Presentation on

ELECTRONIC MEASUREMENT AND INSTRUMENTATION(AECB32) (ECE)

B.TECH V-Semester (IARE-R18)

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COURSE OUTCOMES

- Recall the schematics of measuring systems and performance characteristics of an instrument.
- Explain the measuring instruments and its working principle by using the instrument D' Arsonval Movement
- Demonstrates the various types measuring meters like Digital Voltmeters.
- Describe the basic building blocks of Cathode ray oscilloscopes and cathode ray tubes

COURSE OUTCOMES

- Compare various types of special purpose oscilloscopes with its applications
- Draw Lissajous figures or patterns for the given frequencies.
- Illustrate the working principles of signal generators and signal analysers
- Design a measuring instrument on requirement basis
- Describe Transducers and classify them according to their application

COURSE OUTCOMES

- Extend the concepts of balance bridge to find out the unknown parameter with the given specifications.

- Illustrate the working functionality of strain gauges, LVDT
- compare wave analyzers and spectrum analyzers based on its working functionality

- Develop the appropriate industrial instrument to solve the real world problem and also to measure different physical parameters.

SYLLABUS:

MODULE-I-INTRODUCTION TO MEASURING INSTRUMENTS

MODULE-II-OSCILLOSCOPE

MODULE-III-SIGNAL GENERATOR AND SIGNAL ANALYZERS

MODULE-IV-AC AND DC BRIDGES

MODULE-V-TRANSDUCERS

SYLLABUS:MODULE - I:INTRODUCTION TO MEASURING INSTRUMENTS

Block schematics of measuring systems, performance characteristics, Static characteristics: Accuracy, resolution, precision, gauss error, types of errors, Dynamic characteristics : Repeatability, reproducibility, fidelity, lag; Analog measuring instruments: D' Arsonval movement, DC voltmeters and ammeter, AC voltmeters and current meters, ohmmeters, multimeters, meter protection, extension of range, digital voltmeters: Ramp type, staircase, dual slope integrating type, successive approximation type, specifications of instruments

MODULE-II : OSCILLOSCOPE

Oscilloscopes: CRT, block schematic of CRO, time base circuits, delay lines, high frequency CRO considerations, applications, specifications, special purpose oscilloscopes: Dual trace, dual beam CROs, sampling oscilloscopes, storage oscilloscopes, digital storage CROs, Lissajous figures, frequencymeasurement, phase measurement, CRO probes

MODULE-III : SIGNAL GENERATOR AND SIGNAL ANALYZERS

Signal Generators: AF and RF signal generators, sine and square wave generators, function generators arbitrary waveform generator, sweep frequency generators, video signal generators, and specifications. Signal Analyzers: AF, HF wave analyzers, heterodyne wave analyzers, harmonic distortion, spectrum analyzers, power analyzers

MODULE-IV: AC AND DC BRIDGES

Measurements using DC and AC bridges: Wheat stone bridge, Kelvin bridge, AC bridges, Maxwell, Hay, Schering, Wien, Anderson bridges, Wagner & ground connection

MODULE-V: TRANSDUCERS

Transducers: Classification, strain gauges, force and displacement, transducers, resistance thermometers, hotwire anemometers, LVDT, thermocouples, synchros; Piezoelectric transducers, variable capacitance transducers; Magneto strictive transducers, measurement of physical parameters: Flow measurement, displacement meters, liquid level measurement, measurement of humidity and moisture, velocity, force,pressure, high pressure, vacuum level, temperature measurements.

COURSE OBJECTIVES:

Students will try to learn:

1. The construction and operation of AC & DC voltmeters and ammeters, Oscilloscopes, signal generators, signal analyzers, transducers and LCR meters

2. The application of the principles of electronic measurements to monitor high tension power quality and build spectrum analyzers for scientific and industrial applications

3. To explore the applications of measuring instrument in environment monitoring and health monitoring of a smart car.

MODULE-I

INTRODUCTION TO

MEASURING INSTRUMENTS

INTRODUCTION

- **Measurement** is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.

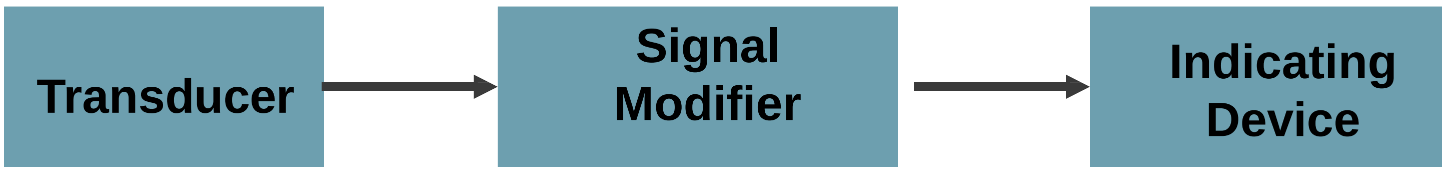
- **Instrumentation** is a technology of measurement which serves sciences, engineering, medicine and etc.

- **Instrument** is a device for determining the value or magnitude of a quantity or variable.

- **Electronic instrument** is based on electrical or electronic principles for its measurement functions.

ELECTRONIC INSTRUMENT

- Basic elements of an electronics instrument



1) Transducer
   - convert a non electrical signal into an electrical signal
2) Signal modifier
   - convert input signal into a suitable signal for the indicating device (e.g amplifier)
3) Indicating device
   - indicates the value of quantity being measure (e.g ammeter)

FUNCTIONS

- **The 3 basic functions of instrumentation**
  - **Indicating – visualize the process/operation**
  - **Recording – observe and save the measurement reading**
  - **Controlling – to control measurement and process**

Performance Characteristics

- The characteristics of measurement instruments which are helpful to know the performance of instrument and help in measuring any quantity or parameter, are known as **Performance Characteristics**.
- Types of Performance Characteristics
- Performance characteristics of instruments can be classified into the following **two types**.
  - **Static Characteristics**
  - **Dynamic Characteristics**

Static Characteristics

- The characteristics of quantities or parameters measuring instruments that **do not vary** with respect to time are called static characteristics.
- Sometimes, these quantities or parameters may vary slowly with respect to time. Following are the list of **static characteristics**.
  - Accuracy
  - Precision
  - Sensitivity
  - Resolution
  - Static Error

Static Characteristics

- Accuracy
- The algebraic difference between the indicated value of an instrument A_i, and the true value A_t, is known as **accuracy**. Mathematically, it can be represented as −

$$Accuracy = A_i - A_t$$

- The term, accuracy signifies how much the indicated value of an instrument, A_i is closer to the true value, A_t.

Static Characteristics

- Static Error
- The difference between the true value, A_t of the quantity that does not vary with respect to time and the indicated value of an instrument, A_i is known as static error, e_s. Mathematically, it can be represented as −
  - $e_s = A_t - A_i$
- The term, static error signifies the inaccuracy of the instrument. If the static error is represented in terms of percentage, then it is called percentage of static error. Mathematically, it can be represented as −
- $\%e_s = e_s / A_t \times 100$
- $\%e_s = A_t - A_i / A_t \times 100$

Static Characteristics

- Precision
- If an instrument indicates the same value repeatedly when it is used to measure the same quantity under same circumstances for any number of times, then we can say that the instrument has high precision.
- Sensitivity
- The ratio of change in output, ΔAout of an instrument for a given change in the input, ΔAin that is to be measured is called sensitivity, S.
- Mathematically it can be represented as −

$$S = \frac{\Delta A_{out}}{\Delta A_{in}}$$

Static Characteristics

- The term *sensitivity* signifies the smallest change in the measurable input that is required for an instrument to respond.

- If the calibration curve is **linear**, then the sensitivity of the instrument will be a constant and it is equal to slope of the calibration curve.

- If the calibration curve is **non-linear**, then the sensitivity of the instrument will not be a constant and it will vary with respect to the input.

Static Characteristics

- Resolution
- If the output of an instrument will change only when there is a specific increment of the input, then that increment of the input is called **Resolution**.
- That means, the instrument is capable of measuring the input effectively, when there is a resolution of the input.

Dynamic Characteristics

- The characteristics of the instruments, which are used to measure the quantities or parameters that vary very quickly with respect to time are called dynamic characteristics. Following are the list of **dynamic characteristics**.
  - Speed of Response
  - Dynamic Error
  - Fidelity
  - Lag

Dynamic Characteristics

- Speed of Response
- The speed at which the instrument responds whenever there is any change in the quantity to be measured is called **speed of response.** It indicates how fast the instrument is.
- Lag
- The amount of delay present in the response of an instrument whenever there is a change in the quantity to be measured is called measuring lag. It is also simply called **lag.**

Dynamic Characteristics

- Dynamic Error
- The difference between the true value At, of the quantity that varies with respect to time and the indicated value of an instrument Ai, is known as dynamic error, ed.

- Fidelity
- The degree to which an instrument indicates changes in the measured quantity without any dynamic error is known as **Fidelity**

Types of Measurement Errors

- The errors, which occur during measurement are known as **measurement errors**. In this chapter, let us discuss about the types of measurement errors.

Types of Measurement Errors

- classify the measurement errors into the following three types.
  - Gross Errors
  - Random Errors
  - Systematic Errors

Types of Measurement Errors

- Gross Errors
- The errors, which occur due to the lack of experience of the observer while taking the measurement values are known as **gross errors**.
- The values of gross errors will vary from observer to observer. Sometimes, the gross errors may also occur due to improper selection of the instrument.
- We can minimize the gross errors by following these two steps.
  - Choose the best suitable instrument, based on the range of values to be measured.
  - Note down the readings carefully

Types of Measurement Errors

- Systematic Errors
- If the instrument produces an error, which is of a constant uniform deviation during its operation is known as **systematic error**. The systematic errors occur due to the characteristics of the materials used in the instrument.
- Types of Systematic Errors

  Instrumental Errors − This type of errors occur due to shortcomings of instruments and loading effects.
- **Environmental Errors** − This type of errors occur due to the changes in environment such as change in temperature, pressure & etc.
- **observational Errors** – This type of errors occur due to observer while taking the meter readings. **Parallax errors** belong to this type of errors.

Types of Measurement Errors

- Random Errors
- The errors, which occur due to unknown sources during measurement time are known as **random errors**. Hence, it is not possible to eliminate or minimize these errors.

- But, if we want to get the more accurate measurement values without any random error, then it is possible by following these two steps.

- **Step1** − Take more number of readings by different observers.
- **Step2** − Do statistical analysis on the readings obtained in Step1.

Types of Measurement Errors

Random Errors

- Following are the parameters that are used in statistical analysis.
  - Mean
  - Median
  - Variance
  - Deviation
  - Standard Deviation

Now, let us discuss about these **statistical parameters**.

Types of Measurement Errors

Mean

Let $x1$,$x2$,$x3$,......xN are the N readings of a particular measurement. The mean or **average value** of these readings can be calculated by using the following formula.

$$m=(x1+x2+x3+....+xN)/N$$

Where, **m is the mean or average value**.

If the number of readings of a particular measurement are more, then the mean or average value will be approximately equal to **true value**

Types of Measurement Errors

Median

- If the number of readings of a particular measurement are more, then it is difficult to calculate the mean or average value. Here, calculate the **median value** and it will be approximately equal to mean value.

- For calculating median value, first we have to arrange the readings of a particular measurement in an **ascending order**. We can calculate the median value by using the following formula, when the number of readings is an **odd number**.

  - **M=x((N+1)/2)**

- We can calculate the median value by using the following formula, when the number of readings is an **even number**.

  - **M=x(N/2)+x([N/2]+1)2**

Types of Measurement Errors

Deviation from Mean

- The difference between the reading of a particular measurement and the mean value is known as *deviation from mean*. In short, it is called *deviation*. Mathematically, it can be represented as

- **$d_i = x_i - m$**

Where,

- d_i is the deviation of *ith* reading from mean.
- x_i is the value of *ith* reading.
- m is the mean or average value.

Standard Deviation

The root mean square of deviation is called **standard deviation**. Mathematically, it can be represented as

$$\sigma = \sqrt{\frac{{d_1}^2 + {d_2}^2 + {d_3}^2 + \dots + {d_N}^2}{N}}$$

The above formula is valid if the number of readings, N is greater than or equal to 20. We can use the following formula for standard deviation, when the number of readings, N is less than 20.

$$\sigma = \sqrt{\frac{{d_1}^2 + {d_2}^2 + {d_3}^2 + \dots + {d_N}^2}{N-1}}$$

Where,

σ is the standard deviation

$d_1, d_2, d_3, \dots, d_N$ are the deviations of first, second, third, …, N_{th} readings from mean respectively.

Types of Measurement Errors

Variance

The square of standard deviation is called **variance**. Mathematically, it can be represented as

$$V=\sigma 2$$

Where,

V **is the variance**

σ **is the standard deviation**

The mean square of deviation is also called **variance**. Mathematically, it can be represented as

$$V=\frac{d_1{}^2+d_2{}^2+d_3{}^2+\ldots\ldots+d_N{}^2}{N}$$

Types of Measurement Errors

Variance

The above formula is valid if the number of readings, N is greater than or equal to 20. We can use the following formula for variance when the number of readings, N is less than 20.

$$V = \frac{d_1^{\,2} + d_2^{\,2} + d_3^{\,2} + \ldots + d_N^{\,2}}{N - 1}$$

Where,

V is the variance

$d_1, d_2, d_3, \ldots, d_N$ are the deviations of first, second, third, …, N_{th} Nth readings from mean respectively.

PROBLE

1.

The expected value of the voltage across a resistor is 80V.However the measurement gives a value of 79V.Calculate, i) Absolute error ii)% error iii)relative accuracy and iv) % of accuracy.

Solution:

i) Absolute error=

ii) % error=

iii) relative accuracy=

iv) % of accuracy=

PROBLE

2.

The expected value of the voltage across a resistor is 20mA.However the measurement gives a value of 18mA.Calculate, i) Absolute error ii)% error iii)relative accuracy and iv) % of accuracy.

Solution:

i) Absolute error=

ii) % error=

iii) relative accuracy=

iv) % of accuracy=

Types of Instruments:

i. **PMMC**
ii. **Electrodynamometer**
iii. **Thermocouple**
iv. **Electrostatic**
v. **Moving iron**
vi. **Hot wire**
vii. **Induction type**
viii. **Rectifier**

Permanent Magnet Moving Coil

- **A permanent magnet moving coil (PMMC)** is one such instrument which is popularly used onboard and has several applications. The other popular nomenclature of this instrument is D'alvanometer and galvanometer.

Principle of Working

- When a current carrying conductor is placed in a magnetic field, it experiences a force and tends to move in the direction as per Fleming's left-hand rule.

Permanent Magnet Moving Coil

Fleming left-hand rule:

- If the first and the second finger and the thumb of the left hand are held so that they are at right angle to each other, then the thumb shows the direction of the force on the conductor, the first finger points towards the direction of the magnetic field and the second finger shows the direction of the current in the wire.

Equation involved

- The interaction between the induced field and the field produced by the permanent magnet causes a deflecting torque, which results in the rotation.

Permanent Magnet Moving Coil

- **The three important torque involved in this instrument are:**
  - Deflecting torque:
  - The force F which will be perpendicular to both the direction of the current flow and the direction of magnetic field as per Fleming's left hand rule can be written as

    - $F = NBIL$

- where N: turns of wire on the coil
- B: flux density in the air gap
- I: current in the movable coil
- L: vertical length of the coil

Permanent Magnet Moving Coil

- Theoretically, the torque (here electro-magnetical torque) is equal to the multiplication of force with distance to the point of suspension.

- Hence Torque on left side of the cylinder T_L = NBIL x W/2 and torque on right side of the cylinder T_R = NBIL x W/2

- Therefore the total torque will be = $T_L + T_R$

  - T = NBILW or NBIA

where A is effective area (A=LxW)

Permanent Magnet Moving Coil

Controlling Torque

- This torque is produced by the spring action and opposes the deflection torque so as the pointer can come to rest at the point where these two torques are equal (Electromagnetic torque = control spring torque).
- The value of control torque depends on the mechanical design of spiral springs and strip suspensions.
- The controlling torque is directly proportional to the angle of deflection of the coil.

Control torque $C_t = C\theta$

where, θ = deflection angle in radians and

C = spring constant Nm /rad .

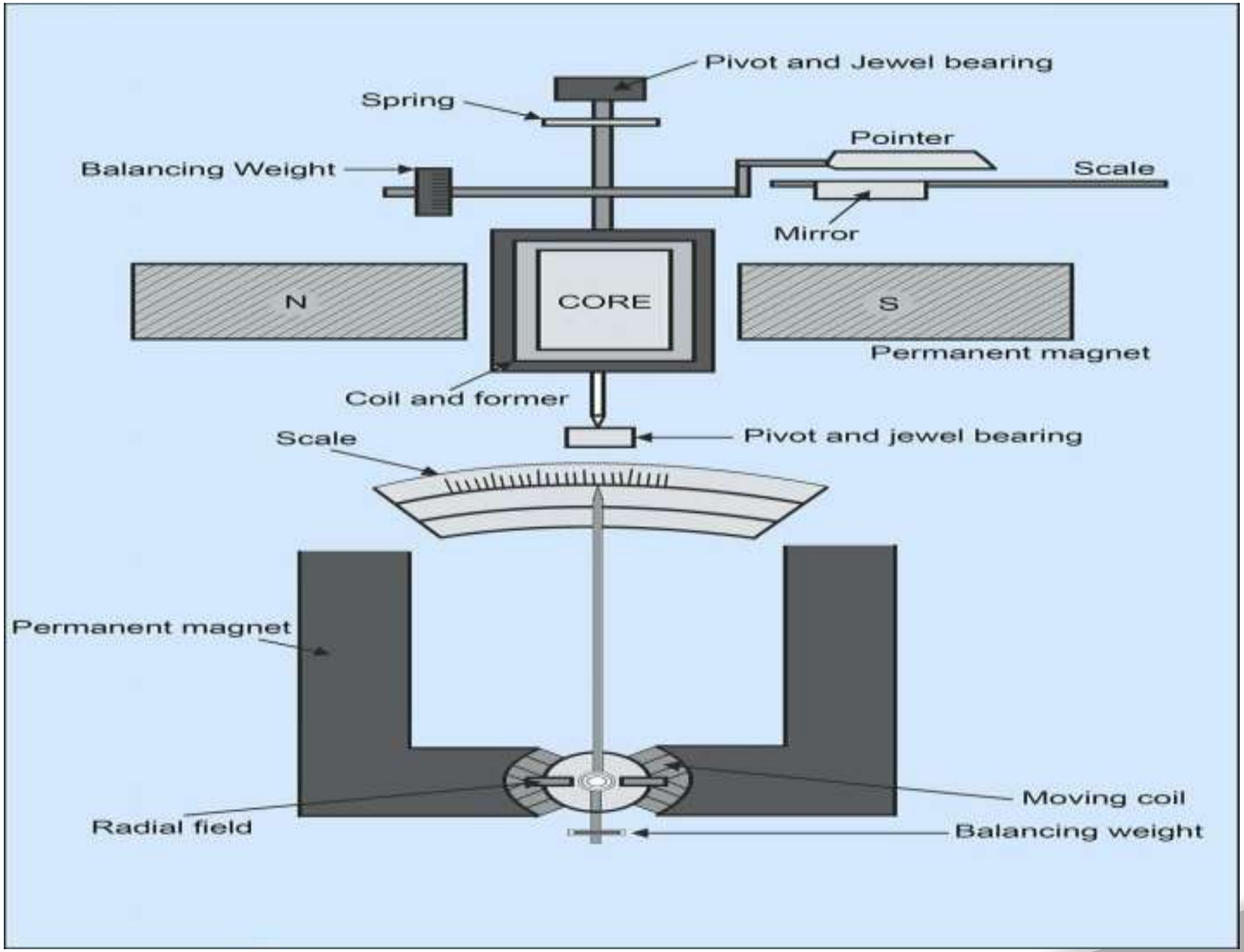
Permanent Magnet Moving Coil

Damping torque

- This torque ensures the pointer comes to an equilibrium position i.e. at rest in the scale without oscillating to give an accurate reading.

- In PMMC as the coil moves in the magnetic field, eddy current sets up in a metal former or core on which the coil is wound or in the circuit of the coil itself which opposes the motion of the coil resulting in the slow swing of a pointer and then come to rest quickly with very little oscillation.

Permanent Magnet Moving Coil



Permanent Magnet Moving Coil

Working

- When a current flow through the coil, it generates a magnetic field which is proportional to the current in case of an ammeter.

- The deflecting torque is produced by the electromagnetic action of the current in the coil and the magnetic field.

- When the torques are balanced the moving coil will stop and its angular deflection represents the amount of electrical current to be measured against a fixed reference, called a scale.

- If the permanent magnet field is uniform and the spring linear, then the pointer deflection is also linear.

Permanent Magnet Moving Coil

Working

➢The controlling torque is provided by two phosphorous bronze flat coiled helical springs. These springs serve as a flexible connection to the coil conductors.

➢Damping is caused by the eddy current set up in the aluminum coil which prevents the oscillation of the coil.

D'ARSORVAL METER MOVEMENT

- Also called Permanent-Magnet Moving Coil (PMMC).
- Based on the moving-coil galvanometer constructed by Jacques d' Arsonval in 1881.

- Can be used to indicate the value of DC and AC quantity.
- Basic construction of modern PMMC can be seen in Figure .

