored in the shift register. From the shift register, the signal is slowly read out and stored in the digital form. This method reduces the cost of the converter and operates up to 100 megasample per second.

The only disadvantage of the digital oscilloscope is that it does not accept the data during digitisation, so it had a blind spot at that time.

Waveform Reconstruction

For visualising the final wave, the oscilloscopes use the technique of inter-polarization. The inter-polarization is the process of creating the new data points with the help of known variable data points. Linear interpolation and sinusoidal interpolation are the two processes of connecting the points together.



In interpolation, the lines are used for connecting the dot together. Linear interpolation is also used for creating the pulsed or square waveform. For sine waveform, the sinusoidal interpolation is utilised in the oscilloscope.

Applications

The applications of the DSO are

- It checks faulty components in circuits
- Used in the medical field
- Used to measure capacitor, inductance, time interval between signals, frequency and time period
- Used to observe transistors and diodes V-I characteristics
- Used to analyze TV waveforms

- Used in video and audio recording equipment’s
- Used in designing
- Used in the research field
- For comparison purpose, it displays 3D figure or multiple waveforms
- It is widely used an oscilloscope

Advantages

The advantages of the DSO are

- Portable
- Have the highest bandwidth
- The user interface is simple
- Speed is high

Disadvantages

The disadvantages of the DSO are

- Complex
- High cost

ANALOG AND DIGITAL INSTRUMENTS

Digital Voltmeter (DVM)

- Used to measure the ac and dc voltages and displays the result in digital form.

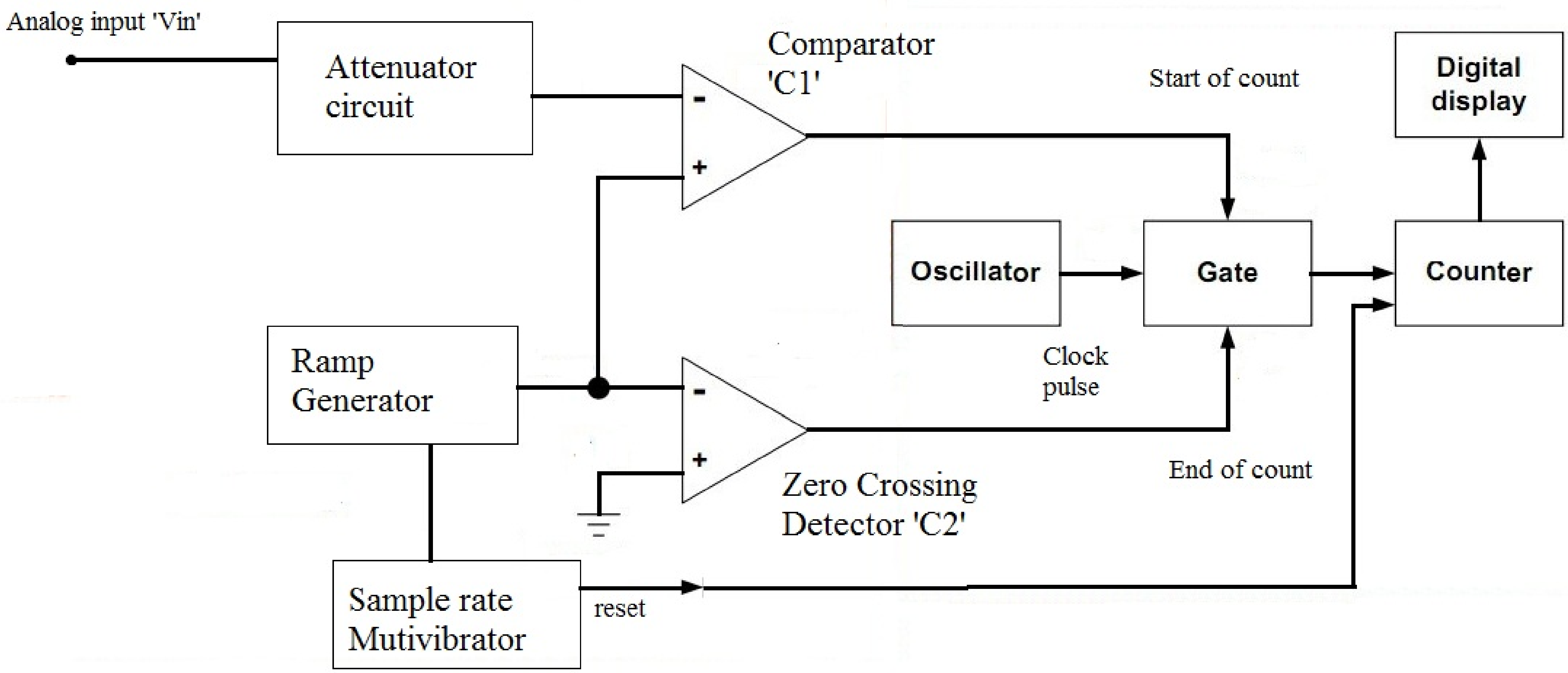
Types:

- Ramp type DVM
- Integrating type DVM
- Potentiometric type DVM
- Successive approximation type DVM
- Continuous balance type DVM

Advantages:

1. Errors on account of parallax and approximations are entirely eliminated
2. Operating speed is increased
3. Data can be fed to memory devices for storage and future computation.
4. Size reduced after the advent of ICs and easily portable.