Operation of D'Arsonval Meter

- When current flows through the coil, the core will rotate.
- Amount of rotation is proportional to the amount of current flows through the coil.
- The meter requires low current (~50uA) for a full scale deflection, thus consumes very low power (25-200 uw).
- Its accuracy is about 2% -5% of full scale deflection

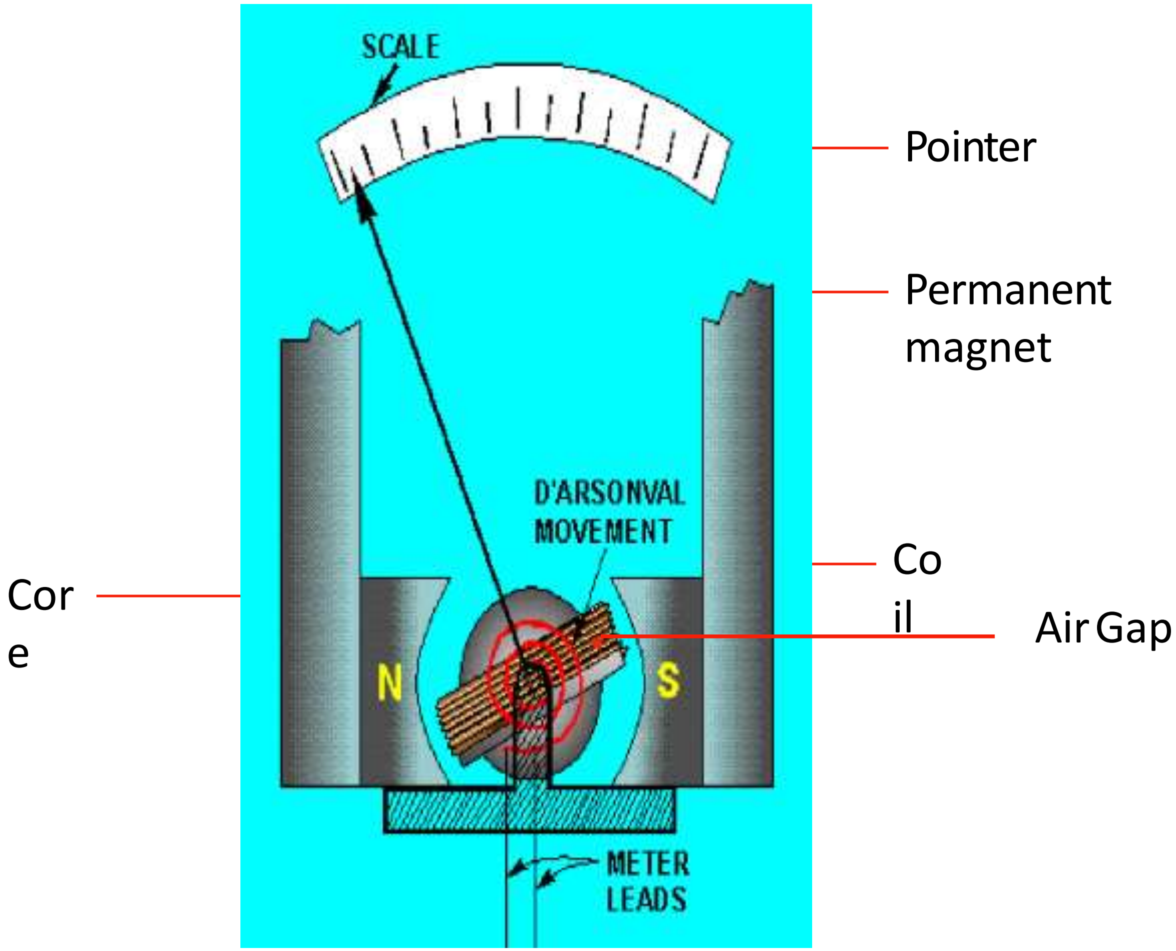


Fig: Modern D'Arsonval Movement

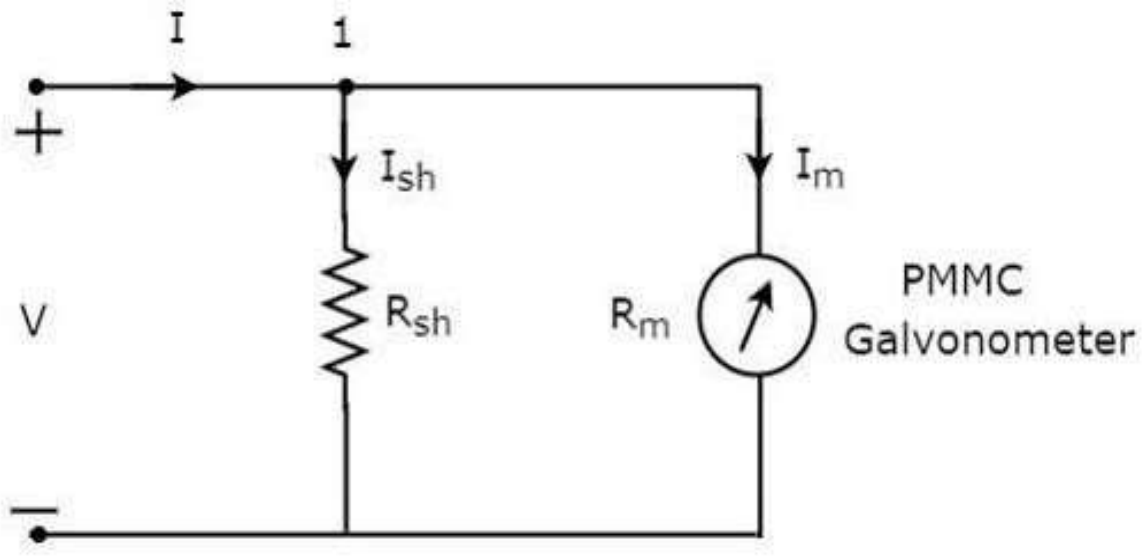
DC Ammeters

- Current is the rate of flow of electric charge. If this electric charge flows only in one direction, then the resultant current is called Direct Current (DC). The instrument, which is used to measure the Direct Current called **DC ammeter**.

- If we place a resistor in parallel with the Permanent Magnet Moving Coil (PMMC) galvanometer, then the entire combination acts as DC ammeter.

DC Ammeters

- The parallel resistance, which is used in DC ammeter is also called shunt resistance or simply, **shunt**.
- The value of this resistance should be considered small in order to measure the DC current of large value.



DC Ammeters

- We have to place this **DC ammeter** in series with the branch of an electric circuit, where the DC current is to be measured. The voltage across the elements, which are connected in parallel is same.

- So, the voltage across shunt resistor, Rsh and the voltage across galvanometer resistance, Rm is same, since those two elements are connected in parallel in above circuit.

DC Ammeters

- **Mathematically**, it can be written as

$$I_{sh} R_{sh} = I_m R_m$$

$$\Rightarrow R_{sh} = \frac{I_m R_m}{I_{sh}}$$ (Equation 1)

The **KCL equation** at node 1 is $$-I + I_{sh} + I_m = 0$$

$$\Rightarrow I_{sh} = I - I_m$$

Substitute the value of Ish in Equation 1.

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$ (Equation 2)

DC Ammeters

The ratio of total Direct Current that is to be measured, I and the full scale deflection current of the galvanometer, I_m is known as **multiplying factor, m**. Mathematically, it can be represented as

$$m = \frac{I}{I_m} \qquad \text{(Equation 4)}$$

$$R_{sh} = \frac{R_m}{m-1} \qquad \text{(Equation 5)}$$

Where,

R_{sh} is the shunt resistance

R_m is the internal resistance of galvanometer

I is the total Direct Current that is to be measured

I_m is the full scale deflection current

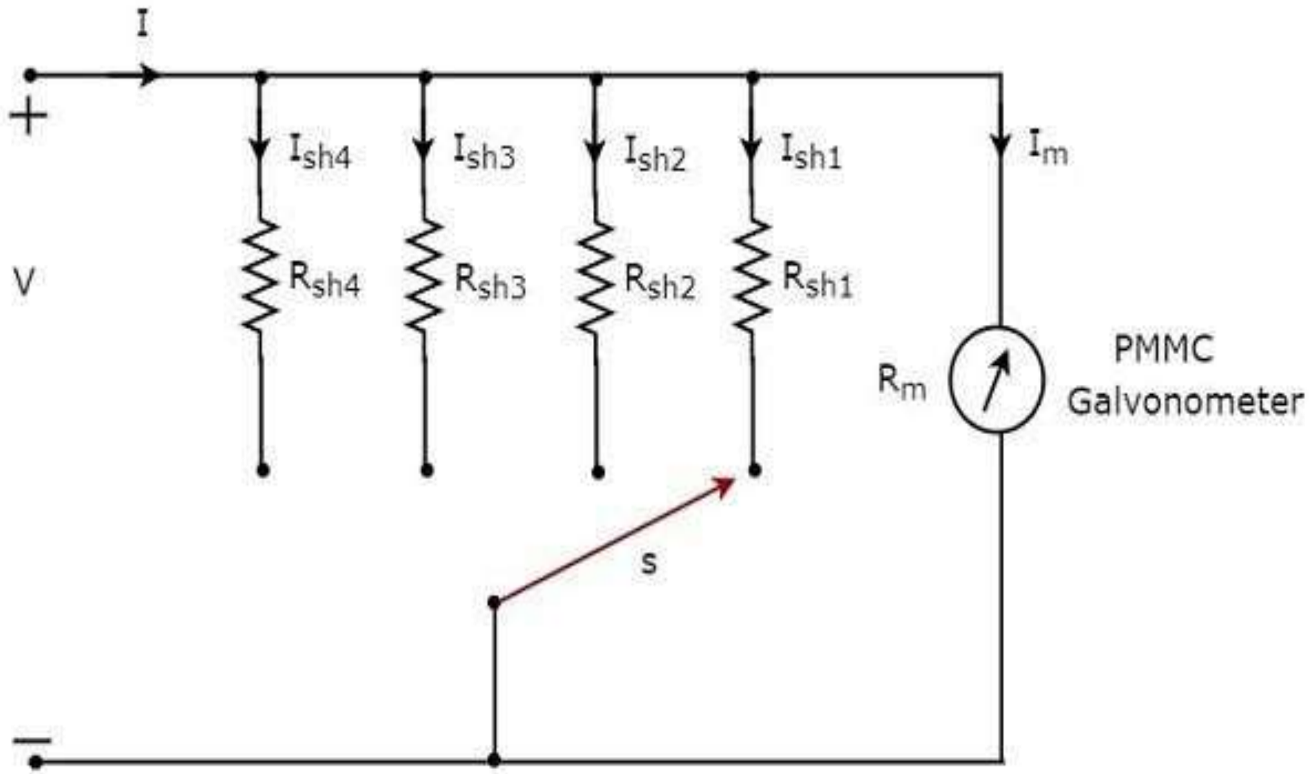
Multi Range DC Ammeter

In previous section, we discussed about DC ammeter which is obtained by placing a resistor in parallel with the PMMC galvanometer. This DC ammeter can be used to measure a **particular range** of Direct Currents.

If we want to use the DC ammeter for measuring the Direct Currents of multiple ranges, then we have to use multiple parallel resistors instead of single resistor and this entire combination of resistors is in parallel to the PMMC galvanometer.

The circuit diagram of multi range DC ammeter is shown in below figure.

Multi Range DC Ammeter



Place this multi range DC ammeter in series with the branch of an electric circuit, where the Direct Current of required range is to be measured. The desired range of currents is chosen by connecting the switch, s to the respective shunt resistor.

Multi Range DC Ammeter

- Let, m1,m2,m3 and m4 are the **multiplying factors** of DC ammeter when we consider the total Direct Currents to be measured as, I1,I2,I3I1,I2,I3 and I4 respectively.

- Following are the formulae corresponding to each multiplying factor.

- $$m_1 = \frac{I_1}{I_m} \qquad m_3 = \frac{I_3}{I_m}$$

$$m_2 = \frac{I_2}{I_m} \qquad m_4 = \frac{I_4}{I_m}$$

Multi Range DC Ammeter

- In above circuit, there are four **shunt resistors**, Rsh1,Rsh2,Rsh3 and Rsh4.
- Following are the formulae corresponding to these four resistors.

$$R_{sh1} = \frac{R_m}{m_1 - 1}$$

$$R_{sh3} = \frac{R_m}{m_3 - 1}$$

$$R_{sh2} = \frac{R_m}{m_2 - 1}$$

$$R_{sh4} = \frac{R_m}{m_4 - 1}$$

DC Voltmeters

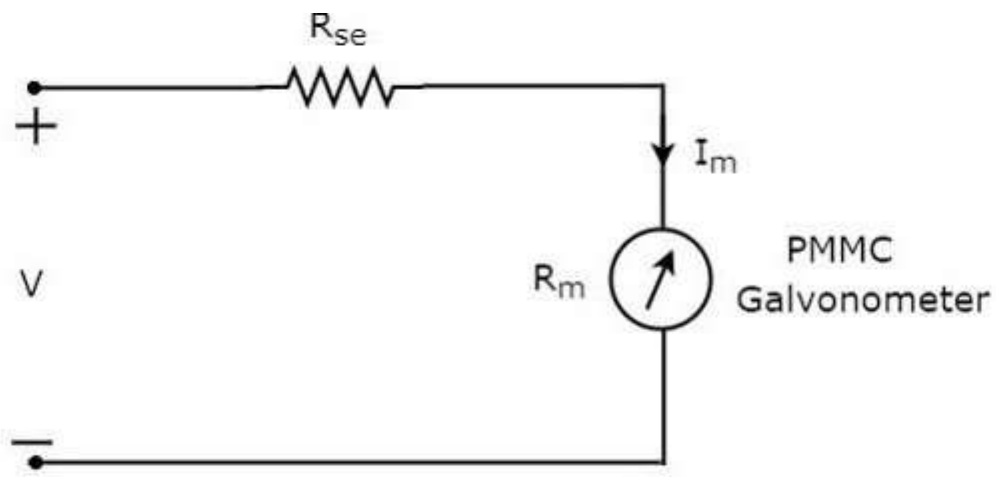
- DC voltmeter is a measuring instrument, which is used to measure the DC voltage across any two points of electric circuit. If we place a resistor in series with the Permanent Magnet Moving Coil (PMMC) galvanometer, then the entire combination together acts as **DC voltmeter**.

- The series resistance, which is used in DC voltmeter is also called series multiplier resistance or simply, multiplier.

- It basically limits the amount of current that flows through galvanometer in order to prevent the meter current from exceeding the full scale deflection value.

DC Voltmeters

- The circuit diagram of DC voltmeter is shown in below figure.



We have to place this DC voltmeter across the two points of an electric circuit, where the DC voltage is to be measured.

DC Voltmeters

Apply KVL around the loop of above circuit.

$$V - I_m R_{se} - I_m R_m = 0 \qquad \text{(Equation 1)}$$

Where,

$$\Rightarrow V - I_m R_m = I_m R_{se}$$

R_{se} is the series multiplier resistance

$$\Rightarrow R_{se} = \frac{V - I_m R_m}{I_m}$$

V is the full range DC voltage that is to be measured

I_m is the full scale deflection current

$$\Rightarrow R_{se} = \frac{V}{I_m} - R_m \qquad \text{(Equation 2)}$$

R_m is the internal resistance of galvanometer

DC Voltmeters

- The ratio of full range DC voltage that is to be measured, V and the DC voltage drop across the galvanometer, Vm is known as **multiplying factor**, m. Mathematically, it can be represented as

  - $m=V/V_m$ (Equation 3)

- From Equation 1, we will get the following equation for **full range DC voltage** that is to be measured, V

  - $V=I_m R_{se} + I_m R_m$ (Equation 4)

DC Voltmeters

- The **DC voltage drop** across the galvanometer, Vm is the product of full scale deflection current, Im and internal resistance of galvanometer, Rm. Mathematically, it can be written as
  - Vm=ImRm (Equation 5)

- **Substitute**, Equation 4 and Equation 5 in Equation 3.

$$m = \frac{I_m R_{se} + I_m R_m}{I_m R_m}$$

DC Voltmeters

$$\Rightarrow m = \frac{R_{se}}{R_m} + 1$$

$$\Rightarrow m - 1 = \frac{R_{se}}{R_m}$$

$$R_{se} = R_m(m - 1) \qquad \text{(Equation 6)}$$

We can find the **value of series multiplier resistance** by using either Equation 2 or Equation 6 based on the available data.

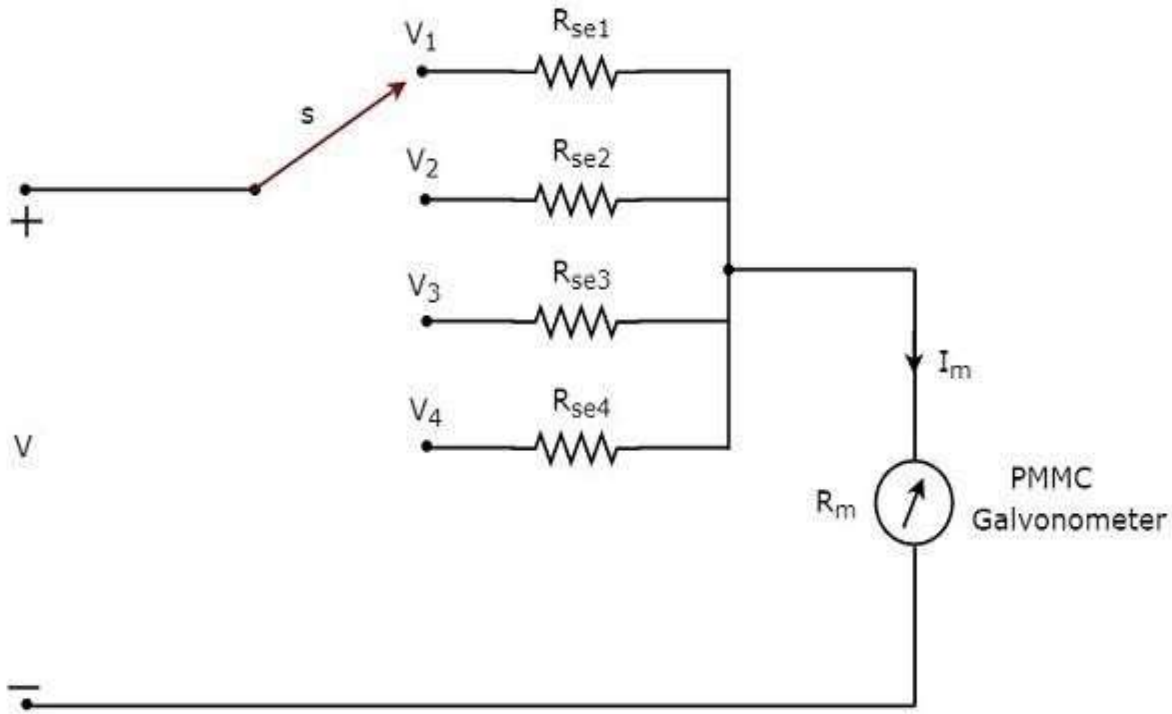
Multi Range DC Voltmeter

In previous section, we had discussed DC voltmeter, which is obtained by placing a multiplier resistor in series with the PMMC galvanometer. This DC voltmeter can be used to measure a **particular range** of DC voltages.

If we want to use the DC voltmeter for measuring the DC voltages of **multiple ranges**, then we have to use multiple parallel multiplier resistors instead of single multiplier resistor and this entire combination of resistors is in series with the PMMC galvanometer.

The **circuit diagram** of multi range DC voltmeter is shown in below figure.

Multi Range DC Voltmeter



We have to place this **multi range DC voltmeter** across the two points of an electric circuit, where the DC voltage of required range is to be measured. We can choose the desired range of voltages by connecting the switch s to the respective multiplier resistor.

Multi Range DC Voltmeter

Let, m1,m2, m3 and m4 are the **multiplying factors** of DC voltmeter when we consider the full range DC voltages to be measured as, V1,V2,V3 and V4 respectively. Following are the formulae corresponding to each multiplying factor.

$$m_1 = \frac{V_1}{V_m}$$

$$m_3 = \frac{V_3}{V_m}$$

$$m_2 = \frac{V_2}{V_m}$$

$$m_4 = \frac{V_4}{V_m}$$

Multi Range DC Voltmeter

In above circuit, there are four **series multiplier resistors**, Rse1,Rse2,Rse3and Rse4.

Following are the formulae corresponding to these four resistors.

$$R_{se1} = R_m(m_1 - 1)$$

$$R_{se3} = R_m(m_3 - 1)$$

$$R_{se2} = R_m(m_2 - 1)$$

$$R_{se4} = R_m(m_4 - 1)$$

So, we can find the resistance values of each series multiplier resistor by using above formulae.

DC Voltmeters-Problem

Calculate the value of multiplier resistance on the 50V range of a DC voltmeter that uses a 500uA meter movement with an internal resistance of 1kΩ.

Solution:

Step-1: The sensitivity of 500uA meter movement is given by,

$$S = 1/I_m = 1/500uA = 2k\Omega/V$$

Step-2: The value of the multiplier resistance can be calculated by

$$R_s = S \times range - R_m$$

$$R_s = 2k\Omega/V \times 50V - 1k\Omega$$

$$= 100k\Omega - 1k\Omega$$

$$= 99k\Omega$$

Ammeters

As the name suggests, **ammeter** is a measuring instrument which measures the current flowing through any two points of an electric circuit.

The unit of current is ampere and the measuring instrument is meter. The word "ammeter" is obtained by combining **"am"** of ampere with **"meter"**.

We can classify the ammeters into the following two types based on the type of current that it can measure.

- DC Ammeters
- AC Ammeters

Ammeters

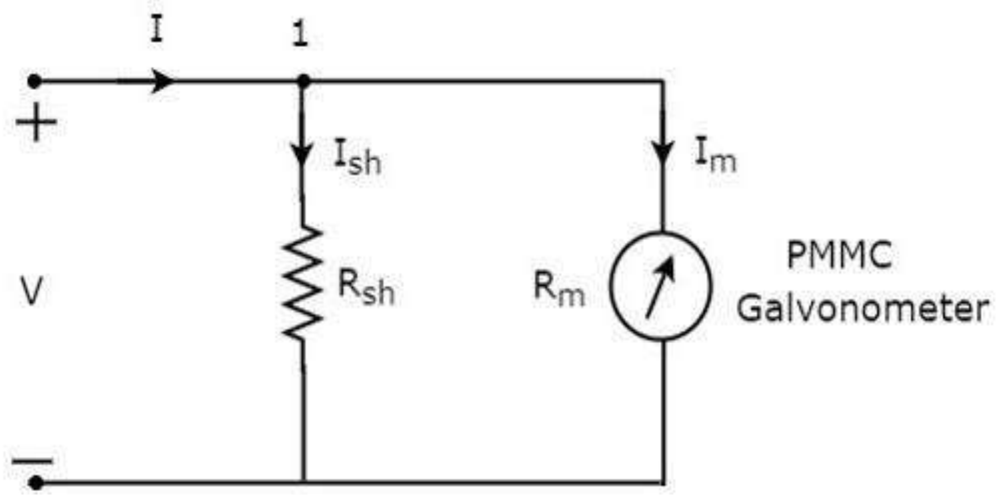
- Current is the rate of flow of electric charge. If this electric charge flows only in one direction, then the resultant current is called Direct Current (DC). The instrument, which is used to measure the Direct Current called **DC ammeter**.

- If we place a resistor in parallel with the Permanent Magnet Moving Coil (PMMC) galvanometer, then the entire combination acts as DC ammeter.

- The parallel resistance, which is used in DC ammeter is also called shunt resistance or simply, **shunt**. The value of this resistance should be considered small in order to measure the DC current of large value.

Ammeters

- The **circuit diagram** of DC ammeter is shown in below fig



We have to place this **DC ammeter** in series with the branch of an electric circuit, where the DC current is to be measured. The voltage across the elements, which are connected in parallel is same.

Ammeters

So, the voltage across shunt resistor, RshRsh and the voltage across galvanometer resistance, RmRm is same, since those two elements are connected in parallel in above circuit.

Mathematically, it can be written as

$I_{sh} R_{sh} = I_m R_m$

$$\Rightarrow \quad R_{sh} = \frac{I_m R_m}{I_{sh}} \qquad \text{(Equation 1)}$$

The **KCL equation** at node 1 is

$$\Rightarrow \quad -I + I_{sh} + I_m = 0$$

$$\Rightarrow \quad I_{sh} = I - I_m$$

Ammeters

Substitute the value of Ish in Equation 1.

$$R_{sh} = \frac{I_m R_m}{I - I_m} \qquad \text{(Equation 2)}$$

Take, Im as common in the denominator term, which is present in the right hand side of Equation 2

$$R_{sh} = \frac{I_m R_m}{I_m((1/I_m) - 1))}$$

$$\Rightarrow R_{sh} = \frac{R_m}{(1/I_m) - 1)} \qquad \text{(Equation 3)}$$

Ammeters

Where,

Rsh is the shunt resistance

Rm is the internal resistance of galvanometer

I is the total Direct Current that is to be measured

Im is the full scale deflection current

The ratio of total Direct Current that is to be measured, II and the full scale deflection current of the galvanometer, Im is known as **multiplying factor, m**. Mathematically, it can be represented as,

$$m=Im \qquad \text{(Equation 4)}$$

$$Rsh=Rm\ /m-1 \qquad \text{(Equation 5)}$$

We can find the **value of shunt resistance** by using either Equation 2 or Equation 5 based on the available data.