Block Diagram - Ramp type DVM



Ramp type DVM

Principle:

Input voltage is converted into digital equivalent by counting the time taken for the ramp wave to decrease from the magnitude of input voltage to 0V.

Construction:

The block diagram of the Ramp-type ADC can be divided into two sections as follows:

1. Voltage to time conversion section
2. Time measurement section

Voltage to time conversion section

- In the voltage to time conversion section, the analog input voltage is fed to the attenuation circuit. The attenuated signal is compared with the the ramp signal generated by the ramp generator given in the block diagram by the input comparator 'C1'. Similarly, The ramp signal generated is compared with 0V via a zero-crossing detector 'C2'. A sample rate multivibrator is connected to the ramp generator whose purpose is to provide an initiating pulse for the ramp generator to start the next ramp voltage for the next measurement. It is also used to reset the counter before generating the next ramp voltage.

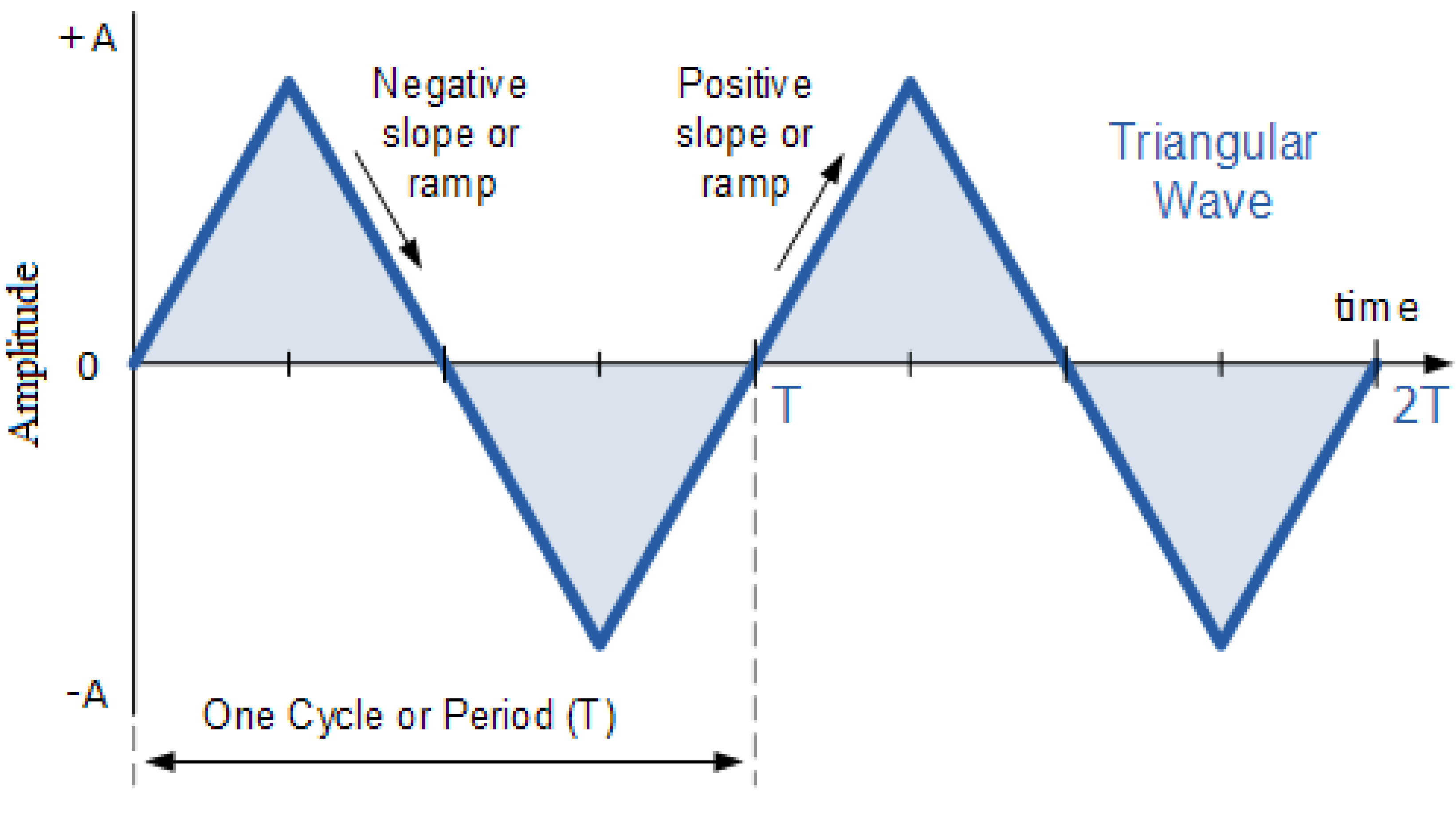
Time measurement section

- In the time measurement section, there is counter which is triggered by a gating pulse. The inputs of the gating pulse are (i) Output of 'C1' (ii) Output of 'C2' (iii) Clock pulse from the oscillator. The counter is reset after each successful completion of time measurement by a control signal from the sample rate multivibrator. The count produced is displayed by connecting suitable display device.

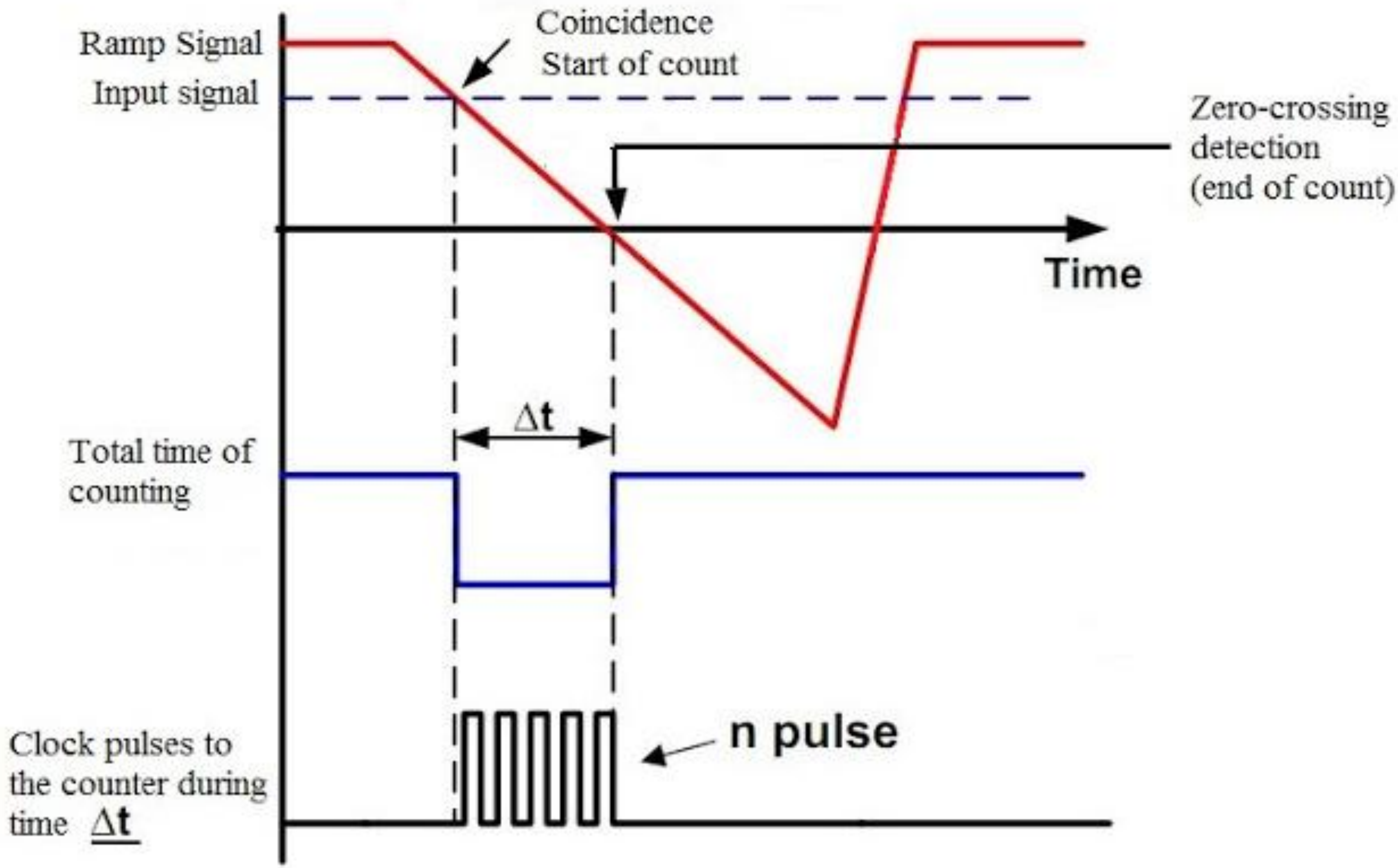
Operation

- Initially, the attenuated signal is compared with a negative going ramp signal generated by the ramp generator. When the ramp voltage coincides with the input signal, the output of 'C1' becomes low. This point is called coincidence point. This initiates the counting process (start of count). The counter continues to count until the ramp voltage reduces and crosses zero (0V). This is detected by zero crossing detector 'C2'. The output of 'C2' becomes high which ends the counting process (end of count).