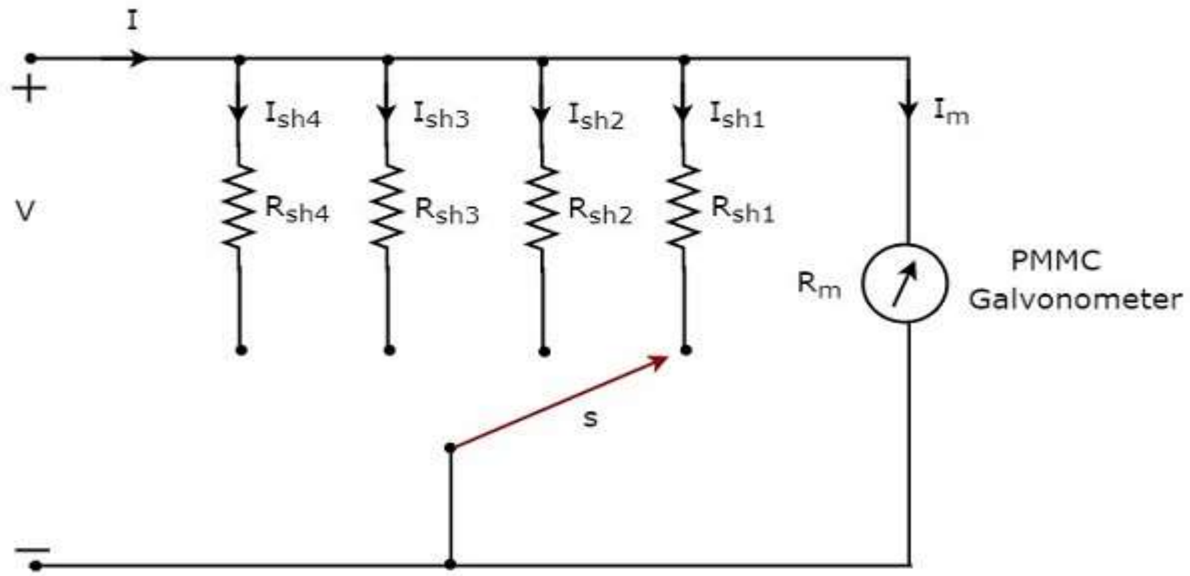
Multi Range DC Ammeter

- In previous section, we discussed about DC ammeter which is obtained by placing a resistor in parallel with the PMMC galvanometer. This DC ammeter can be used to measure a **particular range** of Direct Currents.

- If we want to use the DC ammeter for measuring the Direct Currents of **multiple ranges**, then we have to use multiple parallel resistors instead of single resistor and this entire combination of resistors is in parallel to the PMMC galvanometer.

- The **circuit diagram** of multi range DC ammeter is shown in below figure.

Multi Range DC Ammeter



Place this multi range DC ammeter in series with the branch of an electric circuit, where the Direct Current of required range is to be measured.

The desired range of currents is chosen by connecting the switch, s to the respective shunt resistor.

Multi Range DC Ammeter

Let, m1,m2,m3 and m4 are the **multiplying factors** of DC ammeter when we consider the total Direct Currents to be measured as, I1,I2,I3 and I4 respectively. Following are the formulae corresponding to each multiplying factor.

$$m1 = I1/Im \qquad m2 = I2/Im$$

$$m3 = I3/Im \qquad m4 = I4/Im$$

Inabovecircuit,
there are four **shunt resistors**, Rsh1,Rsh2,Rsh3 and Rsh4. Following are the formulae corresponding to these four resistors.

$$Rsh1 = Rm/m1-1 \qquad Rsh2 = Rm/m2-1$$

$$Rsh3 = Rm/m3-1 \qquad Rsh4 = Rm/m4-1$$

The above formulae will help us find the resistance values of each shunt resistor.

Aryton Shunt Ammeters

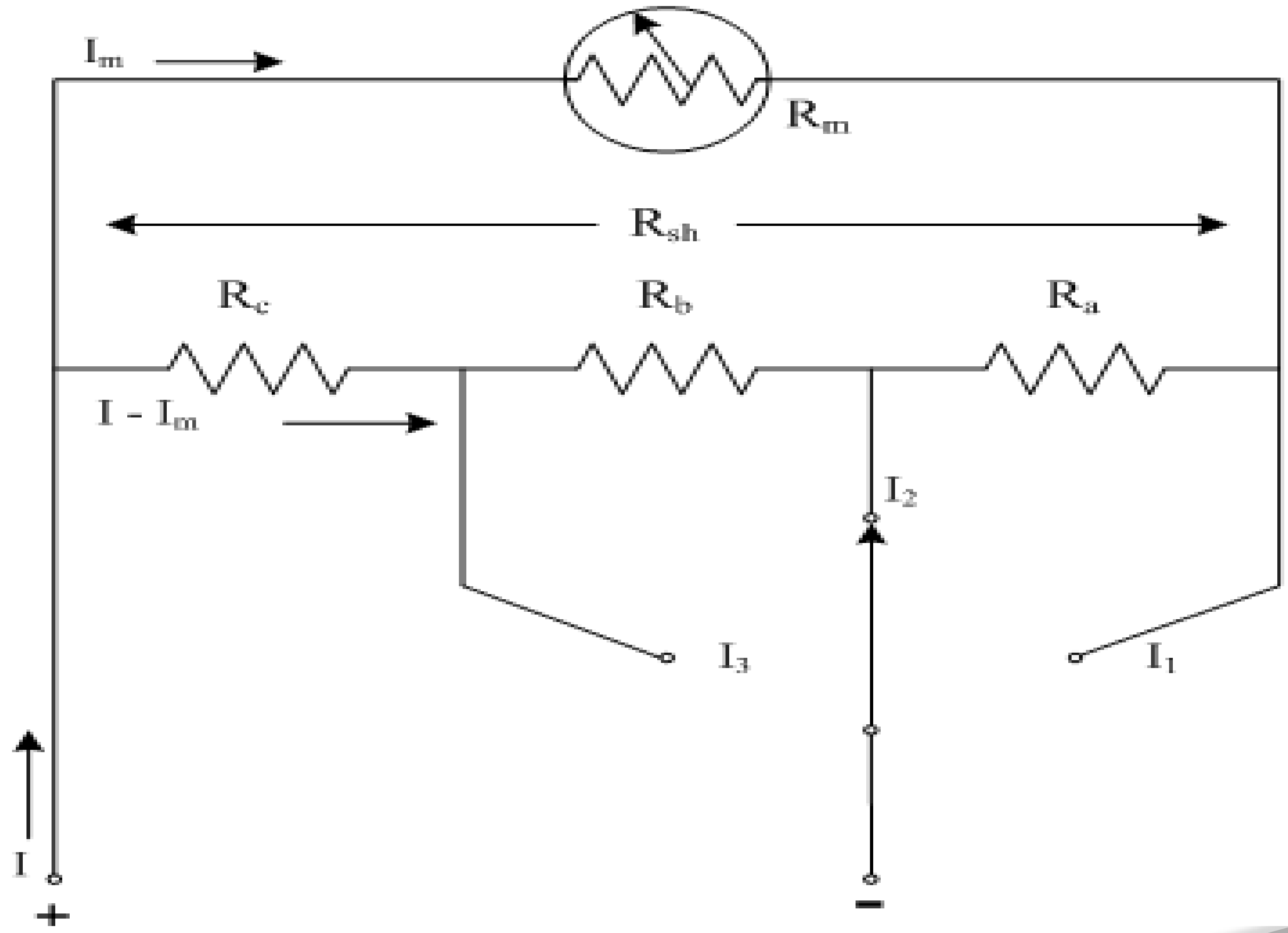
- The shunt resistance discussed in the previous sections work well enough on a single range ammeter. However, on a multiple-range ammeter, the Ayrton shunt is frequently a more suitable design.

- One advantage of the Ayrton shunt is it eliminates the possibility of the moving coil to be in the circuit without any shunt resistance where they protect the deflection instrument of the ammeter from an excessive current flow when switching between shunts.

- Another advantage is that it may be used as a wide range ammeter.

- Reduce cost

Aryton Shunt Ammeters



Aryton Shunt Ammeters

❖ Position of the switch:

a) ‘1’: Ra parallel with series combination of Rb, Rc and the meter movement. Current through the shunt is more than the current through the meter movement, thereby protecting the meter movement and reducing its sensitivity.

b) ‘2’: Ra and Rb in parallel with the series combination of Rc and the meter movement. The current through the meter is more than the current through the shunt resistance.

c) ‘3’: Ra, Rb and Rc in parallel with the meter. Maximum current flows through the meter movement and very little through the shunt. This will increase the sensitivity.

Aryton Shunt Ammeters

- The individual resistance values of the shunts are calculated starting from the most sensitive range, I1 and works towards the least sensitive range, I3.

- At the most sensitive range (point A), the shunt can be computed using equation,

$$Rsh=Rm/m-1$$

- The equation needed to compute the value of each Ra, Rb and Rc can be developed by observing Figure.
  - Notice that, Ra+Rb+Rc = Rsh

- Now, observe **at point B,**

$$(Rb + Rc) \parallel (Ra + Rm)$$

Then the voltage across the branch can be written as

$$V(Rb + Rc) = V(Ra + Rm)$$

Aryton Shunt Ammeters

In current and resistance terms we can write as

$$(Rb + Rc)(I2 - Im) = Im\ (Ra + Rm)$$

$$I2\ (Rb + Rc) - Im\ (Rb + Rc) = Im\ (Ra + Rm)$$

$$I2\ (Rb + Rc) = Im\ (Rb + Rc) + Im(Ra + Rm)$$

$$= Im\ (Ra + Rb + Rc + Rm)$$

$$= Im\ (Rsh + Rm)$$

$$Rb+Rc = Im\ (Rsh + Rm) / I2$$

At point C,

$$Rc \parallel (Ra + Rb + Rm)$$

Thus, in current and resistance terms we can write it as

$$V\ Rc = V\ (Ra + Rb + Rm)$$

Aryton Shunt Ammeters

$$(Rc)(I3-Im) = (Ra + Rb + Rm)(Im)$$

$$I3Rc = Im(Ra + Rb + Rc + Rm)$$

$$I3Rc = Im\ (Rsh + Rm)$$

$$Rc = Im\ (Rsh + Rm)/I3$$

The value of Rb can be obtained by substituting equation,

$$R_b = I_m(R_{sh} + R_m)\left[\frac{1}{I_2} - \frac{1}{I_3}\right]$$

Aryton Shunt Ammeters

Calculate the value for R_a, R_b and R_c as shown in Figure given the value of internal resistance, $R_m = 1\ k\Omega$ and full scale current of the moving coil = 100 µA. The required range of current are: $I_1 = 10\ mA$, $I_2 = 100\ mA$ and $I_3 = 1A$.

Solution

At the most sensitive range,

$$n = I / Im$$
$$= 10\ mA / 100\ \mu A$$
$$= 100$$

Total shunt resistance, $R_{sh} = R_m / (n-1)$

$$= 1\ k\Omega / 99$$
$$= 10.1\ \Omega$$

Using equation (at point C),

$$R_c = (100\ \mu A)(10.1\ \Omega + 1k\Omega) / 1A = 0.101\ \Omega$$

Using equation R_b

$$R_b = (100\ \mu A)(10.1\ \Omega + 1k\Omega)[(1/100mA) - (1/1A))]$$
$$= 0.909\ \Omega$$

For R_a, since $R_{sh} = R_a + R_b + R_c$, thus $R_a = R_{sh} - (R_b + R_c)$

$$R_a = 10.1\ \Omega - (0.909\ \Omega + 0.101\ \Omega)$$
$$= 9.09\ \Omega$$

AC Voltmeters

- The instrument, which is used to measure the AC voltage across any two points of electric circuit is called **AC voltmeter**. If the AC voltmeter consists of rectifier, then it is said to be rectifier based AC voltmeter.
- The DC voltmeter measures only DC voltages. If we want to use it for measuring AC voltages, then we have to follow these two steps.
- **Step1** − Convert the AC voltage signal into a DC voltage signal by using a rectifier.
- **Step2** − Measure the DC or average value of the rectifier's output signal.
- We get **Rectifier based AC voltmeter**, just by including the rectifier circuit to the basic DC voltmeter.

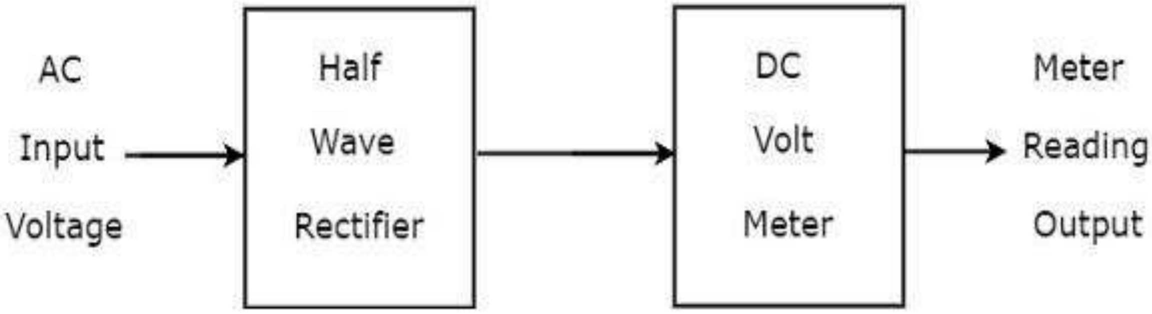
AC Voltmeters

- **Types of Rectifier based AC Voltmeters**

  Following are the **two types** of rectifier based AC voltmeters.
  - AC voltmeter using Half Wave Rectifier
  - AC voltmeter using Full Wave Rectifier

- **AC Voltmeter using Half Wave Rectifier**

  If a Half wave rectifier is connected ahead of DC voltmeter, then that entire combination together is called AC voltmeter using Half wave rectifier. The **block diagram** of AC voltmeter using Half wave rectifier is shown in below figure

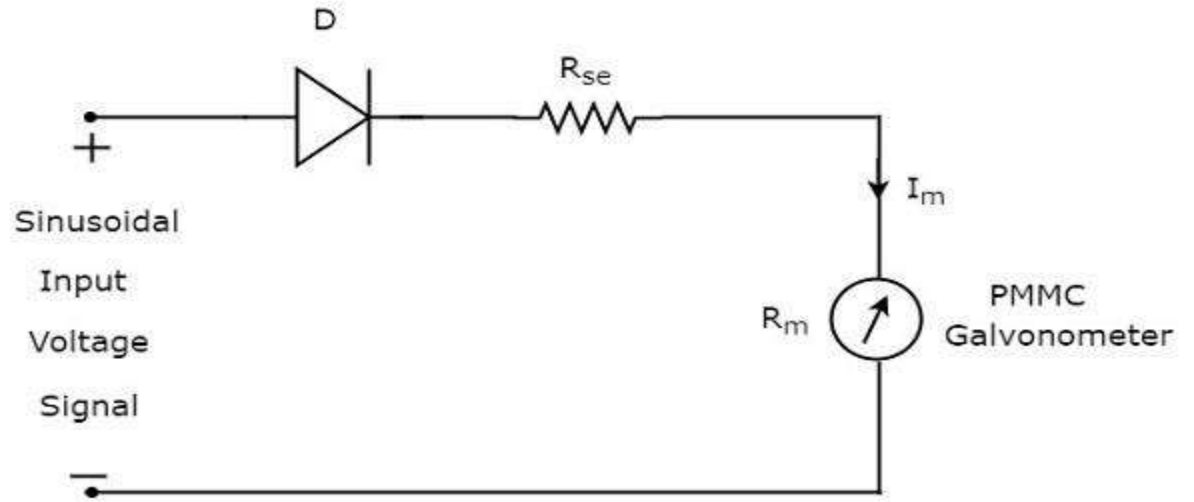


AC Voltmeters

➢The above block diagram consists of two blocks: half wave rectifier and DC voltmeter.

➢We will get the corresponding circuit diagram, just by replacing each block with the respective component(s) in above block diagram.

➢So, the **circuit diagram** of AC voltmeter using Half wave rectifier will look like as shown in below figure.



AC Voltmeters

The **rms value** of sinusoidal (AC) input voltage signal is

$$V_{rms} = V_m/\sqrt{2}$$

$$\Rightarrow V_m = \sqrt{2}\, V_{rms}$$

$$\Rightarrow V_m = 1.414 V_{rms}$$

Where,

Vm is the maximum value of sinusoidal (AC) input voltage signal.

- The **DC** or average value of the Half wave rectifier’s output signal is

$$V_{dc} = V_m/\pi$$

Substitute, the value of Vm in above equation.

$$V_{dc} = 1.414 V_{rms}/\pi$$

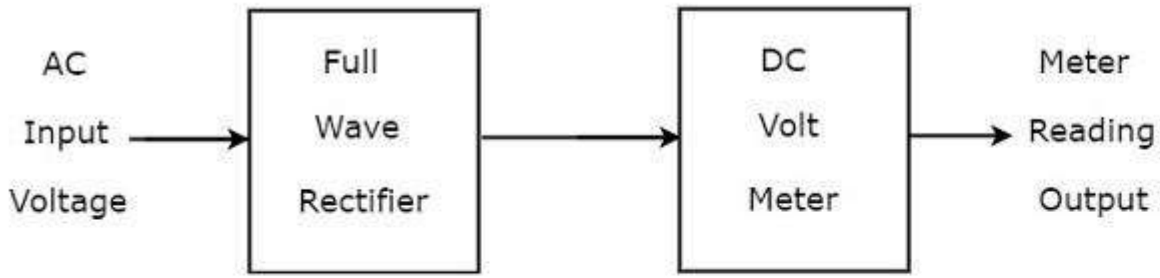
$$V_{dc} = 0.45 V_{rms}$$

Therefore, the AC voltmeter produces an output voltage, which is equal to **0.45** times the rms value of the sinusoidal (AC) input voltage signal

AC Voltmeters

AC Voltmeter using Full Wave Rectifier

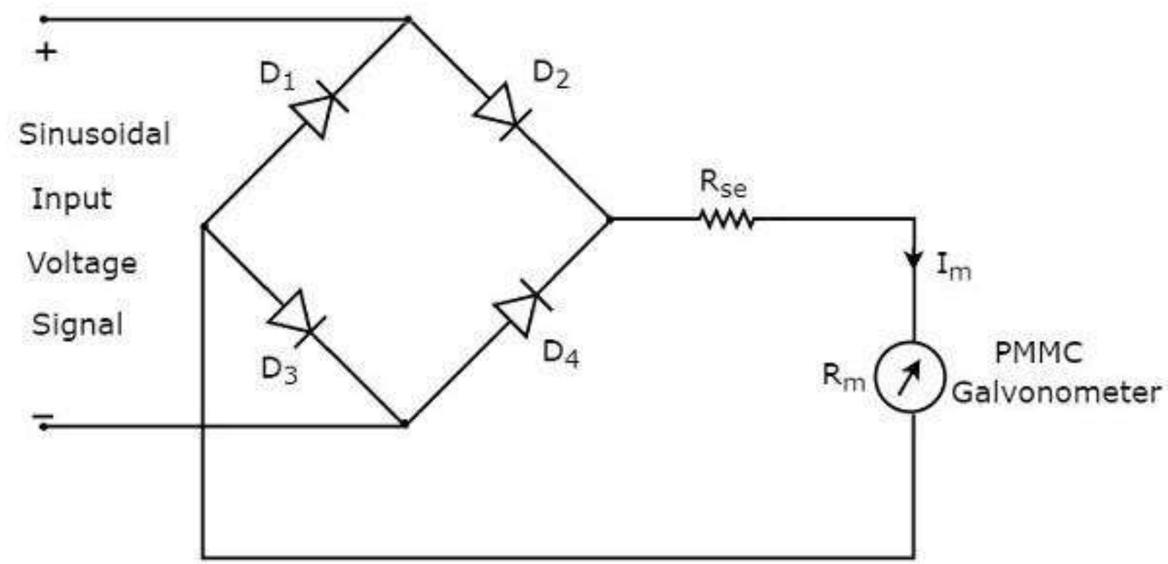
If a Full wave rectifier is connected ahead of DC voltmeter, then that entire combination together is called AC voltmeter using Full wave rectifier.



The above block diagram consists of two blocks: full wave rectifier and DC voltmeter. We will get the corresponding circuit diagram just by replacing each block with the respective component(s) in block diagram.

AC Voltmeters

➢So, the **circuit diagram** of AC voltmeter using Full wave rectifier will look like as shown in below figure.



The **rms value** of sinusoidal (AC) input voltage signal is

⇒ $V_{rms} = V_m/\sqrt{2}$

⇒ $V_m = \sqrt{2}\, V_{rms}$ ⇒ $V_m = 2V_{rms}$

⇒ $V_m = 1.414 V_{rms}$

Where, Vm is the maximum value of sinusoidal (AC) input voltage signal.

AC Voltmeters

The **DC** or average value of the Full wave rectifier's output signal is

$$V_{dc}=2V_m/\pi$$

Substitute, the value of Vm in above equation

$$V_{dc}=2\times1.414V_{rms}/\pi$$

$$V_{dc}=0.9V_{rms}$$

Therefore, the AC voltmeter produces an output voltage, which is equal to **0.9** times the rms value of the sinusoidal (AC) input voltage signal.

AC Voltmeters-Problem

Example 2.9 : *An a.c. voltmeter uses half wave rectifier and the basic meter with full scale deflection current of 1 mA and the meter resistance of 200 Ω. Calculate the multiplier resistance for a 10 V r.m.s. range on the voltmeter.*

Solution : The meter uses half wave rectifier and input is 10 V r.m.s.

$$\therefore \quad E_{av} = \frac{1}{2}(E_{av} \text{ over a cycle of input})$$

Now

$$E_p = \sqrt{2}\, E_{r.m.s.} = 14.14 \text{ V}$$

$$E_{av} = 0.6\, E_p = 8.99 \approx 9 \text{ V}$$

$$\therefore \quad E_{av}\ (\text{output}) = \frac{1}{2} \times 9 = 4.5 \text{ V}$$

$$E_{dc} = 0.45\ E_{r.m.s.}$$

$$\therefore \quad R_s = \frac{E_{dc}}{I_{dc}} - R_m = \frac{0.45\, E_{r.m.s.}}{I_{dc}} - R_m = \frac{0.45 \times 10}{1 \times 10^{-3}} - 200$$

$$= 4.3 \text{ k}\Omega$$

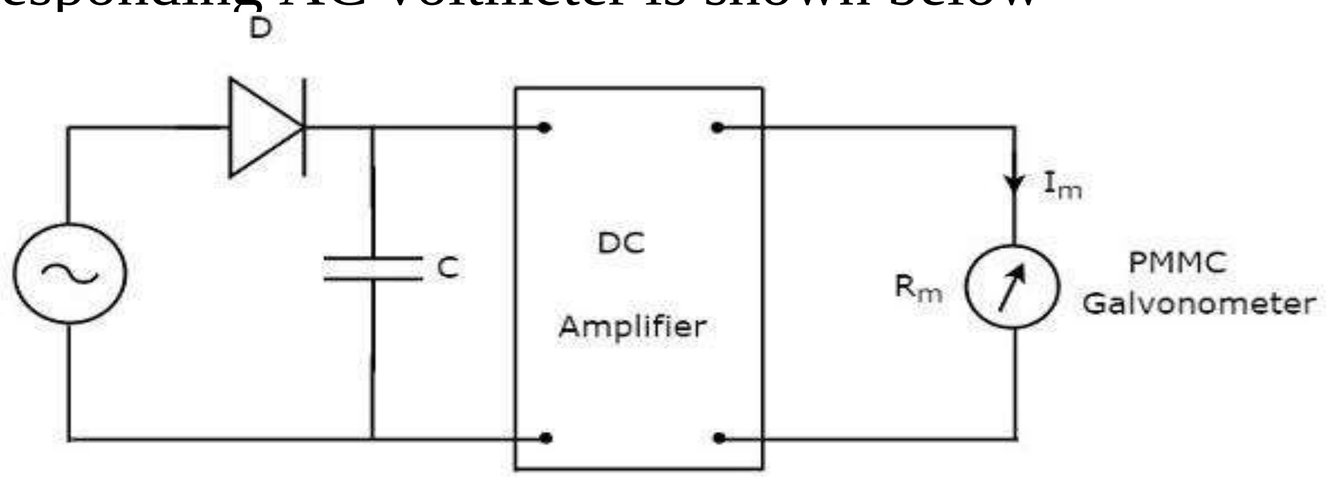
This is the required multiplier resistance.

we discussed about rectifier based AC voltmeters. This chapter covers the following two types of AC voltmeters.