Triangular wave displaying Ramp type



Waveform Analysis



Waveform

- The count displayed is the count of number of clock pulses produced by the oscillator during the time in which the ramp signal is less than the input signal and greater than 0V (ie) |input signal| > ramp > 0V. This count gives the digital equivalent of input analog voltage.

DVM

Equations Involved:

$(\Delta)t = t2 - t1 = Vin/m = nT$;

Hence, $Vin = nmT$;

where

t1-> start of count

t2-> end of count

Vin-> input analog voltage

m-> slope of the ramp curve

n-> number of clock pulses to counter

T-> clock period

DVM

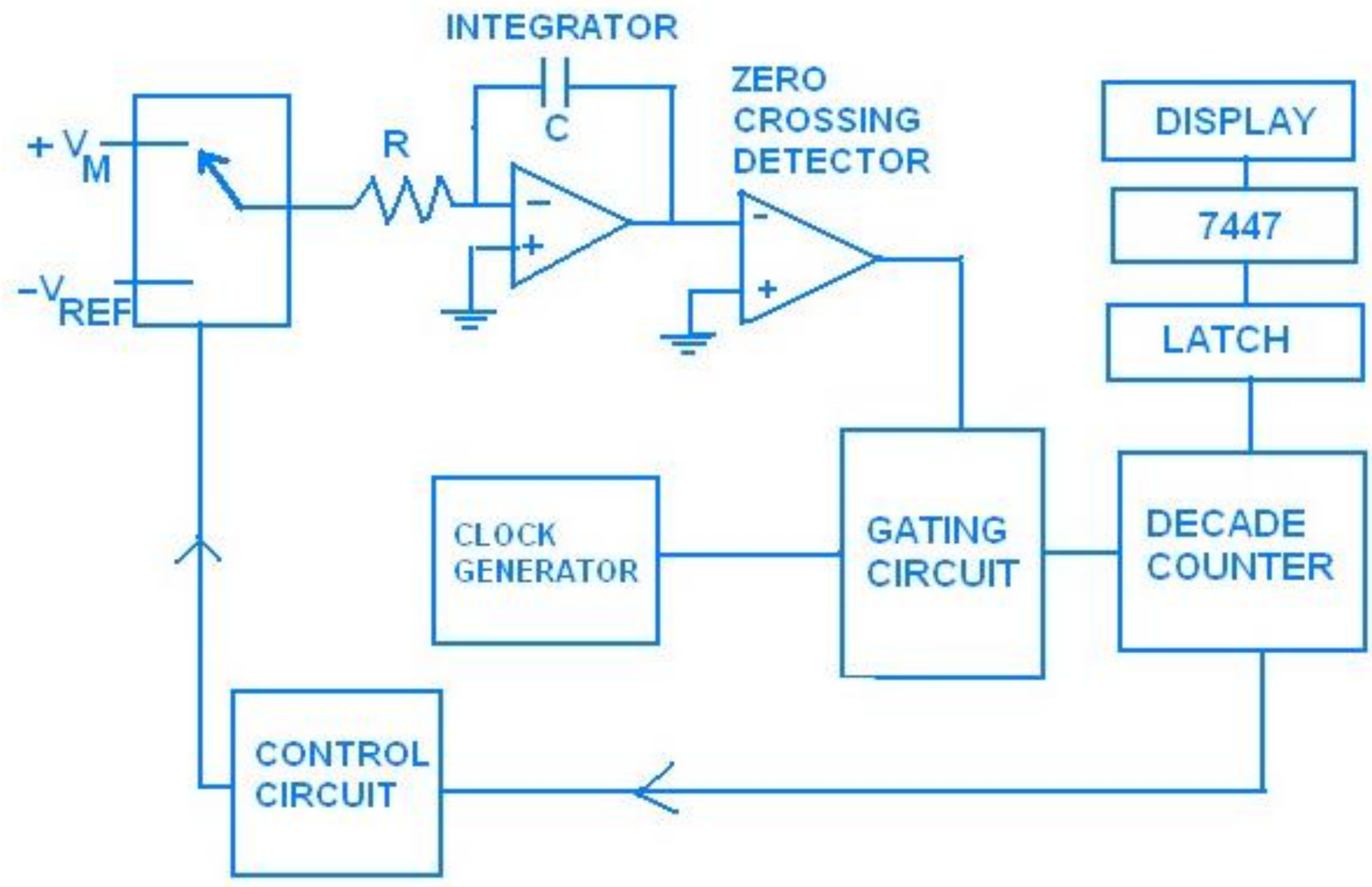
Merits:

- low cost
- simple, easy to design
- long distance transmission of output pulse is possible

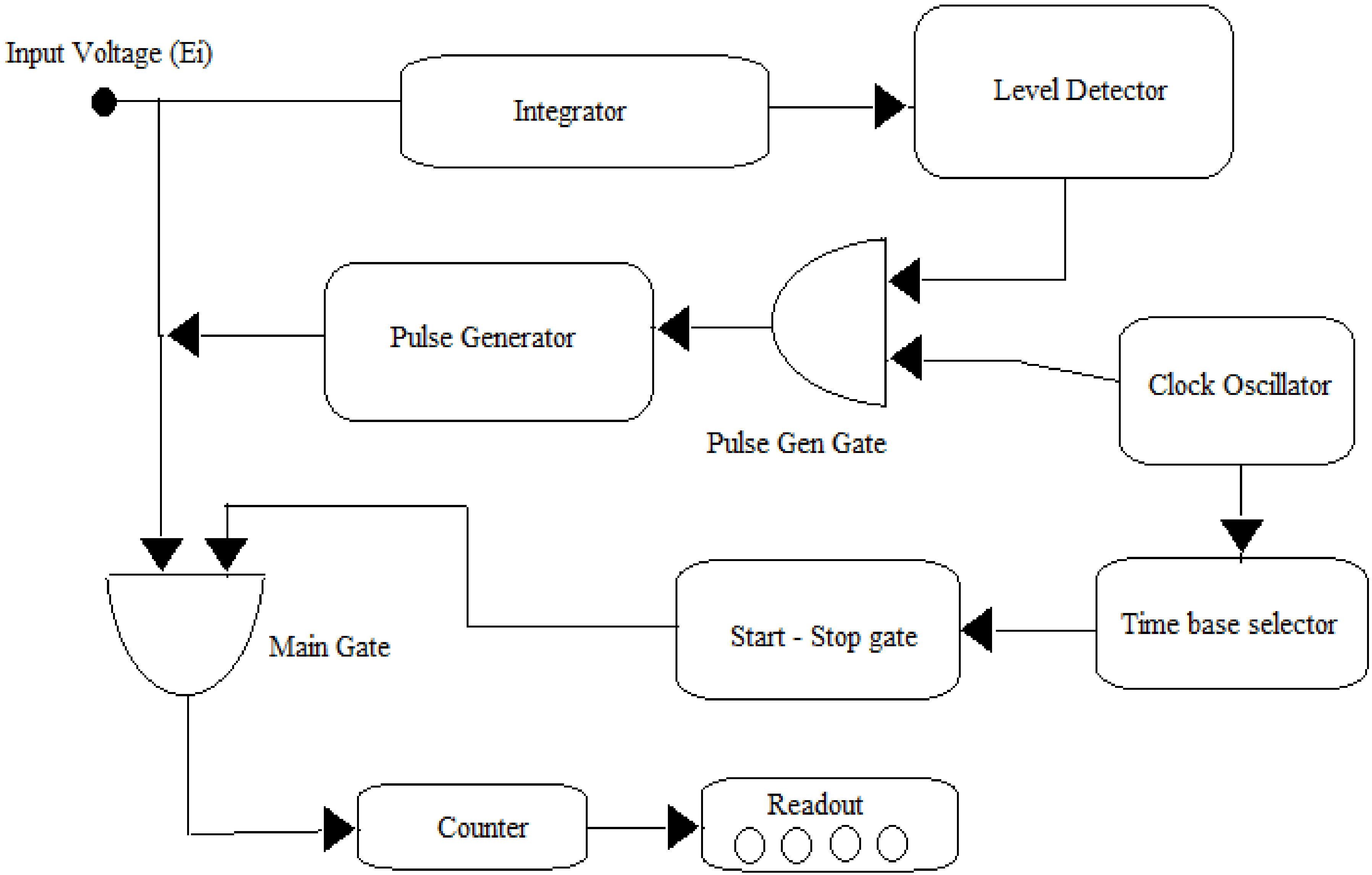
Demerits:

- accuracy of output greatly depends on linearity of the ramp.(since only one ramp is used)
- input filter are needed for filtering noise from input signal.

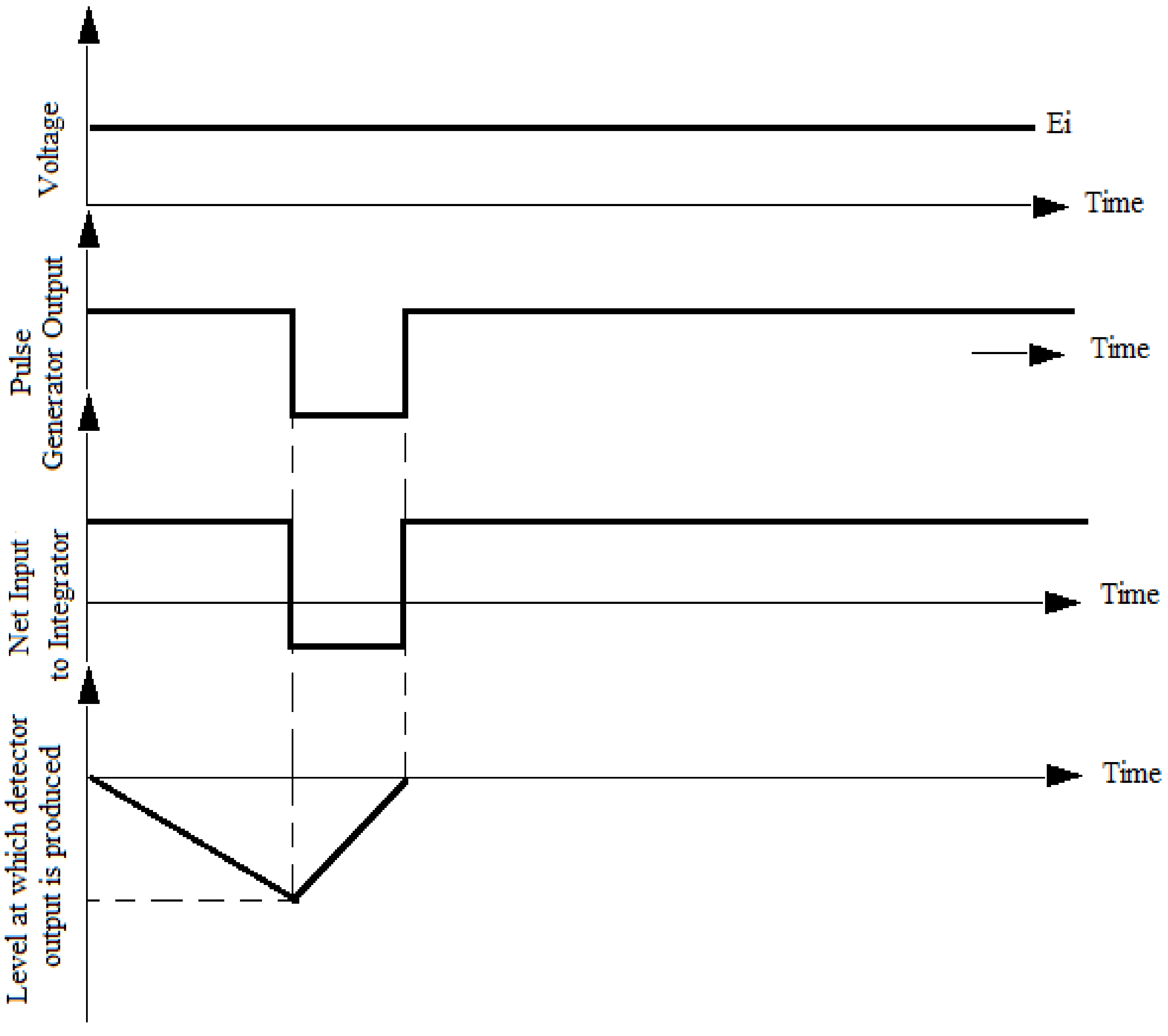
Dual Slope Integrating type DVM



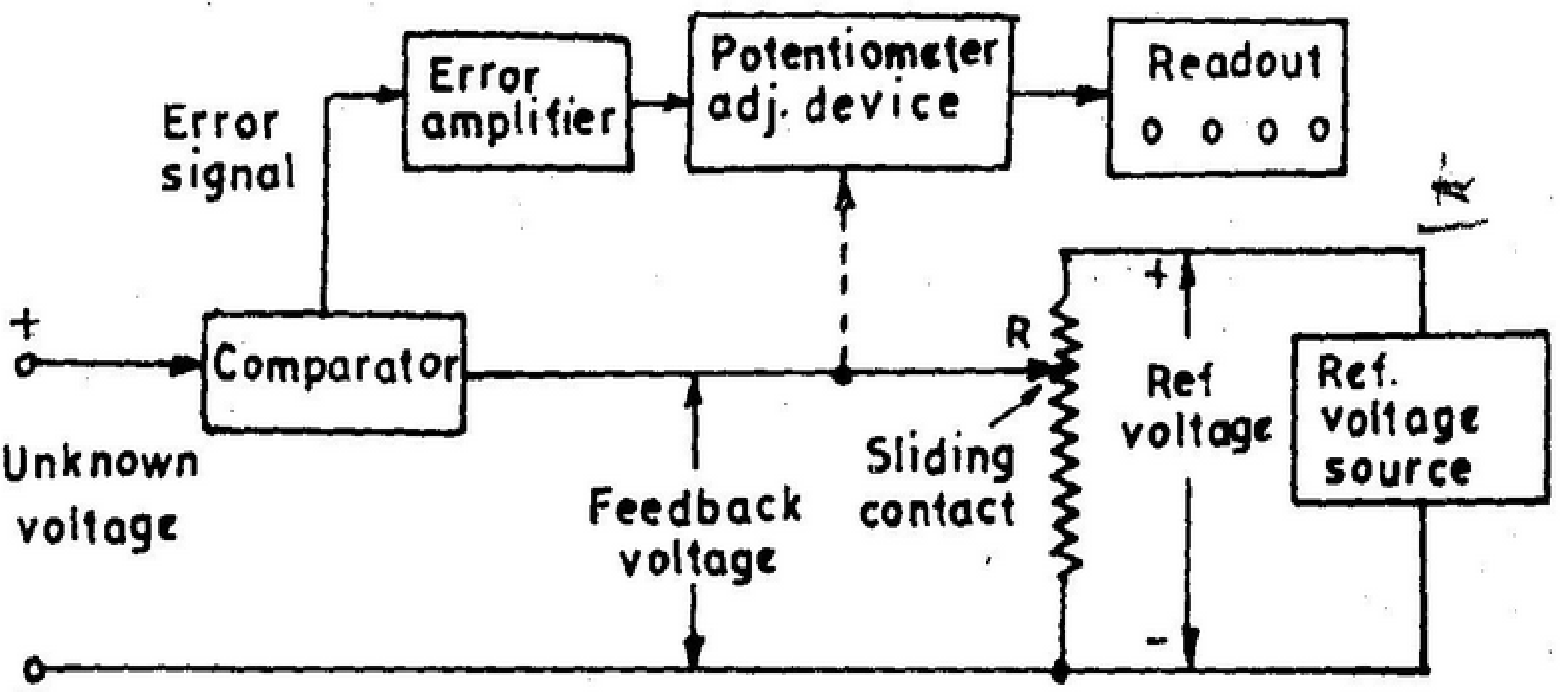
Block Diagram of Integrator type DVM



Waveform of output voltage



Potentiometric type Digital voltmeter