- **Peak responding AC voltmeter**
- **True RMS responding AC voltmeter**

Peak Responding AC Voltmeter

As the name suggests, the peak responding AC voltmeter responds to **peak values** of AC voltage signal. That means, this voltmeter measures peak values of AC voltages. The **circuit diagram** of peak responding AC voltmeter is shown below −



AC Voltmeters

- The above circuit consists of a diode, capacitor, DC amplifier and PMMC galvanometer. The diode present in the above circuit is used for rectification purpose.

- So, the diode converts AC voltage signal into a DC voltage signal. The capacitor charges to the peak value of this DC voltage signal.

- During **positive half cycle** of AC voltage signal, the diode conducts and the capacitor charges to the peak value of AC voltage signal.

- When the value of AC voltage signal is less than this value, the diode will be reverse biased.

AC Voltmeters

- Thus, the capacitor will discharge through resistor of DC amplifier till the next positive half cycle of AC voltage signal.

- When the value of AC voltage signal is greater than the capacitor voltage, the diode conducts and the process will be repeated.

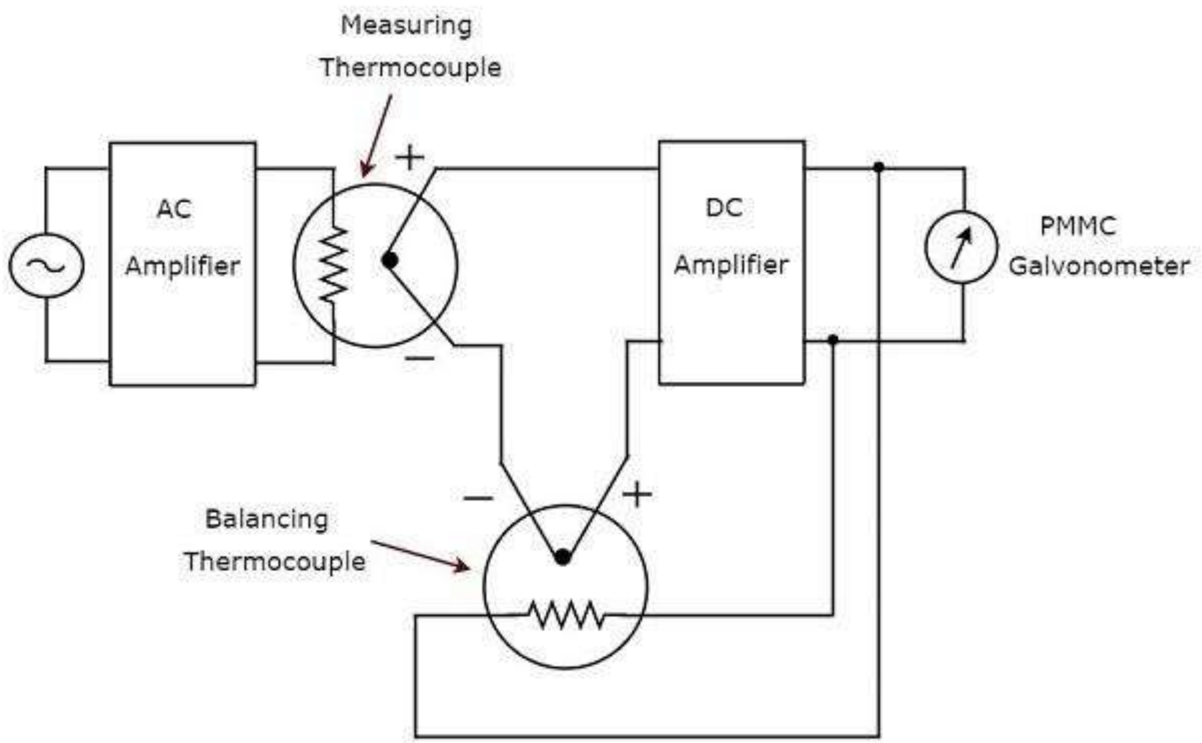
- We should select the component values in such a way that the capacitor charges fast and discharges slowly.

- As a result, the meter always responds to this capacitor voltage, i.e. the **peak value of AC voltage**.

AC Voltmeters

True RMS Responding AC Voltmeter

- As the name suggests, the true RMS responding AC voltmeter responds to the true RMS values of AC voltage signal. This voltmeter measures RMS values of AC voltages.



AC Voltmeters

Mathematically we can write,

$$V_o = A(V_1 - V_2)$$

where A = High gain of d.c. amplifier

$$\therefore \quad V_1 - V_2 = \frac{V_o}{A} \approx 0$$

... As A is very very high

In balanced condition of bridge and as A is very high,

$$V_1 = V_2$$

Now V_1 = Output of measuring thermocouple

and V_2 = Output of balancing thermocouple

$$\therefore \quad V_1 = KE^2_{r.m.s.}$$

where $E_{r.m.s.}$ = R.M.S. value of the input

and

$$V_2 = KV_o^2$$

where V_o = Output d.c. voltage

As K is same due to same thermal environment used for the two thermocouples,

$$E^2_{r.m.s.} = V_o^2$$

$$\therefore \quad V_o = E_{r.m.s.}$$

Key Point: *The voltage measured by the meter is r.m.s value of the a.c. input.*

AC Ammeter

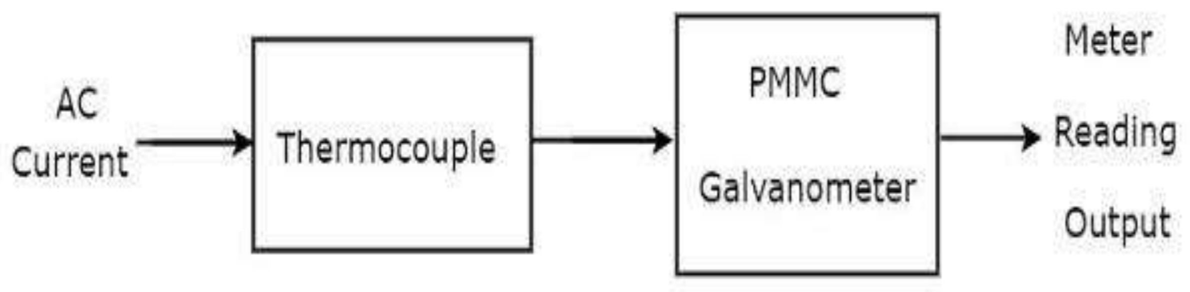
Current is the rate of flow of electric charge. If the direction of this electric charge changes regularly, then the resultant current is called **Alternating Current (AC)**.

The instrument, which is used to measure the Alternating Current that flows through any branch of electric circuit is called **AC ammeter**.

Example − Thermocouple type AC ammeter.

Thermocouple Type AC Ammeter

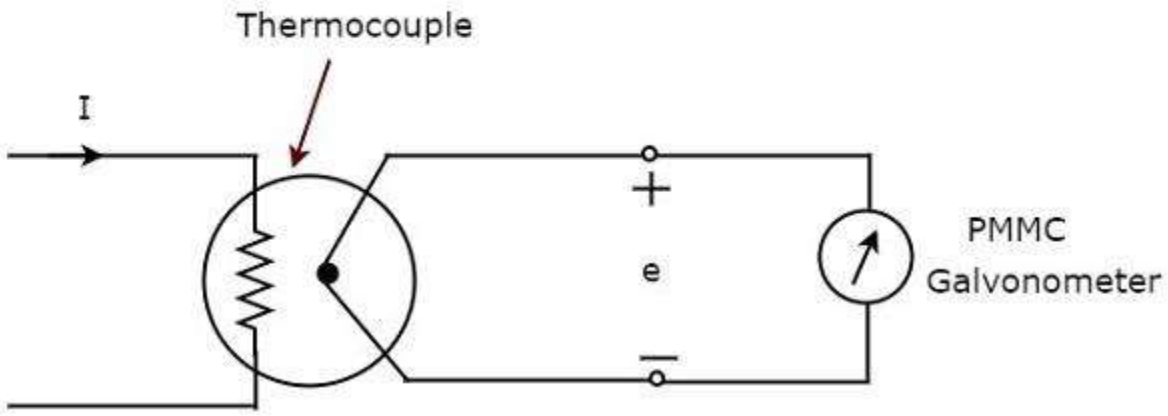
If a Thermocouple is connected ahead of PMMC galvanometer, then that entire combination is called thermocouple type AC ammeter.



AC Ammeter

The above block diagram consists of mainly two blocks: a thermocouple, and a PMMC galvanometer. We will get the corresponding circuit diagram, just by replacing each block with the respective component(s) in above block diagram.

So, the **circuit diagram** of thermocouple type AC ammeter will look like as shown in below figure.



AC Ammeter

- Thermocouple generates an EMF, e, whenever the Alternating Current, I flows through heater element.

- This EMF, e is directly proportional to the rms value of the current, I that is flowing through heater element. So, we have to calibrate the scale of PMMC instrument to read **rms values of current**.

- So, with this chapter we have completed all basic measuring instruments such as DC voltmeters, AC voltmeters, DC ammeters and AC ammeters.

Ohmmeters and MultiMeters

Ohmmeters

The instrument, which is used to measure the value of resistance between any two points in an electric circuit is called **ohmmeter**.

It can also be used to find the value of an unknown resistor. The units of resistance are ohm and the measuring instrument is meter. So, the word "ohmmeter" is obtained by combining the words **"ohm"** and **"meter"**.

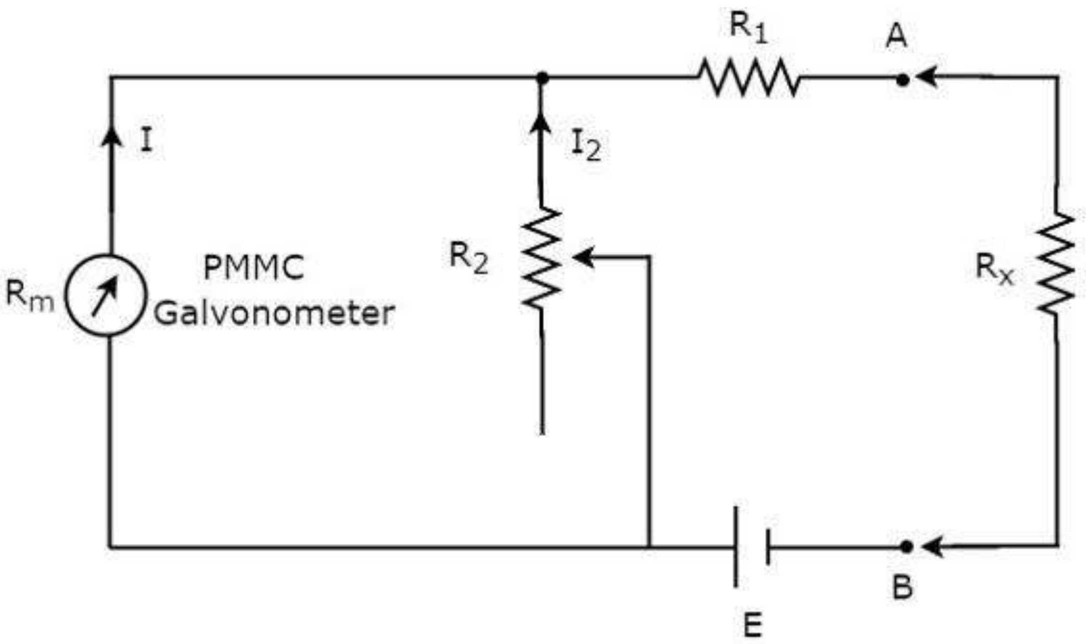
Types of Ohmmeters

Following are the **two types** of ohmmeters.

- Series Ohmmeter
- Shunt Ohmmeter

Series Ohmmeter

- If the resistor's value is unknown and has to be measured by placing it in series with the ohmmeter, then that ohmmeter is called series ohmmeter. The **circuit diagram** of series ohmmeter is shown in below figure.



Ohmmeters

Series Ohmmeter

- The part of the circuit, which is left side of the terminals A & B is **series ohmmeter**. So, we can measure the value of unknown resistance by placing it to the right side of terminals A & B. Now, let us discuss about the **calibration scale** of series ohmmeter.

- If $R_x=0\Omega$, then the terminals A & B will be short circuited with each other. So, the meter current gets divided between the resistors, R1 and R2. Now, vary the value of resistor, R2 in such a way that the entire meter current flows through the resistor, R1 only.

- In this case, the meter shows full **scale deflection current**. Hence, this full scale deflection current of the meter can be represented as 0Ω.

Series Ohmmeter

- If Rx=∞Ω, then the terminals A & B will be open circuited with each other. So, no current flows through resistor, R1. In this case, the meter shows null deflection current. Hence, this null deflection of the meter can be represented as ∞Ω.

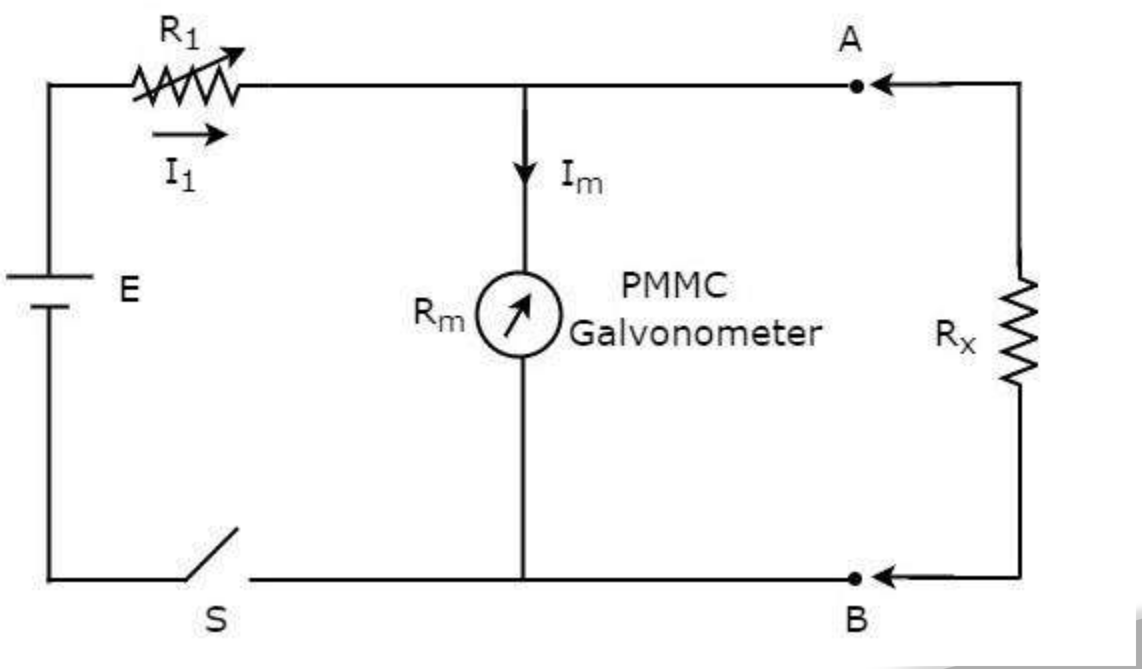
- In this way, by considering different values of Rx, the meter shows different deflections. So, accordingly we can represent those deflections with the corresponding resistance value.

- The series ohmmeter consists of a calibration scale. It has the indications of 0 Ω and ∞Ω at the end points of right hand and left hand of the scale respectively.

- Series ohmmeter is useful for measuring **high values of resistances.**

Shunt Ohmmeter

- If the resistor's value is unknown and to be measured by placing it in parallel (shunt) with the ohmmeter, then that ohmmeter is called shunt ohmmeter. The **circuit diagram** of shunt ohmmeter is shown in below figure.



Ohmmeters

Shunt Ohmmeter

- The part of the circuit, which is left side of the terminals A & B is **shunt ohmmeter**. So, we can measure the value of unknown resistance by placing it to the right side of terminals A & B.

- Now, let us discuss about the **calibration scale** of shunt ohmmeter. Close the switch, S of above circuit while it is in use.

- If Rx=0Ω, then the terminals A & B will be short circuited with each other. Due to this, the entire current, I1I1 flows through the terminals A & B.

- In this case, no current flows through PMMC galvanometer. Hence, the **null deflection** of the PMMC galvanometer can be represented as 0Ω.

Shunt Ohmmeter

- If Rx=∞Ω, then the terminals A & B will be open circuited with each other. So, no current flows through the terminals A & B. In this case, the entire current, I1 flows through PMMC galvanometer.
- If required vary (adjust) the value of resistor, R1 until the PMMC galvanometer shows full scale deflection current. Hence, this **full scale deflection** current of the PMMC galvanometer can be represented as ∞Ω
- In this way, by considering different values of Rx, the meter shows different deflections.
- So, accordingly we can represent those deflections with the corresponding resistance values.

Ohmmeters

Shunt Ohmmeter

- The shunt ohmmeter consists of a calibration scale. It has the indications of 0Ω and ∞Ω at the end points of left hand and right hand of the scale respectively.

- Shunt ohmmeter is useful for measuring **low values of resistances**. So, we can use either series ohmmeter or shunt ohmmeter based on the values of resistances that are to be measured i.e., high or low.

Shunt Ohmmeter

- The shunt ohmmeter consists of a calibration scale. It has the indications of 0Ω and ∞Ω at the end points of left hand and right hand of the scale respectively.

- Shunt ohmmeter is useful for measuring **low values of resistances**. So, we can use either series ohmmeter or shunt ohmmeter based on the values of resistances that are to be measured i.e., high or low.

Problem

A 100 Ω basic movement is to be used as an ohmmeter requiring full scale deflection of 1 mA and internal battery voltage of 3 V. A half scale deflection marking of 1 kΩ is required. Calculate

(i) the value of R_1 and R_2 (ii) Maximum value of R_2 to compensate for a 3% drop in battery voltage

Solution Given $I_m = 1$ mA, $R_m = 100\ \Omega$, $R_h = 1\ k\Omega$, $V = 3V$

(i) To find R_1 and R_2

Step 1:

$$R_1 = R_h - \frac{I_{fsd} \times R_m \times R_h}{V} = 1\ k\Omega - \frac{1\ mA \times 100 \times 1\ k\Omega}{3}$$

$$= 1\ k\Omega - \frac{100}{3} = 1000\ \Omega - 33.3\ \Omega$$

$$= 966.7\ \Omega$$

Step 2:

$$R_2 = \frac{I_{fsd} \times R_m \times R_h}{V - I_{fsd} \times R_h} = -\frac{1\ mA \times 100 \times 1\ k\Omega}{3 - 1\ mA \times 1\ k\Omega} = \frac{100}{3-1} = \frac{100}{2} = 50\ \Omega$$

Ohmmeters

Step 3:

(ii) The internal battery voltage is 3 V. 3% of 3 V is .09 V.

Therefore, the battery voltage drop with 3% drop is 3 V – .09 V = 2.91V

$$R_2 = \frac{I_{fsd} \times R_m \times R_h}{V - I_{fsd} \times R_h} = -\frac{1\,\text{mA} \times 100 \times 1\,\text{k}\Omega}{2.91 - 1\,\text{mA} \times 1\,\text{k}\Omega} = \frac{100}{2.91 - 1} = \frac{100}{1.91} = 52.36\,\Omega$$

$$R_2 = 52.36\,\Omega$$

MultiMeters

- we discussed about voltmeters, ammeters and ohmmeters. These measuring instruments are used to measure voltage, current and resistance respectively. That means, we have separate measuring instruments for measuring voltage, current and resistance.

- Suppose, if a single measuring instrument can be used to measure the quantities such as voltage, current & resistance one at a time, then it is said to be multimeter.

- It has got the name multimeter, since it can measure multiple electrical quantities one at a time.

MultiMeters

Digital Multimeter (DMM)

Portable Analog Multimeter

Hand-held DMM

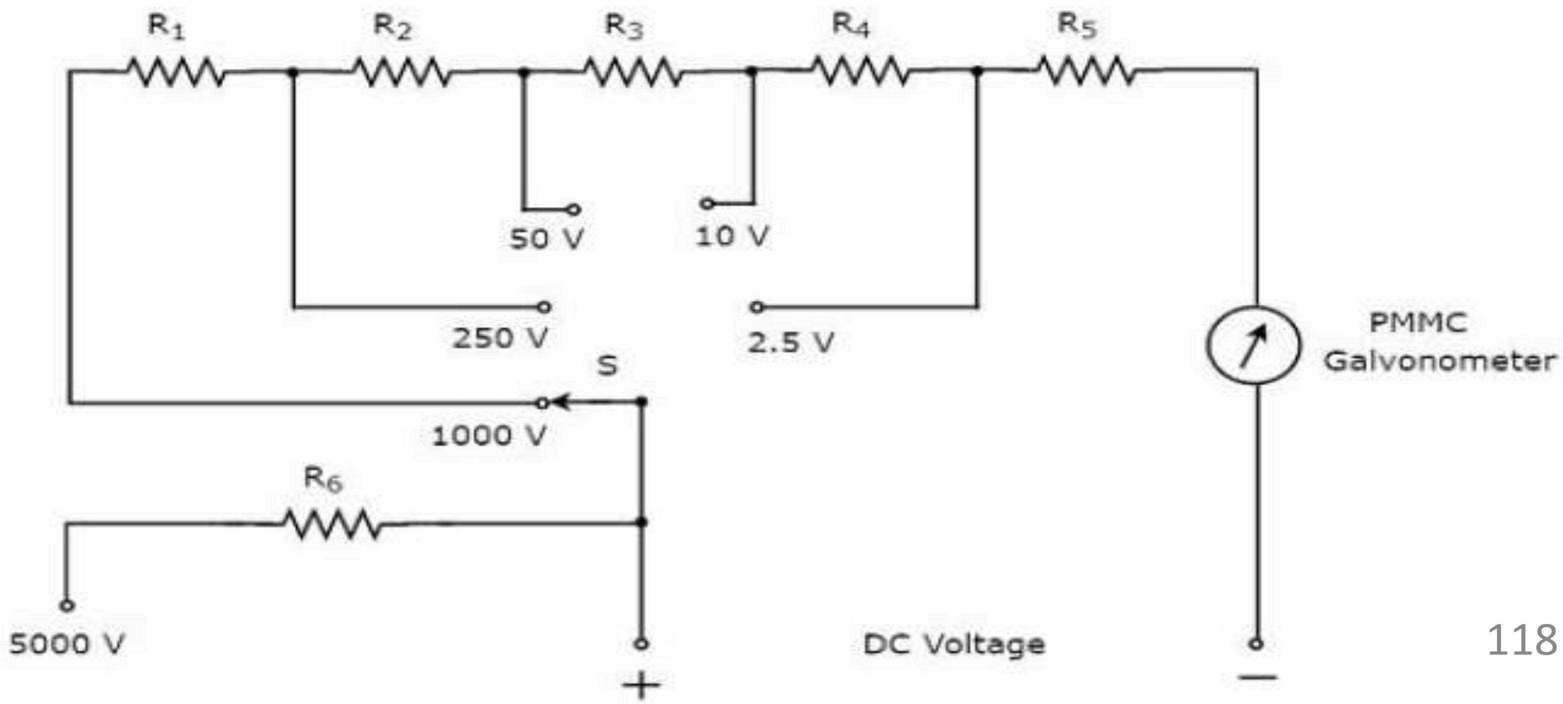
Bench-top DMM

Measurements by using Multimeter

➢ Multimeter is an instrument used to measure DC & AC voltages, DC & AC currents and resistances of several ranges. It is also called Electronic Multimeter or Voltage Ohm Meter (VOM).

DC voltage Measurement

➢ The part of the circuit diagram of Multimeter, which can be used to measure DC voltage is shown in below figure.



Measurements by using Multimeter

- The above circuit looks like a multi range DC voltmeter. The combination of a resistor in series with PMMC galvanometer is a **DC voltmeter**. So, it can be used to measure DC voltages up to certain value.

- We can increase the range of DC voltages that can be measured with the same DC voltmeter by increasing the resistance value.

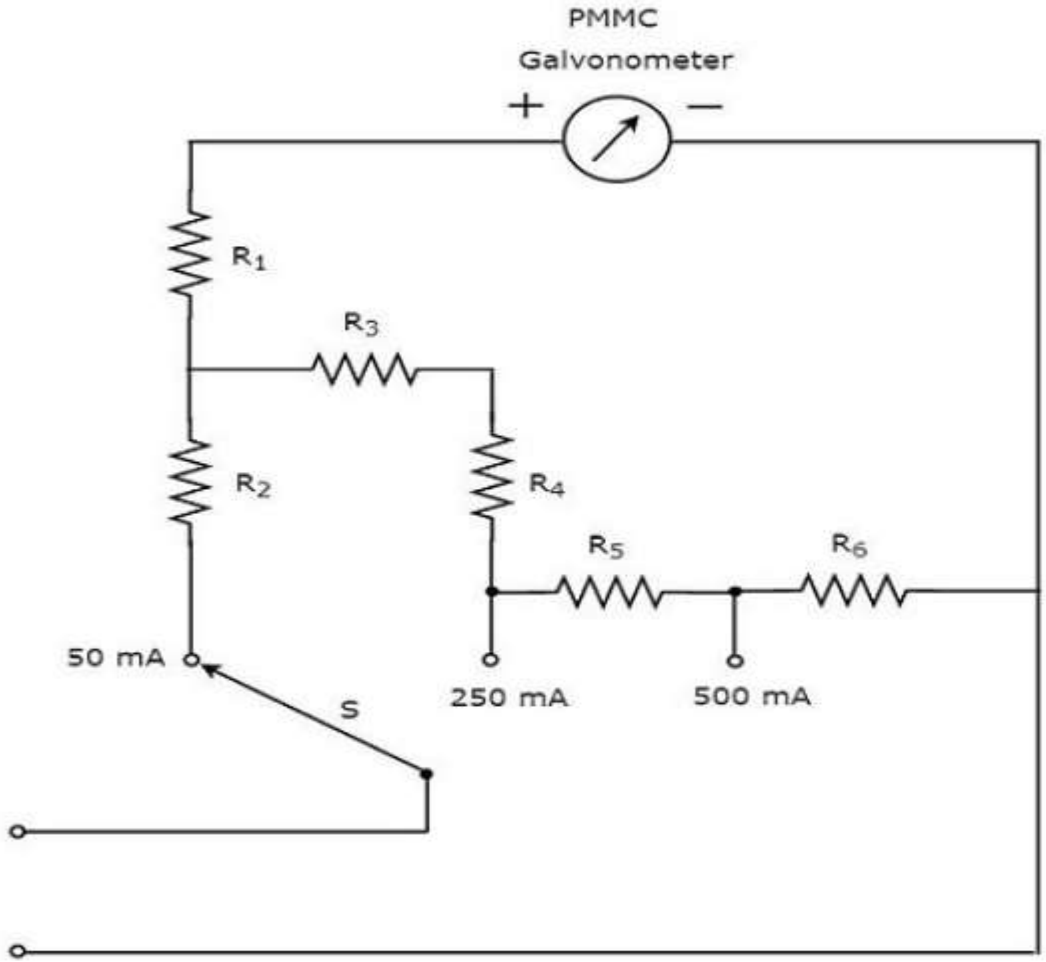
- the equivalent resistance value increases, when we connect the resistors are in **series**.

- In above circuit, we can measure the DC voltages up to **2.5V** by using the combination of resistor, R5 in series with PMMC galvanometer.

- By connecting a resistor, R4 in series with the previous circuit, we can measure the DC voltages up to **10V**.

DC Current Measurement

The part of the **circuit diagram** of Multimeter, which can be used to measure DC current is shown in below figure.



DC Current Measurement

- The above circuit looks like a multi range DC ammeter. the combination of a resistor in parallel with PMMC galvanometer is a DC ammeter. So, it can be used to measure DC currents up to certain value.

- We can get different ranges of DC currents measured with the same DC ammeter by placing the resistors in parallel with previous resistor.

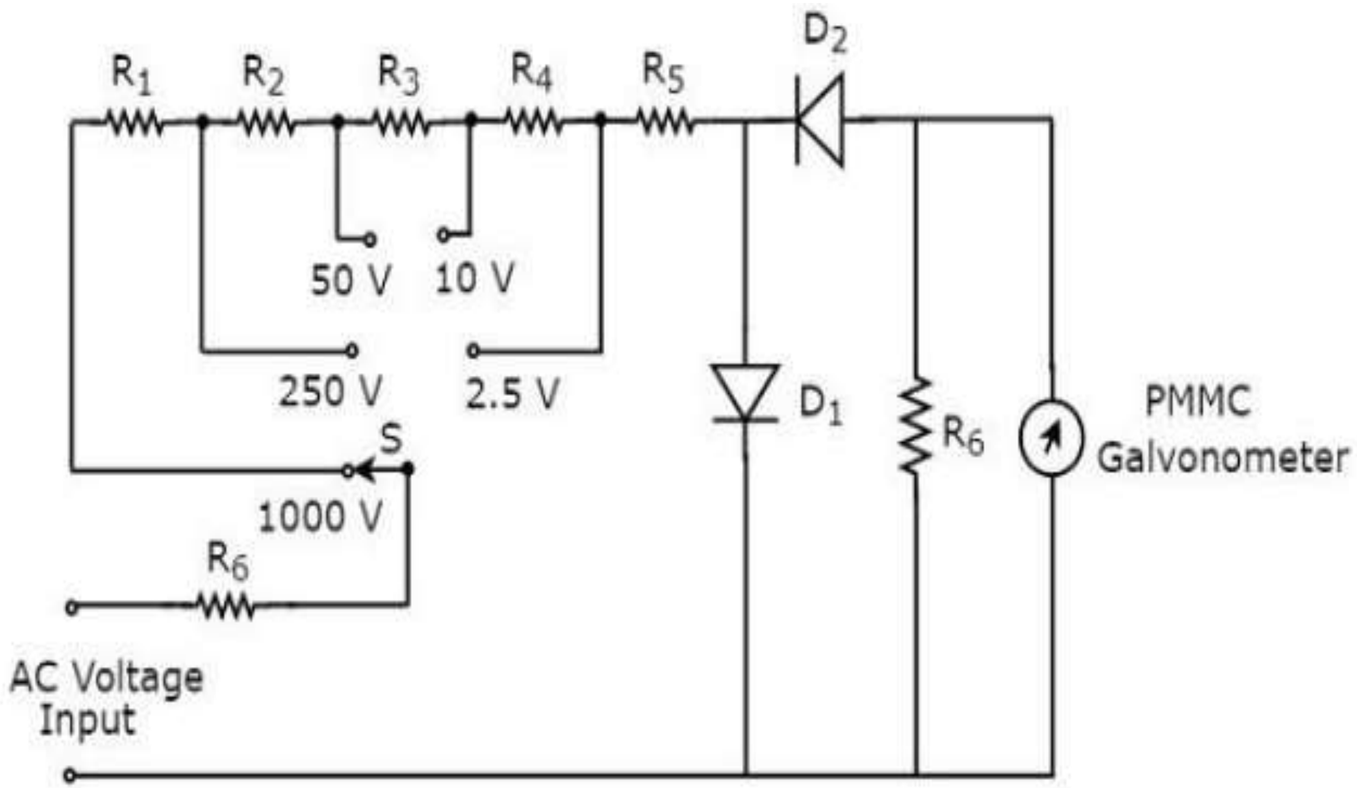
DC Current Measurement

- In above circuit, the resistor, R1 is connected in series with the PMMC galvanometer in order to prevent the meter gets damaged due to large current.

- We can measure the DC current that is flowing through any two points of an electric circuit, by connecting the switch, S to the desired current range

AC voltage Measurement

The part of the circuit diagram of Multimeter, which can be used to measure AC voltage is shown in below figure.



AC voltage Measurement

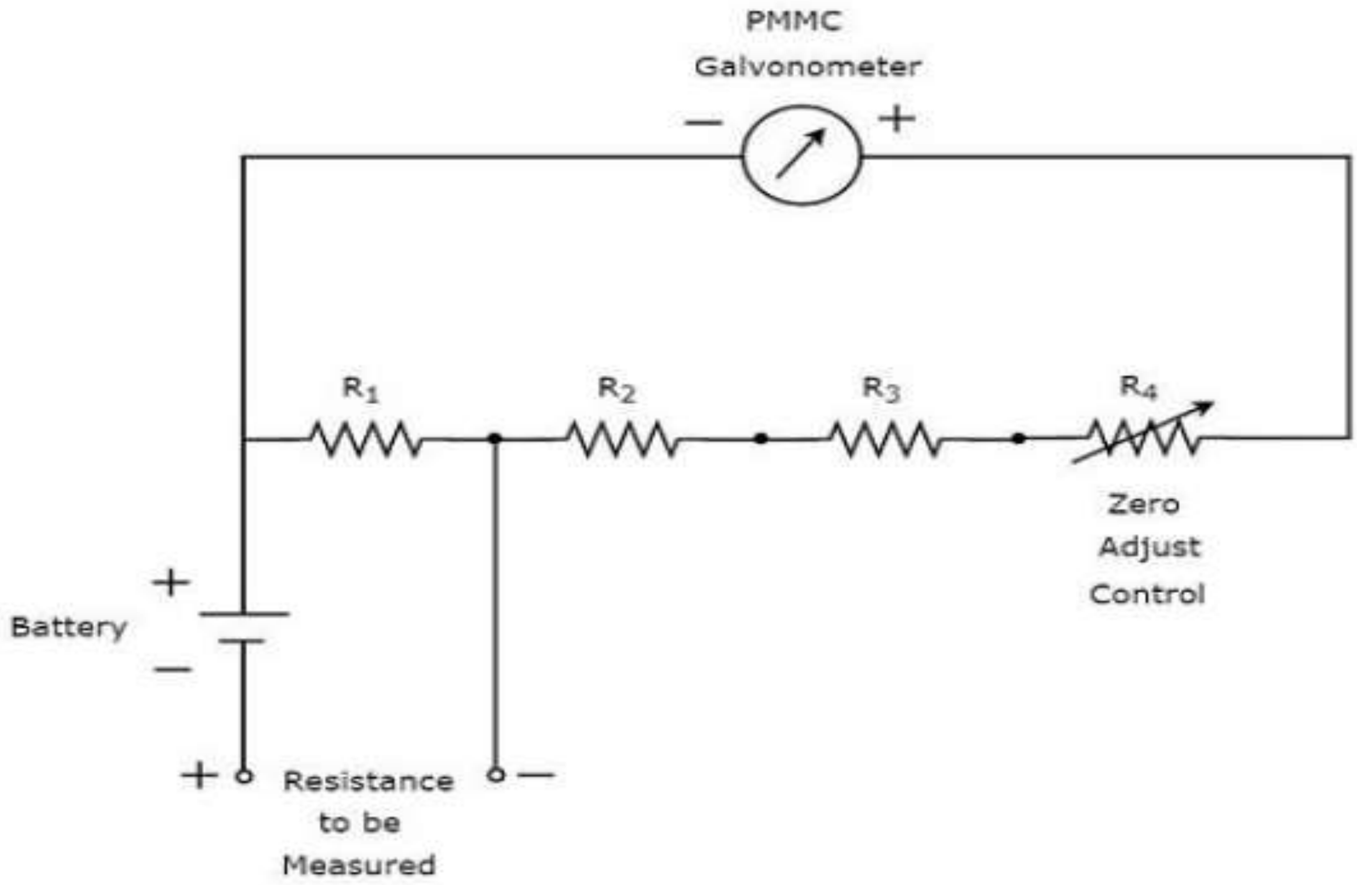
The above circuit looks like a multi range AC voltmeter. We know that, we will get AC voltmeter just by placing rectifier in series (cascade) with DC voltmeter.

The above circuit was created just by placing the diodes combination and resistor, R6 in between resistor, R5 and PMMC galvanometer.

We can measure the AC voltage across any two points of an electric circuit, by connecting the switch, S to the desired voltage range.

Resistance Measurement

The part of the circuit diagram of Multimeter, which can be used to measure resistance is shown in below figure.



Resistance Measurement

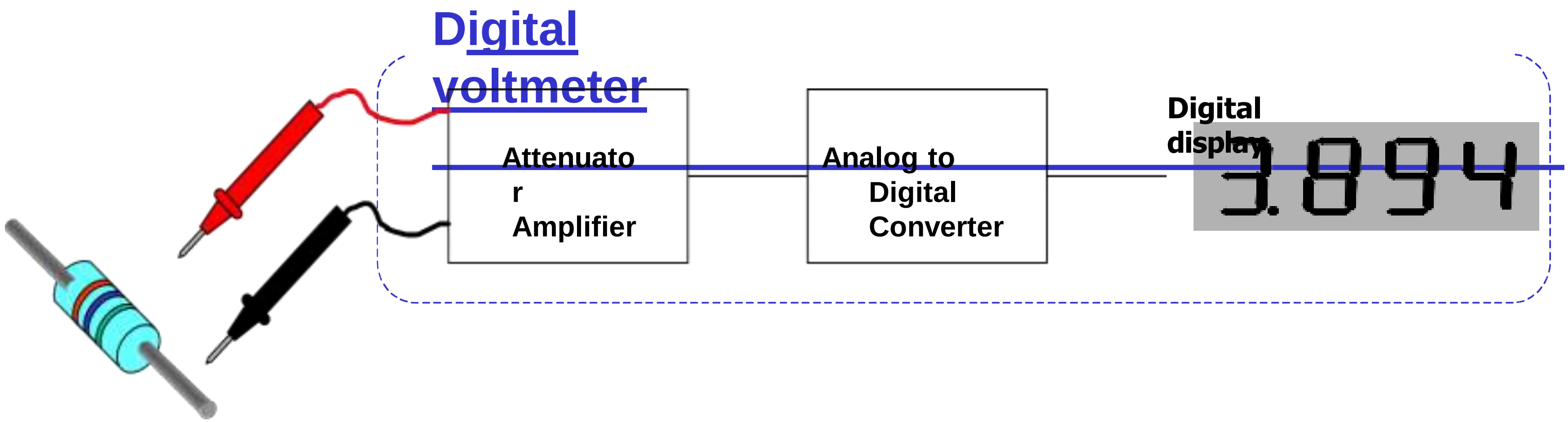
- We have to do the following two tasks before taking any measurement.
  - Short circuit the instrument
  - Vary the zero adjust control until the meter shows full scale current. That means, meter indicates zero resistance value.

- Now, the above circuit behaves as shunt ohmmeter and has the scale multiplication of 1, i.e. 10^0.

- We can also consider higher order powers of 10 as the scale multiplications for measuring high resistances

Digital Voltmeter (DVM)

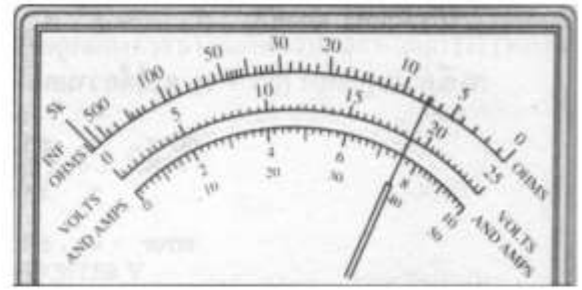
DVM is essentially an Analog to digital converter (A/D) with a digital display



Digital MultiMeter (DMM)

= electronic Volt Ohm Millimeter with digital display

Comparison of Digital and Analog



Digital meter	Analog meter
Leaves no doubt about the measured quantity.	Wrong scale might be used or might be read incorrectly.
Superior resolution and accuracy. (±0.5% or better)	Inferior resolution and accuracy. (±3% in common)
Indicates a negative quantity when the terminal polarity is reversed	Pointer attempts to deflect to the left when the polarity is reversed
No usually damaged by rough treatment	Can be damaged when dropped from bench level

Digital Voltmeters

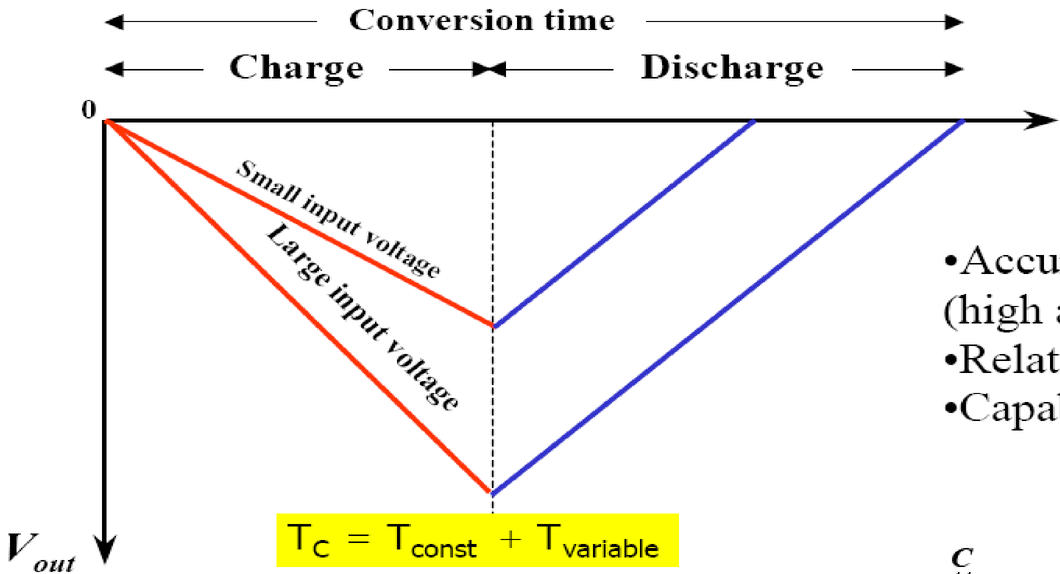
Digital voltmeters can be classified according to the following broad categories:

(a) Ramp-type DVM
(b) Integrating DVM
(c) Continuous-balance DVM
(d) Successive-approximation DVM

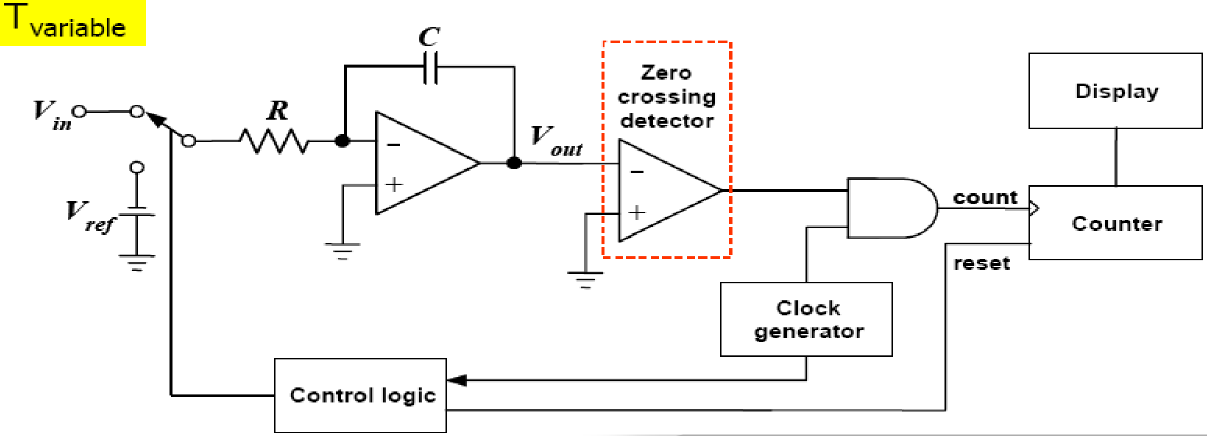
Dual-slope DVM

- The dual-slope type of A to D conversion is a very popular method for digital voltmeter applications. When compared to other types of analog-to-digital conversion techniques, the dual-slope method is slow but is quite adequate for a digital voltmeter used for laboratory measurements.
- For data acquisition applications, where a number of measurements are required, faster techniques are recommended.
- When a dual-slope AID converter is used for a DVM the counters may be decade rather than binary and the segment and digit drivers may be contained in the chip.

Dual-slope Digital Voltmeter



- Accuracy does not depend on ***R C*** and Clock (high accuracy)
- Relatively slow
- Capable to reject noise

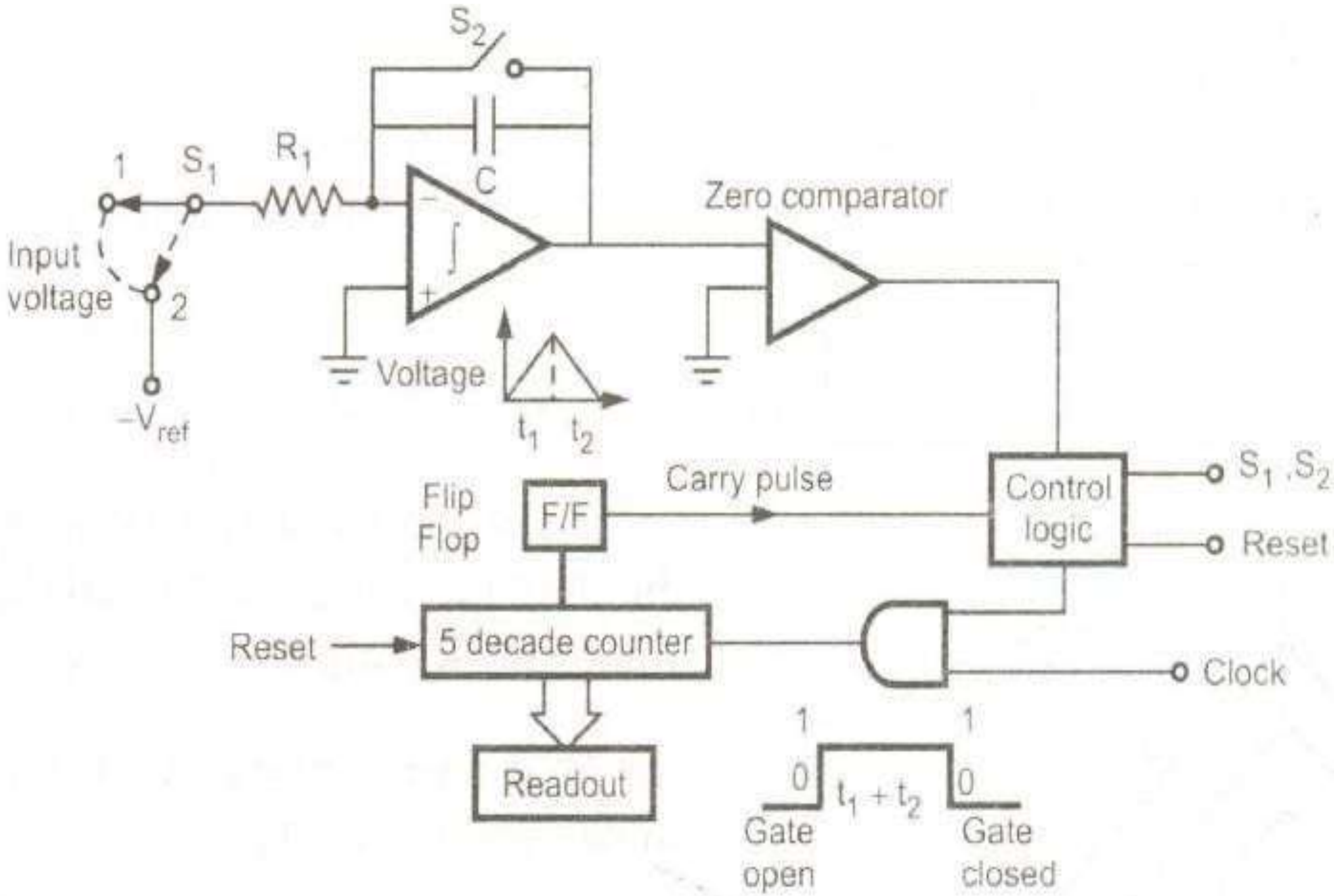


Dual slope type Digital Voltmeter

- This is the most popular method of analog to digital conversion. In the ramp techniques, the noise can cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration.
- The basic principle of this method is that the input signal is integrated for a fixed interval of time.
- And then the same integrator is used to integrate the reference voltage with reverse slope.
- Hence the name given to the technique is **dual slope integration technique.**

Dual slope type Digital Voltmeter

The block diagram of dual slope integrating type DVM is shown in the Fig. It consists of five blocks, an op-amp used as an integrator, a zero comparator, clock pulse generator, a set of decimal counters and a block of control logic.