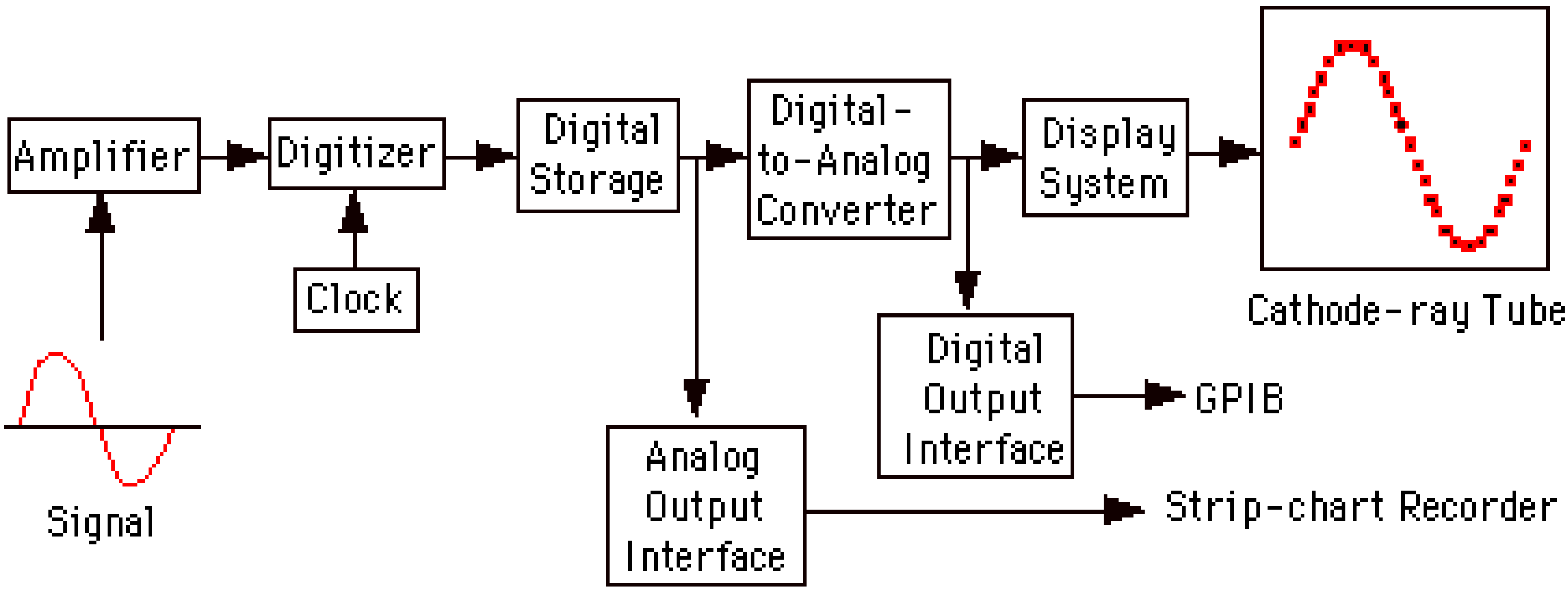
DIGITAL MULTIMETER

- Digital multimeter is an instrument used to measure voltage, current and resistance and display the measured voltage using LCD or LED to display the results in floating point format