When the switch Sl is in position 1, the capacitor C starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp is given by,

$$V_{out} = -\frac{1}{R_1 C}\int_0^{t_1} V_{in}\, dt$$

$$\therefore \quad \boxed{V_{out} = -\frac{V_{in}\, t_1}{R_1\, C}}$$

where t_1 = Time for which capacitor is charged

V_{in} = Input voltage

R_1 = Series resistance

C = Capacitor in feedback path

After the interval t I, the input voltage is disconnected and a negative voltage -Vref is connected by throwing the switch S1 in position 2. In this position, the output of the op-amp is given by,

$$V_{out} = \frac{1}{R_1 C} \int_0^{t_2} -V_{ref}\, dt$$

$$\boxed{V_{out} = -\frac{V_{ref}\, t_2}{R_1\, C}}$$

Subtracting (1) from (2),

$$V_{out} - V_{out} = 0 = \frac{-V_{ref}\, t_2}{R_1\, C} - \left(\frac{-V_{in}\, t_1}{R_1\, C}\right)$$

$$\therefore \quad \frac{V_{ref}\, t_2}{R_1\, C} = \frac{V_{in}\, t_1}{R_1\, C}$$

$$\therefore \quad V_{ref}\, t_2 = V_{in}\, t_1$$

$$\therefore \quad \boxed{V_{in} = V_{ref} \cdot \frac{t_2}{t_1}}$$

The advantages of this technique are:

- Excellent noise rejection as noise and superimposed a.c. are averaged out during the process of integration.
- The RC time constant does not affect the input voltage measurement.
- The capacitor is connected via an electronic switch. This capacitor is an auto zero capacitor and avoids the effects of offset voltage.
- The integrator responds to the average value of the input hence sample and hold circuit is not necessary.
- The accuracy is high and can be readily varied according to the specific requirements.

The only disadvantage of this type of DVM is its slow speed.

Ramp-Type DVM

Ramp-Type DVM

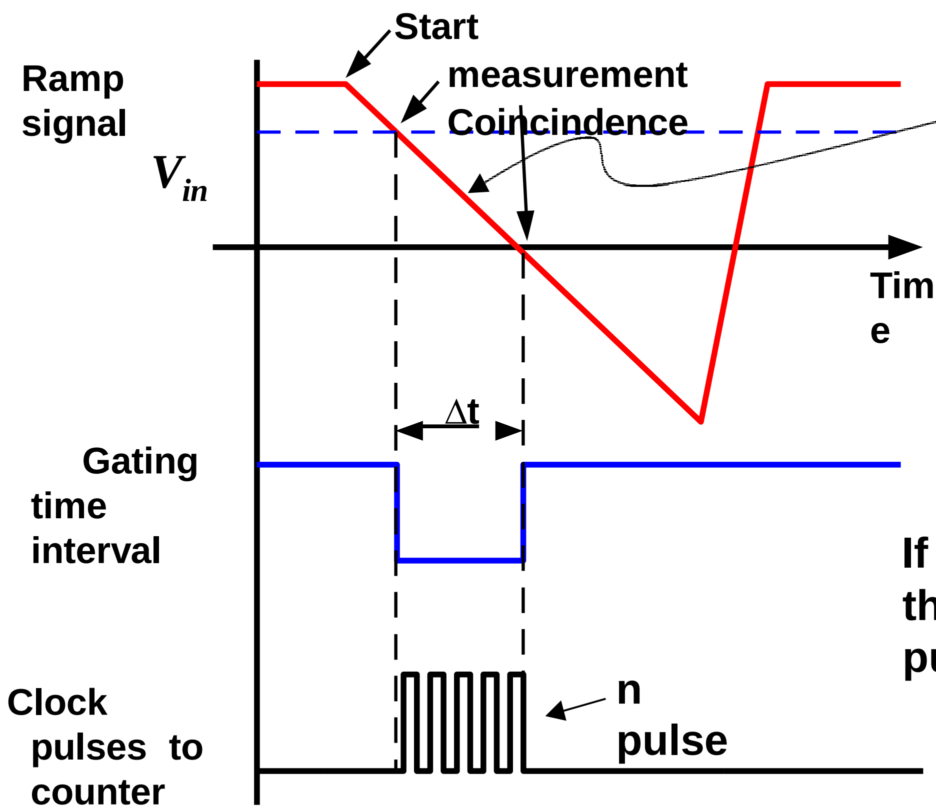
- The operating principle of the ramp-type DVM is based on the measurement of the time it takes for a linear ramp voltage to rise from 0 V to the level of the input voltage, or to decrease from the level of the input voltage to zero.

- This time interval is measured with an electronic time-interval counter, and the count is displayed as a number of digits on electronic indicating tubes. Conversion from a voltage to a time interval is illustrated by the waveform diagram of Figure below.

Ramp-type Digital Voltmeter

(also called single slope)

Operation principle: **The measurement of the time it takes for a linear ramp voltage to rise from O V to the level of the input voltage, or to decrease from the level of the input voltage to zero. This time interval is measured with an electronic time-interval counter.**



$V_{ramp}(t) = V_o - m\,t$

Where m is the ramp rate

$V_{ramp}(t_1) = V_{in} = V_o - m\,t_1$

$V_{ramp}(t_2) = 0 = V_o - m\,t_2$

$\Delta t = t_2 - t_1 = V_{in}/m$

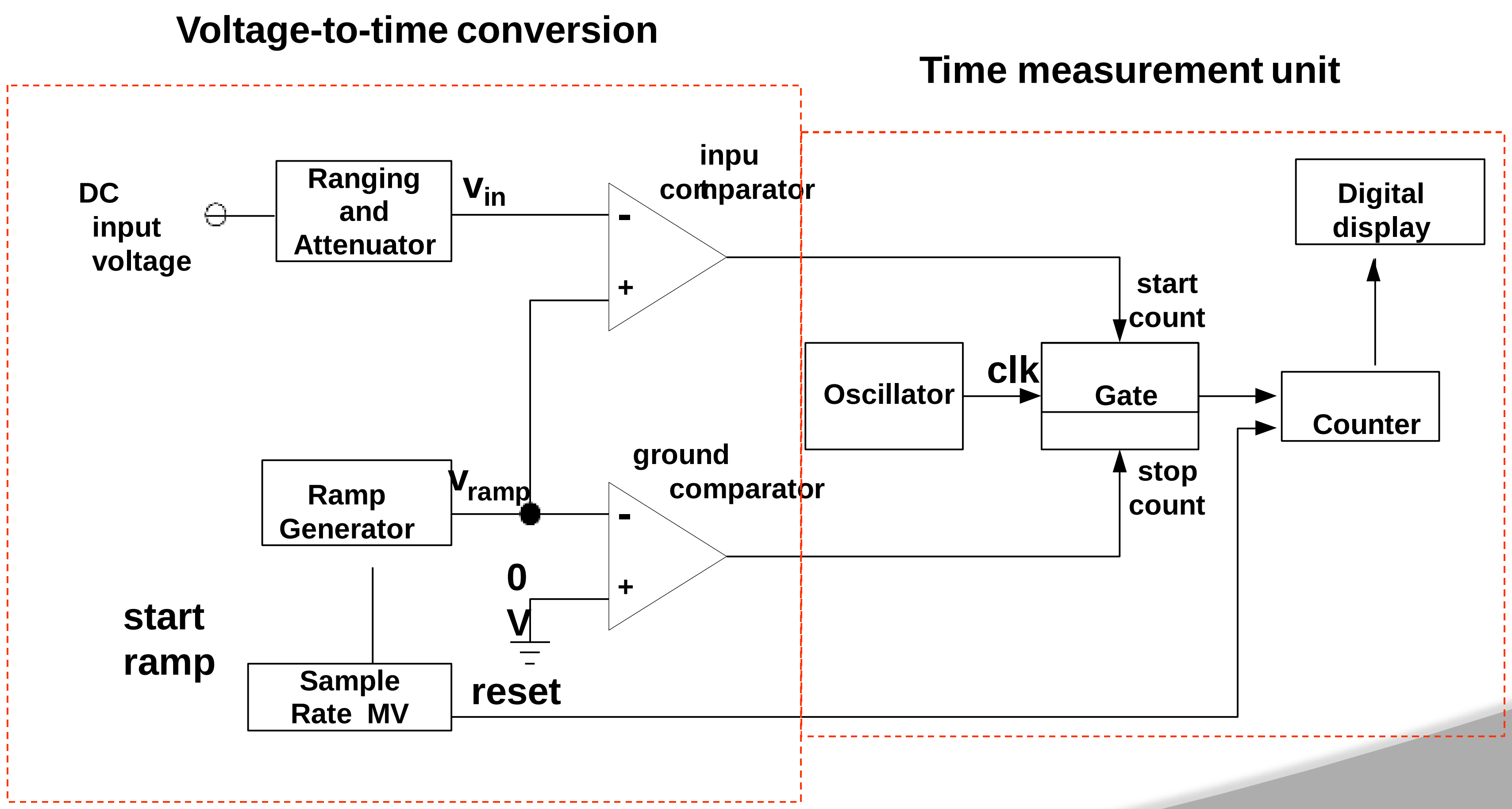
If the period of the clock is T, then during the time interval Δt_1, the number of pulses is

$\Delta t \approx nT$ or $V_{in} \approx nmT$

- Accuracy depends on both the ramp rate and clock period.

Voltage-to-time conversion using gated clock

Ramp-type Digital Voltmeter



Block diagram of a ramp-type digital voltmeter.

Ramp-type Digital Voltmeter

- The block diagram shown above is **ramp type digital voltmeter(DVM)**. You can see there is a ramp generator. This is generating a waveform which is representing a ramp.

- The heart of the circuit is the ramp generator. Therefore it is called **ramp type digital voltmeter(DVM)**.

- The input which should be measured is given at input voltage. This input is fed to ranging and attenuator circuit which will amplify the signal if it is small or attenuates the signal if it is large.

Ramp-type Digital Voltmeter

- This is given to an input comparator which will compare two signals and generates the output. One input to the input comparator is from the input voltage and another input is from the ramp.

- This input voltage and ramp signal are compared and output is given. If the ramp signal is more than input voltage there will be no output but if the input voltage is greater than the ramp signal then a is generated which will open the gate.

- Now when the gate gets opened, clock oscillator will send clock pulses which are counted by the counter and displayed on the screen.

Ramp-type Digital Voltmeter

- The ground comparator will compare the ramp signal and ground and output is given. This output will stop the flow of purchase from clock oscillator by closing the gate. The sample rate multivibrator is used to reset the ramp generator.

- The operating **principle of ramp type digital voltmeter** is to measure the time that a linear ramp voltage takes to change from the level of the input voltage to zero voltage (or vice versa).

- This time interval is measured with an electronic time interval counter and the count is displayed as a number of digits on electronic indicating tubes of the output readout of the voltmeter.

Ramp-type Digital Voltmeter

- The conversion of a voltage value of a time interval is shown in the below timing diagram.

- At the start of measurement, a ramp voltage is initiated. A negative going ramp is shown in the below figure but a positive going ramp may also be used. The ramp voltage value is continuously compared with the voltage being measured (unknown voltage). At the instant, the value of ramp voltage is equal to that of unknown voltage a coincidence circuit, called an input comparator, generates a pulse which opens a gate (see above block diagram).

Ramp-type Digital Voltmeter

- At the start of the measurement cycle, a ramp voltage is initiated; this voltage can be positive-going or negative-going.
- The negative-going ramp, shown in Fig. , is continuously compared with the unknown input voltage. At the instant that the ramp voltage equals the unknown voltage, a coincidence circuit, or comparator, generates a pulse which opens a gate.
- This gate is shown in the block diagram of below figure. The ramp voltage continues to decrease with time until it finally reaches 0 V (or ground potential) and a second comparator generates an output pulse which closes the gate.

Ramp-type Digital Voltmeter

- The ramp voltage continues to decrease till it reaches ground level (zero voltage). At this instant, another comparator called ground comparator generates a pulse and closes the gate.

- The time elapsed between the opening and closing of the gate is **t** as indicated in the below timing diagram of **ramp type digital voltmeter**.

- During this time interval pulses from a clock pulse generator pass through the gate and are counted and displayed.

Staircase Ramp-type Digital Voltmeter

Principles of ADC (Analog to Digital Conversion):

- The input signal is compared with an internally generated voltage which is increased in steps starting from zero. The number of steps needed to reach the full compensation is counted. A simple compensation type is the staircase ramp.

Staircase Ramp Digital Voltmeter

- The basic principle is that the input signal V is compared with an internal staircase voltage, V generated by a series circuit consisting of a pulse generator (clock), a counter counting the pulses and a digital to analog converter, converting the counter output into a dc signal.

- As soon as V is equal to V , the input comparator closes a gate between the clock and the counter, the counter stops and its output is shown on the display.

- The basic block diagram is shown in Fig.

Staircase Ramp Digital Voltmeter

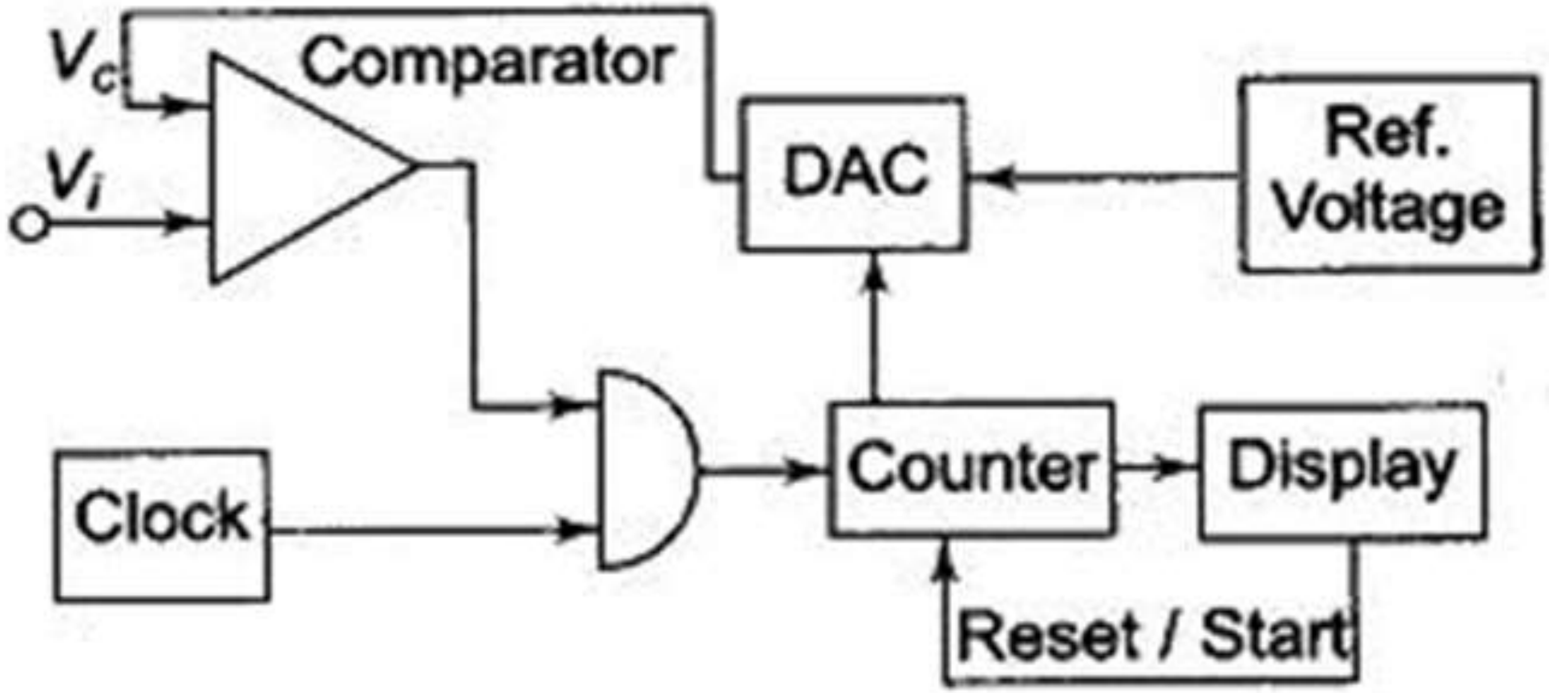


Fig. Block Diagram of a Staircase Ramp Type

Staircase Ramp Digital Voltmeter

Operation of the Circuit

- The clock generates pulses continuously. At the start of a measurement, the counter is reset to 0 at time t1 so that the output of the digital to analog converter (DAC) is also 0.

- If V is not equal to zero, the input comparator applies an output voltage that opens the gate so that clock pulses are passed on to the counter through the gate. The counter starts counting and the DAC starts to produce an output voltage increasing by one small step at each count of the counter.

- The result is a staircase voltage applied to the second input of the comparator, as shown in Fig.

Staircase Ramp Digital Voltmeter

Operation of the Circuit

- This process continues until the staircase voltage is equal to or slightly greater than the input voltage Vi .

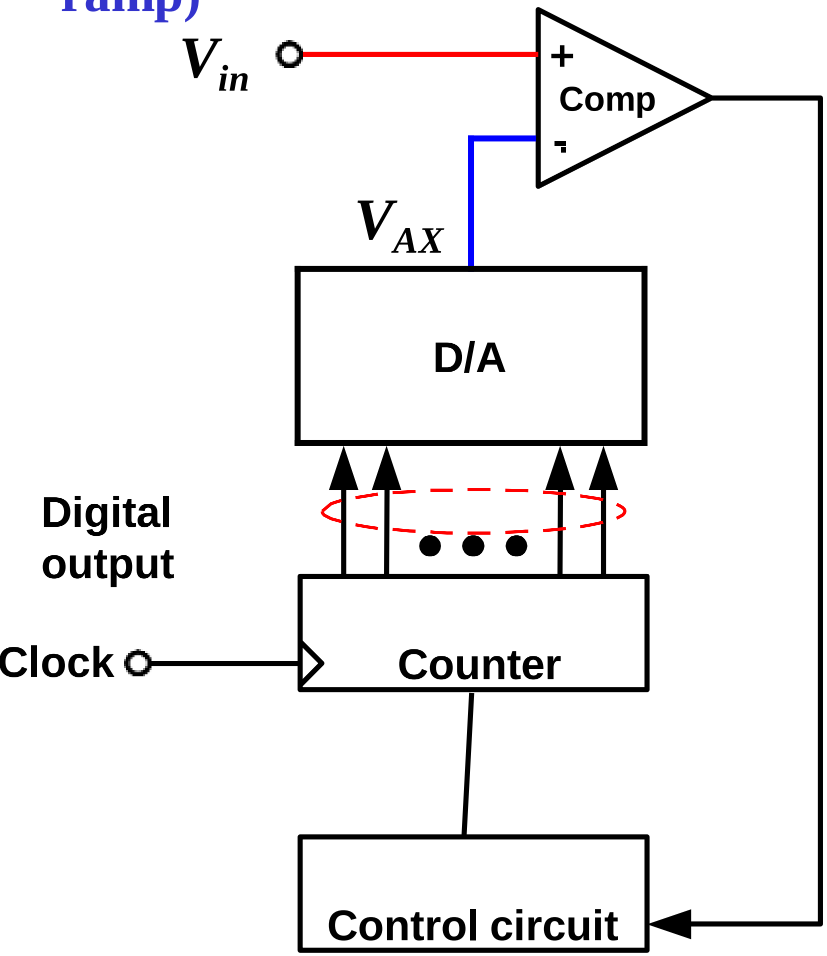
- At that instant t2 , the output voltage of the input comparator changes state or polarity, so that the gate closes and the counter is stopped. The display unit shows the result of the count.

- As each count corresponds to a constant dc step in the DAC output voltage, the number of counts is directly proportional to Vc and hence to Vi . By appropriate choice of reference voltage, the step height of the staircase voltage can be determined.

Staircase Ramp Digital Voltmeter

(also called digital ramp)

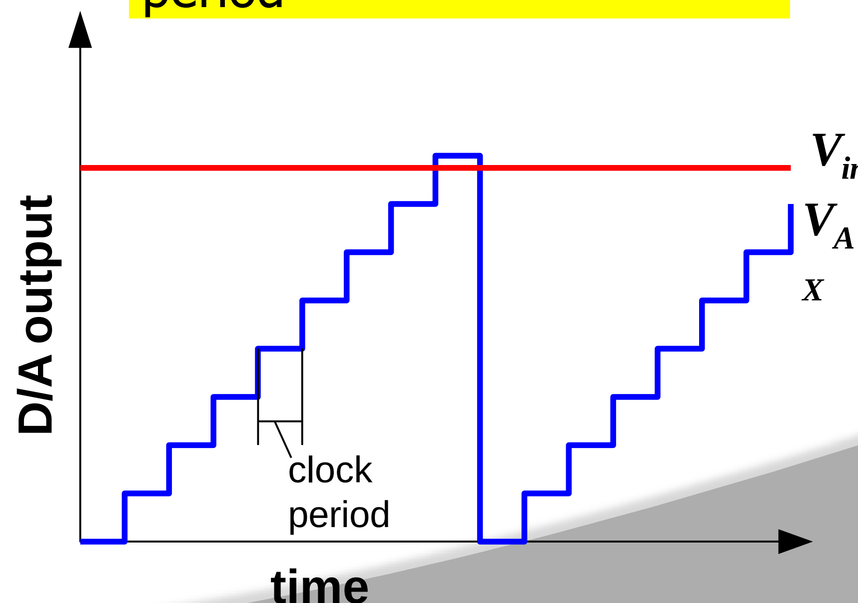
Compare the input voltage to the internally generated stair case ramp.



Block diagram

- The most simple A/D
- Slow conversion and conversion time depends on the magnitude of input signal.

$T_{C,max} = (2^N - 1) \times$ Clock period



Successive Approximations

- The successive approximations principle can be easily understood using a simple example; the determination of the weight of an object. By using a balance and placing the object on one side and an approximate weight on the other side, the weight of the object is determined.

- If the weight placed is more than the unknown weight, the weight is removed and another weight of smaller value is placed and again the measurement is performed.

- Now if it is found that the weight placed is less than that of the object, another weight of smaller value is added to the weight already present, and the measurement is performed.

Successive Approximations

- If it is found to be greater than the unknown weight the added weight is removed and another weight of smaller value is added.

- In this manner by adding and removing the appropriate weight, the weight of the unknown object is determined.

- The successive approximation DVM works on the same principle. Its basic block diagram is shown in Fig.

Successive Approximations

Table 5.1

$V_{in} = 1\,V$	Operation	D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0	Compare	Output	Voltage
00110011	D_7 Set	1	0	0	0	0	0	0	0	$V_{in} < V_{out}$	D_7 Reset	2.5
,,	D_6 Set	0	1	0	0	0	0	0	0	$V_{in} < V_{out}$	D_6 Reset	1.25
,,	D_5 Set	0	0	1	0	0	0	0	0	$V_{in} > V_{out}$	D_5 Set	0.625
,,	D_4 Set	0	0	1	1	0	0	0	0	$V_{in} > V_{out}$	D_4 Set	0.9375
,,	D_3 Set	0	0	1	1	1	0	0	0	$V_{in} < V_{out}$	D_3 Reset	0.9375
,,	D_2 Set	0	0	1	1	0	1	0	0	$V_{in} < V_{out}$	D_2 Reset	0.9375
,,	D_1 Set	0	0	1	1	0	0	1	0	$V_{in} > V_{out}$	D_1 Set	0.97725
,,	D_0 Set	0	0	1	1	0	0	1	1	$V_{in} > V_{out}$	D_0 Set	0.99785

Successive Approximations

- When the start pulse signal activates the control circuit, the successive approximation register (SAR) is cleared. The output of the SAR is 00000000. V_{out} of the D/A converter is 0.