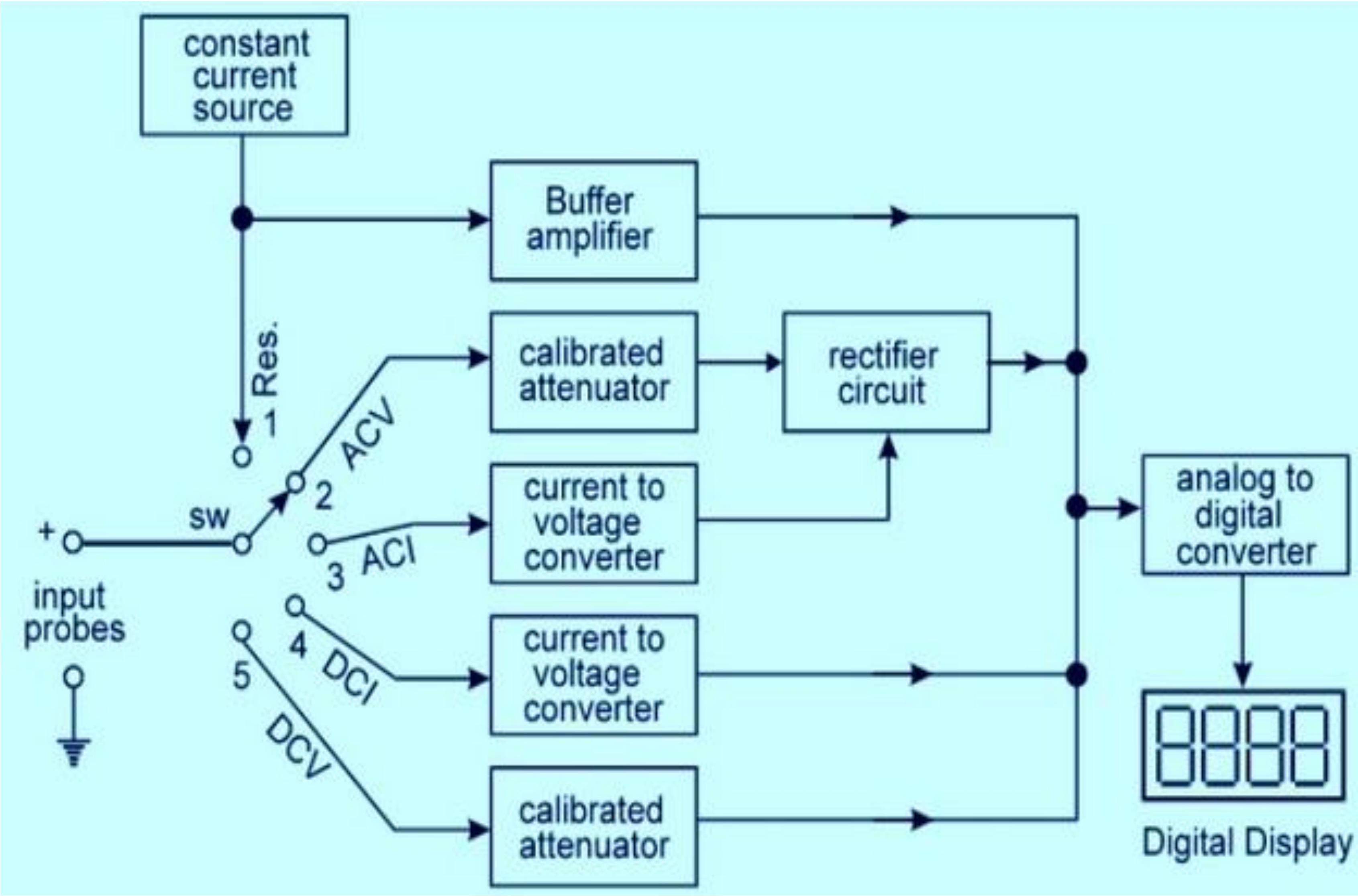
Special characters

- DMM has a variety of special features that are designed for a wide number of applications
- Frequency
- Temperature
- Capacitance
- Continuity check
- Diode check

Digital Storage Oscilloscope



Block diagram



Advantages

- Easy to handle
- Very accurate
- Noise signals absent
- Portable
- Has very good resolution