- Now, if $V_{in} > V_{out}$ the comparator output is positive. During the first clock pulse, the control circuit sets the D_7 to 1, and V_{out} jumps to the half reference voltage. The SAR output is 10000000.

- If V_{out} is greater than V_{in} the comparator output is negative and the control circuit resets D_7. However, if V_{in} is greater than V_{out} the comparator output is positive and the control circuits keep D_7 set.

- Similarly the rest of the bits beginning from D_7 to D_0 are set and tested. Therefore, the measurement is completed in 8 clock pulses.

Successive Approximations

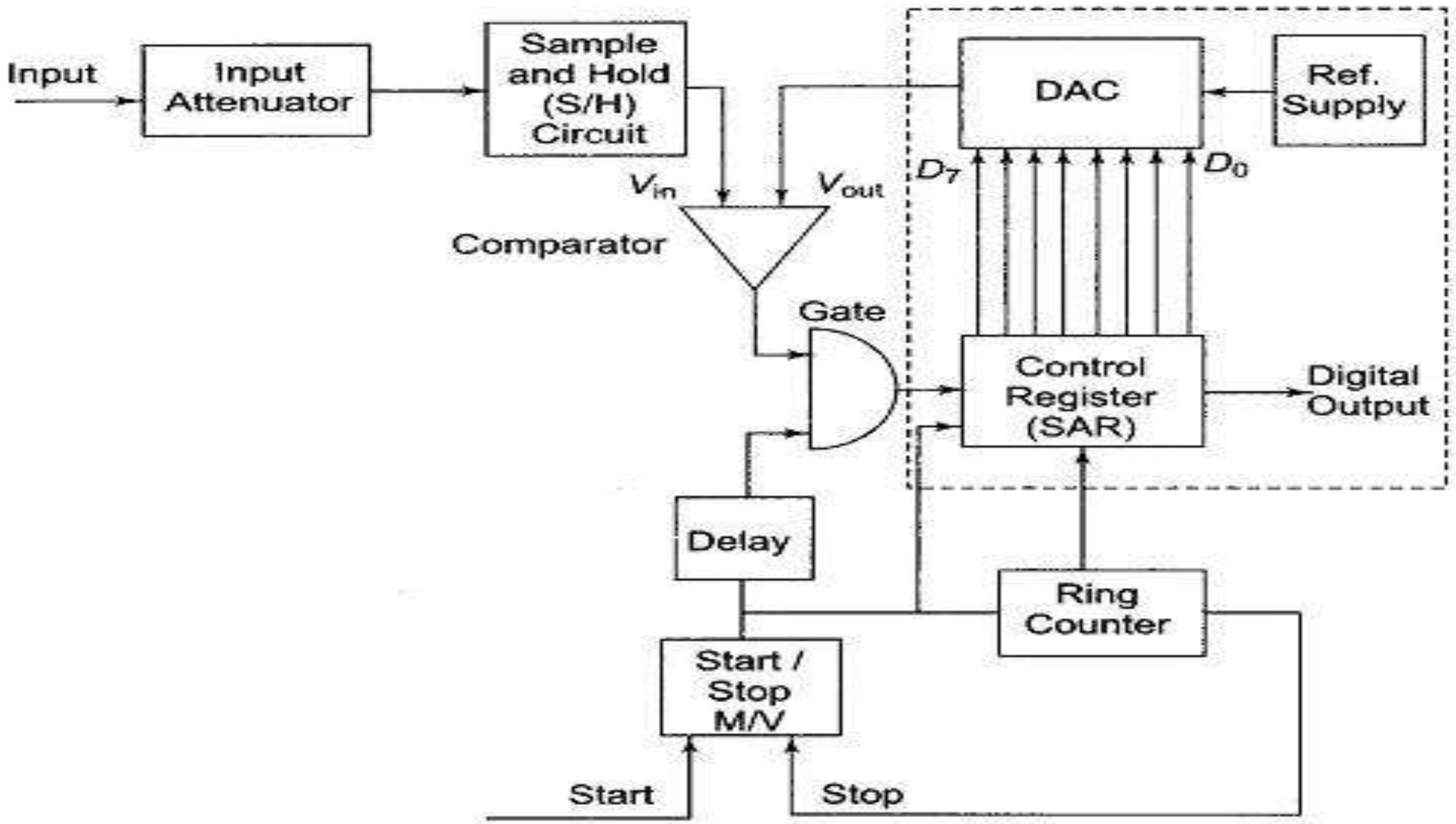


Fig. 5.10 : Successive Approximation DVM

Successive Approximations

- At the beginning of the measurement cycle, a start pulse is applied to the start-stop multivibrator. This sets a 1 in the MSB of the control register and a 0 in all bits (assuming an 8-bit control) its reading would be 10000000.

- This initial setting of the register causes the output of the D/A converter to be half the reference voltage, i.e. 1/2 V. This converter output is compared to the unknown input by the comparator.

- If the input voltage is greater than the converter reference voltage, the comparator output produces an output that causes the control register to retain the 1 setting in its MSB and the converter continues to supply its reference output voltage of 1/2 V_{ref}.

Successive Approximations

- The ring counter then advances one count, shifting a 1 in the second MSB of the control register and its reading becomes 11000000.
- This causes the D/A converter to increase its reference output by 1 increment to 1/4 V, i.e. 1/2 V + 1/4 V, and again it is compared with the unknown input.
- If in this case the total reference voltage exceeds the unknown voltage, the comparator produces an output that causes the control register to reset its second MSB to 0.
- The converter output then returns to its previous value of 1/2 V and awaits another input from the SAR. When the ring counter advances by 1, the third MSB is set to 1 and the converter output rises by the next increment of 1/2 V + 1/8 V.

Successive Approximations

- The measurement cycle thus proceeds through a series of successive approximations. Finally, when the ring counter reaches its final count, the measurement cycle stops and the digital output of the control register represents the final approximation of the unknown input voltage.

Digital Multimeter

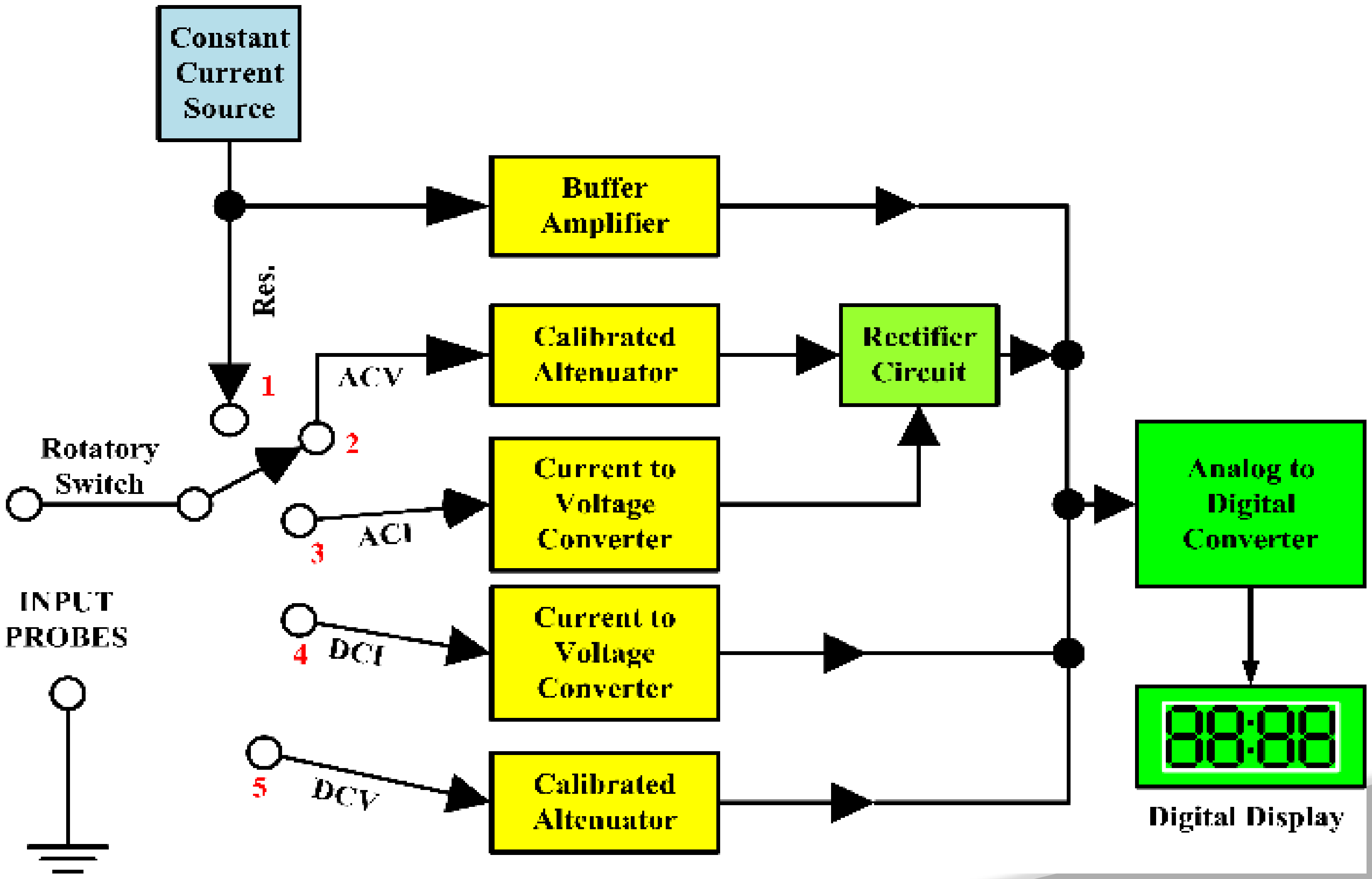
- The digital multimeter is an instrument which is capable of measuring a.c. voltages, d.c. voltages, a.c. and d.c. currents and resistances *over several ranges*. *The basic circuit of a digital multimeter is always a d.c. voltmeter as shown in the Fig*

- The current is converted to voltage by passing it through low shunt resistance. The a.c. quantities are converted to d.c. by employing various rectifier and filtering circuits.

- While for the resistance measurements the meter consists of a precision low current source that is applied across the unknown resistance while gives d.c. voltage.

- All the quantities are digitized using analog to digital converter and displayed in the digital form on the display.

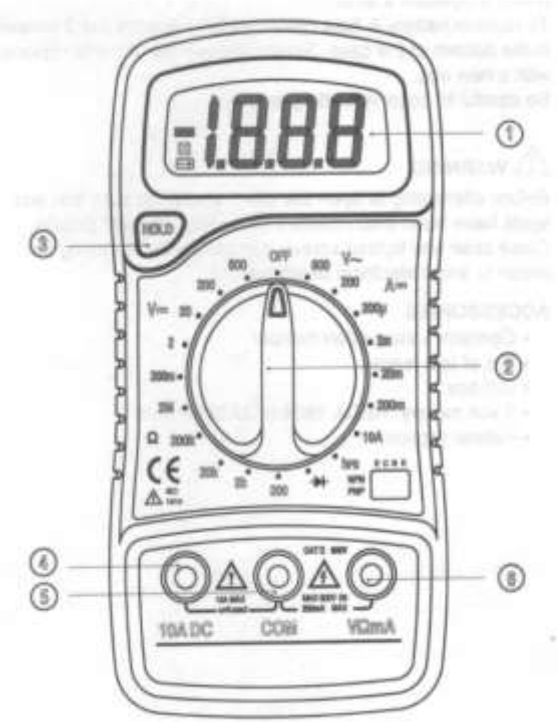
Digital Multimeter



Digital Multimeter

- The basic building blocks of digital multimeter are several *AID converters, counting circuitry and an attenuation circuit. Generally dual slope integration type ADC is prefprred in the multimeters. The single attenuator circuit is used for both a.c. and d.c. measurements in many commercial multimeters.*

Typical specification of DMM



General

Maximum voltage between terminals	:600 V
Fuse protection	:200mA/250V
Power	:9V battery
Display	:LCD 31/2 digits, updates 2-3/ sec.
Input impedance	:10 MΩ
Frequency range	:40-400 Hz
Measuring method	Dual-slope integration
Over range indication	Only figure “1” on the display
Polarity indication	“-” displayed for negative polarity

Accuracy of DMM

Indicate as ± (% of reading + No. of digits)

Ex. ± (0.5% of rdg + 1 digits) sometimes simplify as ± (0.5 + 1)

Ex. For an accuracy of ± (0.5 + 1) , calculate the maximum error of in the 1.800 V reading error = ± (0.5% of 1.800 + 0.001 V)

= ± (0.009 + 0.001 V) = ± 0.01 V or ± 0.56% of reading

Ex A 20 V dc voltage is measured by analog and digital multimeters. The analog instrument is on its 25 V range , and its specified accuracy is ± 2%. The digital meter has 3 ½ digit display and an accuracy of ±(0.6+1). Determine the measurement accuracy in each case.

3½ digit display

Analog instrument:

$$\text{Voltage error} = \pm 2\% \text{ of } 25\text{ V}$$
$$= \pm 0.5\text{ V}$$
$$\text{error} = \pm \frac{0.5\text{ V}}{20\text{ V}} \times 100\%$$
$$= \pm 2.5\%$$

Digital instrument:

For 20 V displayed on a 3 ½ digit display

$$1\text{ Digit} = 0.1\text{ V}$$

$$\text{Voltage error} = \pm (0.6\% \text{ of reading} + 1\text{ Digit})$$
$$= \pm (1.2\text{ V} + 0.1\text{ V})$$
$$= \pm 0.22\text{ V}$$
$$\text{error} = \pm \frac{0.22\text{ V}}{20\text{ V}} \times 100\%$$
$$= \pm 1.1\%$$

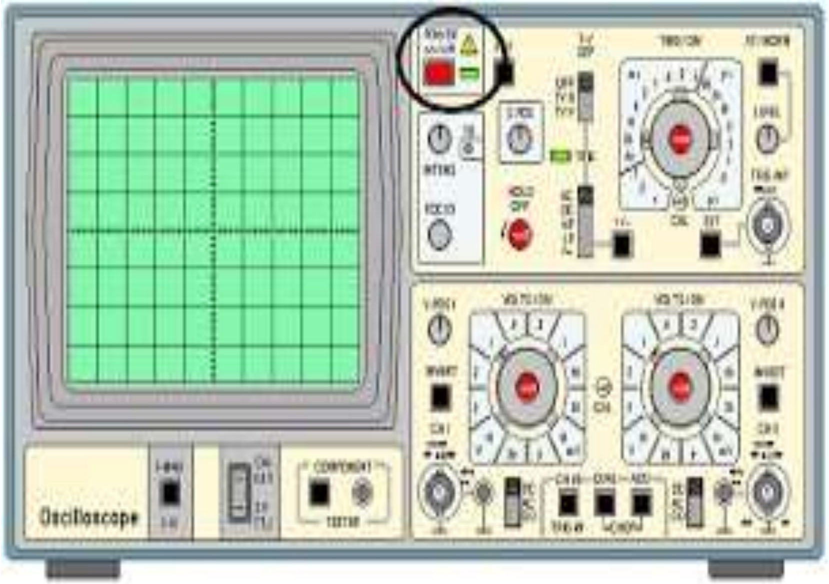
•

MODULE-II
OSCILLOSCOPE

INTRODUCTION

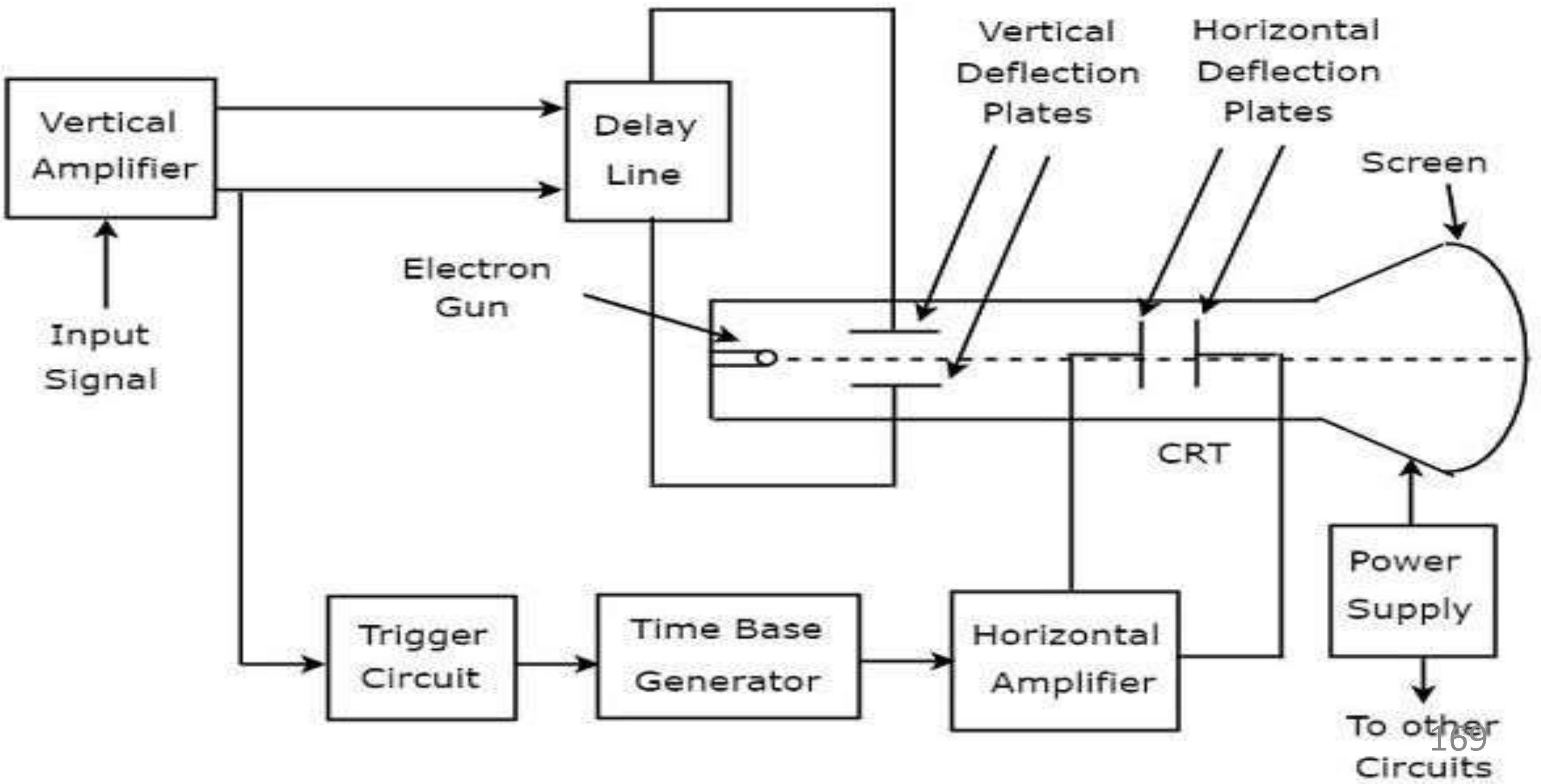
- The cathode-ray oscilloscope (CRO) is a multipurpose display instrument used for the observation, measurement , and analysis of waveforms by plotting amplitude along y-axis and time along x-axis.
- CRO is generally an x-y plotter; on a single screen it can display different signals applied to different channels.
- It can measure amplitude, frequencies and phase shift of various signals.

Oscilloscope is an electronic equipment, which displays a voltage waveform. Among the oscilloscopes, Cathode Ray Oscilloscope (CRO) is the basic one and it displays a time varying signal or waveform



Block Diagram of CRO

Cathode Ray Oscilloscope (CRO) consists a set of blocks. Those are vertical amplifier, delay line, trigger circuit, time base generator, horizontal amplifier, Cathode Ray Tube (CRT) & power supply.



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

The function of each block of

Vertical Amplifier − It amplifies the input signal, which is to be displayed on the screen of CRT.

Delay Line − It provides some amount of delay to the signal, which is obtained at the output of vertical amplifier. This delayed signal is then applied to vertical deflection plates of CRT.

Trigger Circuit − It produces a triggering signal in order to synchronize both horizontal and vertical deflections of electron beam.

Time base Generator − It produces a sawtooth signal, which is useful for horizontal deflection of electron beam.

The function of each block of

Horizontal Amplifier − It amplifies the sawtooth signal and then connects it to the horizontal deflection plates of CRT.

Power supply − It produces both high and low voltages. The negative high voltage and positive low voltage are applied to CRT and other circuits respectively.

The function of each block of

Cathode Ray Tube (CRT) – It is the major important block of CRO and mainly consists of four parts. Those are electron gun, vertical deflection plates, horizontal deflection plates and fluorescent screen.

The electron beam, which is produced by an electron gun gets deflected in both vertical and horizontal directions by a pair of vertical deflection plates and a pair of horizontal deflection plates respectively.

Finally, the deflected beam will appear as a spot on the fluorescent screen.

CATHODE-RAY TUBE

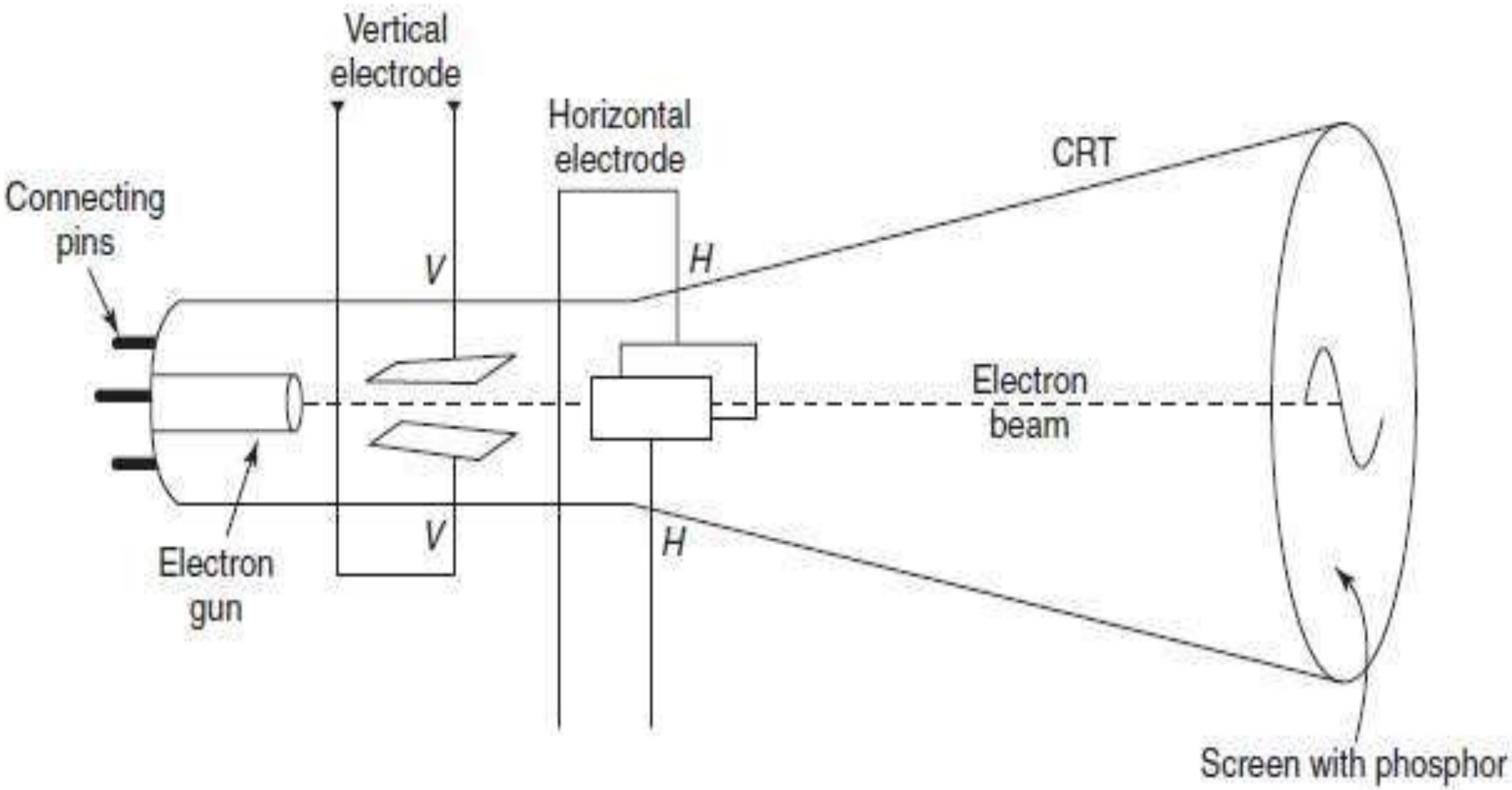


Figure 14-2 Components of a cathode-ray oscilloscope

Working of CRT

- Cathode Ray Tube (CRT) is a computer display screen, used to display the output in a standard composite video signal.

- The working of CRT depends on movement of an electron beam which moves back and forth across the back of the screen.

- The source of the electron beam is the electron gun; the gun is located in the narrow, cylindrical neck at the extreme rear of a CRT which produces a stream of electrons through thermionic emission.

- Usually, A CRT has a fluorescent screen to display the output signal.

Working of CRT

- The operation of a CRT monitor is basically very simple. A cathode ray tube consists of one or more electron guns, possibly internal electrostatic deflection plates and a phosphor target.

- The electron beam produces a tiny, bright visible spot when it strikes the phosphor-coated screen.

- In every monitor device the entire front area of the tube is scanned repetitively and systematically in a fixed pattern called a raster. An image (raster) is displayed by scanning the electron beam across the screen.

Working of CRT

- The phosphor's targets are begins to fade after a short time, the image needs to be refreshed continuously. Thus CRT produces the three color images which are primary colors.

- Here we used a 50 Hz rate to eliminate the flicker by refreshing the screen.

Construction of CRT

- Here we used a 50 Hz rate to eliminate the flicker by refreshing the screen.

- The Electrons Gun Assembly, Deflection Plate Assembly, Fluorescent Screen, Glass Envelope, Base are the important parts of the CRT.

- The electron gun emits the electron beam, and through deflecting plates, it is strikes on the phosphorous screen.

Advantages of CRT

i. CRT's are less expensive than other display technologies.

ii. They operate at any resolution, geometry and aspect ratio without decreasing the image quality.

iii. CRTs produce the very best color and gray-scale for all professional calibrations.

iv. Excellent viewing angle.

v. It maintains good brightness and gives long life service.

Features of CRT

- The use of CRT technology has quickly declined since the introduction of LCDs but they are still unbeatable in certain ways.

- CRT monitors are widely used in a number of electrical devices such as computer screens, television sets, radar screens, and oscilloscopes used for scientific and medical purposes.

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..

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.

FLUORESCENT SCREEN

- These electrons are collected or trapped by an aqueous solution of graphite called "Aquadag" which is connected to the second anode.

- Aquadag is a trade name for a water based colloidal graphite coating commonly used in cathode ray tubes (CRTs).

- 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%.

Cathode

- The heater keeps the cathode at a higher temperature and electrons flow from the heated cathode towards the surface of the cathode.

- The accelerating anode has a small hole at its center and is maintained at a high potential, which is of positive polarity. The order of this voltage is 1 to 20 kV, relative to the cathode.

- This potential difference creates an electric field directed from right to left in the region between the accelerating anode and the cathode.

- Electrons pass through the hole in the anode travel with constant horizontal velocity from the anode to the fluorescent screen. The electrons strike the screen area and it glows brightly.

Deflecting Plates

- Two pairs of deflecting plates allow the beam of electrons.
- An electric field between the first pair of plates deflects the electrons horizontally, and an electric field between the second pair deflects them vertically.
- The electrons travel in a straight line from the hole in the accelerating anode to the center of the screen when no deflecting fields are present, where they produce a bright spot.

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.

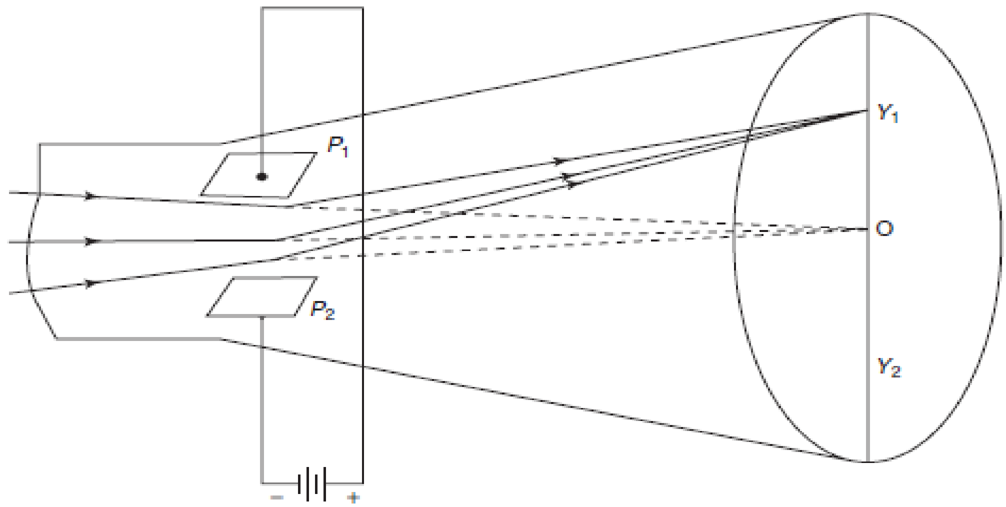
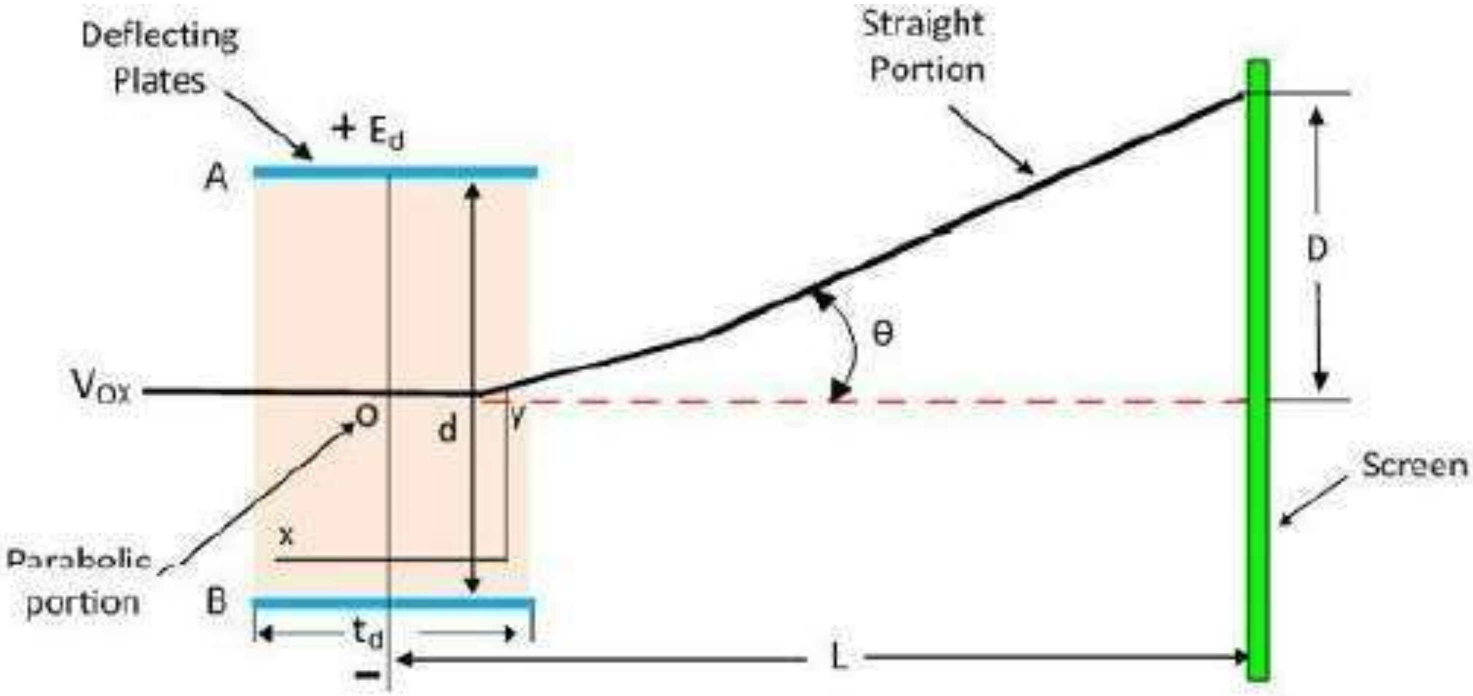


Figure 14-3(a) Deflecting system using parallel vertical plates

Theory of electrostatic deflection in CRO



Theory of electrostatic deflection in CRO

E_0 = Voltage of pre-accelerating anode in volt.

e = charge of an electron in coulomb.

m = mass of electron in Kg.

V_{OX} = velocity of the electron when entering into the deflecting plates in meter per second.

E_d = potential between deflecting plates in Volts.

d = distance between deflecting plate in the meter.

L_d = length of deflecting plate in meters.

L = Distance between screen and the mid of the deflecting plates.

D = deflection of the electron beam on the screen in the Y direction.

Theory of electrostatic deflection in CRO

When the electron moves from the accelerating cathode to anode, they lose their potential energy. The formula gives the potential energy of the electron.

$$P.E = eE_a$$

The electrons gain the kinetic energy. And their energy is given by the equation

$$K.E = \frac{1}{2} m v_{ox}^2$$

Theory of electrostatic deflection in CRO

Equating the potential and kinetic energy we get the velocity of the electron when it enters in the deflecting plates.

$$v_{ox} = \left[\frac{2eE_a}{m}\right]^{1/2}$$

The velocity of the electron in X direction remains same throughout the deflection plate because no force was acting in the X direction.

$$\varepsilon_y = \frac{E_d}{d}$$

Theory of electrostatic deflection in CRO

The equation gives the electric field intensity in the Y direction

$$F_y = e\varepsilon_y = \frac{eE_d}{d}$$

The force acting on the electron in the Y direction

$$F_y = ma_y$$

$$a_y = \frac{e\varepsilon_Y}{m}$$

The initial velocity of the electron enters into the deflection plate is equal to zero, and the equation gives the displacement of an electron in the Y direction at any time t

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

Theory of electrostatic deflection in CRO

The velocity in the Y direction is constant, and the displacement in the Y direction is given as

$$x = v_{ox}t$$

$$t = \frac{x}{v_{ox}}$$

Substituting the value of t in the displacement equation y gives

$$y = \frac{1}{2}\frac{e\varepsilon_y}{m}\left[\frac{x}{v_{ox}}\right]^2$$

The above equation represents parabola. The slope at any point is given as

$$\frac{dy}{dx} = \frac{e\varepsilon_y}{mv_{ox}^2}$$

Theory of electrostatic deflection in CRO

By substituting the $x = l_d$, we get the value of $\tan\theta$

$$\tan\theta = \frac{1}{2}\frac{e\varepsilon_y}{mv_{ox}^2} l_d = \frac{eE_d l_d}{mdv_{ox}^2}$$

After passing through the deflection plate, the electrons move into the straight line. This straight line is the tangent to the parabola at $x = l_d$ and intersect the X-axis at point O. The equation gives the location of the point

$$x = \frac{y}{\tan\theta} = \frac{\frac{1}{2}\frac{e\varepsilon_y}{m}\cdot\frac{{l_d}^2}{v^2{}_{ox}}}{\frac{e\varepsilon_y l_d}{mdv_{ox}^2}} = \frac{l_d}{2}$$

Theory of electrostatic deflection in CRO

The deflection D on the screen is expressed as $D = L\tan\theta = \frac{LeE_d l_d}{mdv_{ox}^2}$

By substituting the value of v^2_{ox} in the above equation we get

$$D = \frac{LeE_d l_d}{md} \cdot \frac{m}{2eE_a} = \frac{LE_d l_d}{2dE_a}$$

So the deflection of the electron is directly proportional to the deflecting voltage.

Theory of electrostatic deflection in CRO

Deflection sensitivity (S) of a CRT is defined as the deflection on the screen per unit deflecting voltage.

$$S = \frac{D}{E_d} = \frac{Ll_d}{2dE_a}$$

Deflection factor (G) is the reciprocal of deflection sensitivity.

$$G = \frac{1}{S} = \frac{2dE_a}{Ll_d}$$

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.

TIME-BASE GENERATORS

- 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.

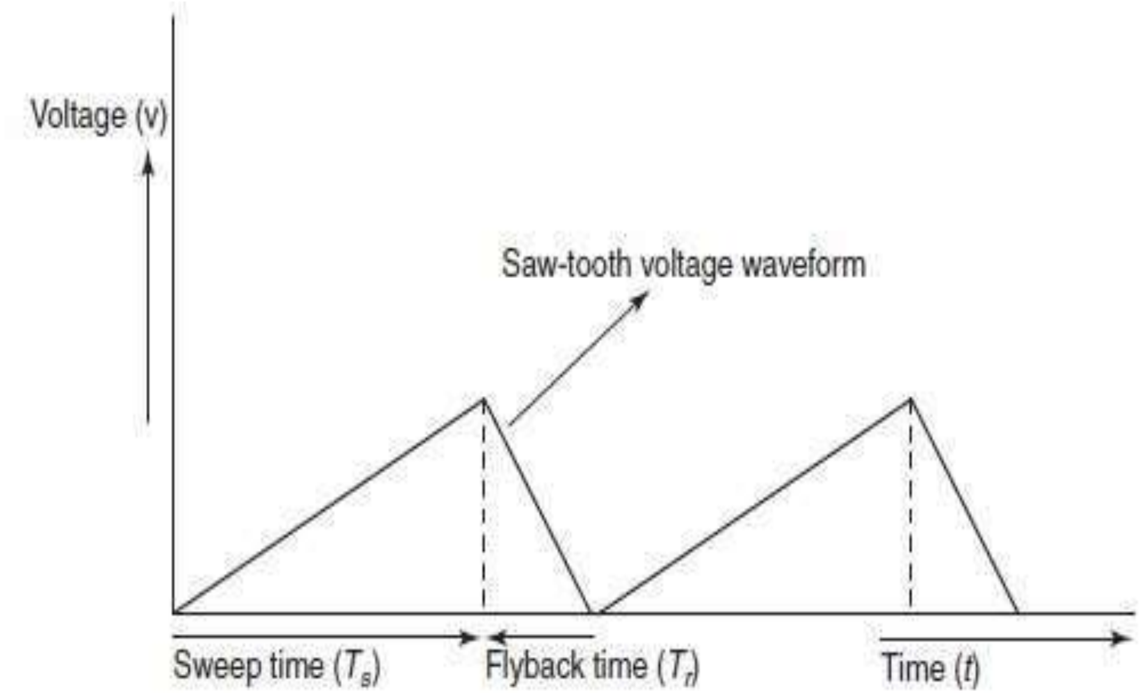


Figure 14-6 Typical saw-tooth waveform applied to the horizontal deflection plates

SIMPLE SAW-TOOTH GENERATOR

- The circuit shown in Fig. 14-7(a) is a simple sweep circuit, in which the capacitor C charges through the resistor R.

- The capacitor discharges periodically through the transistor T1, which causes the waveform shown in Fig. 14-7(b) to appear across the capacitor of the transistor to turn it ON for short time in t

TIME-BASE GENERATOR USING UJT

- The continuous sweep CRO uses the UJT as a time-base generator. When power is first applied to the UJT, it is in the OFF state and CT changes exponentially through RT .
- The UJT emitter voltage VE rises towards VBB and VE reaches the plate voltage VP.

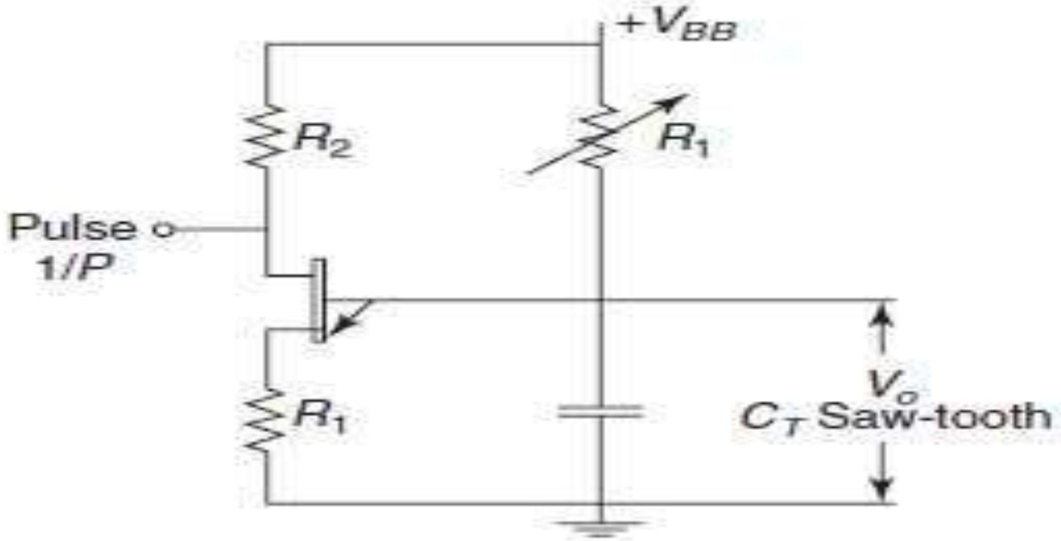


Figure 14-7 (c) Time-base generator using UJT

TIME-BASE GENERATOR USING UJT

- The emitter-to-base diode becomes forward biased and the UJT triggers ON. This provides a low resistance discharge path and the capacitor dischar ges rapidly.
- When the emitter voltage VE reaches the minimum valuerapidly, the UJT goes OFF.
- The capacitor recharges and the RT is used for continuous control of frequency within a range and CT is varied or changed in steps. They are some times known as timing resistor and timing capacitor
cycle repeat.

Delay line circuit

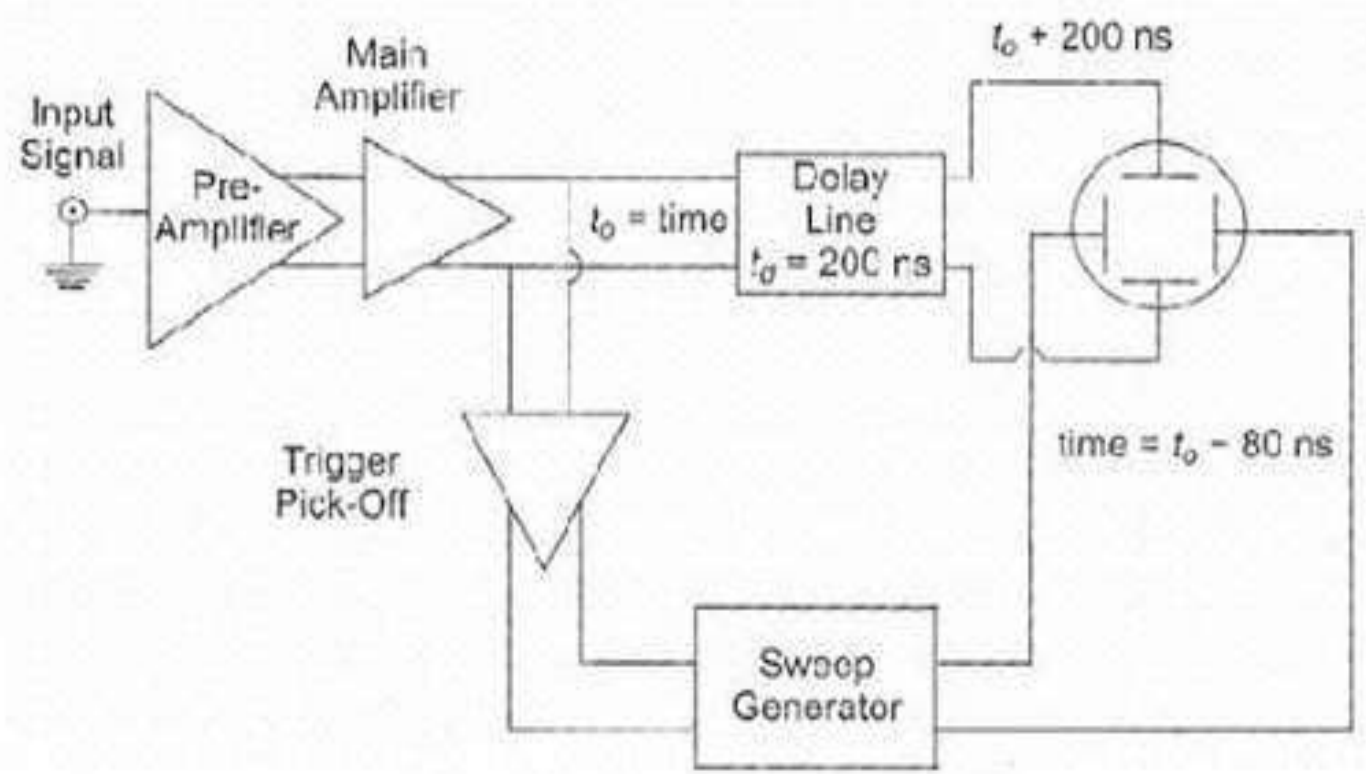


fig 3.1 Delay Line Circuit

Delay line circuit

The delay line is used to delay the signal for some time in the vertical sections. When the delay line is not used, the part of the signal gets lost.

Thus the input signal is not applied directly to the vertical plates but is delayed by some time using a delay line circuit as shown in the Fig.

Delay line circuit

If the trigger pulse is picked off at a time t = to after the signal has passed through the main amplifier then signal is delayed by XI nanoseconds while sweep takes YI nanoseconds to reach.

The design of delay line is such that the delay time XI is higher than the time YI' Generally XI is 200 nsec while is 80 ns, thus the sweep starts well in time and no part of the signal is lost.

Delay line circuit

There are two types of delay lines used in CR.O. which are:

- Lumped parameter delay line
- Distributed parameter delay line

FREQUENCY RESPONSE

- The bandwidth of an oscilloscope detects the range of frequencies that can be accurately reproduced on the CRT screen. The greater the bandwidth, the wider is the range of observed frequencies.

- The bandwidth of an oscilloscope is the range of frequencies over which the gain of the vertical amplifier stays within 3 db of the mid-band frequency gain, as shown in Fig..

- Rise time is defined as the time required for the edge to rise from 10–90% of its maximum amplitude. An approximate relation is given as follows:

FREQUENCY RESPONSE

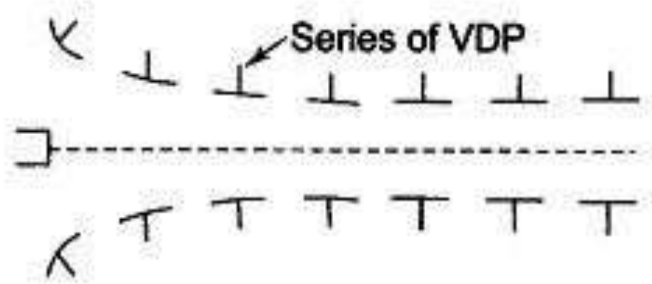


Fig. 7.17 **Travelling Wave CRO**

$$t_r \times BW = 0.35$$

where, t_r is the rise time in seconds and BW is the band width in Hertz.

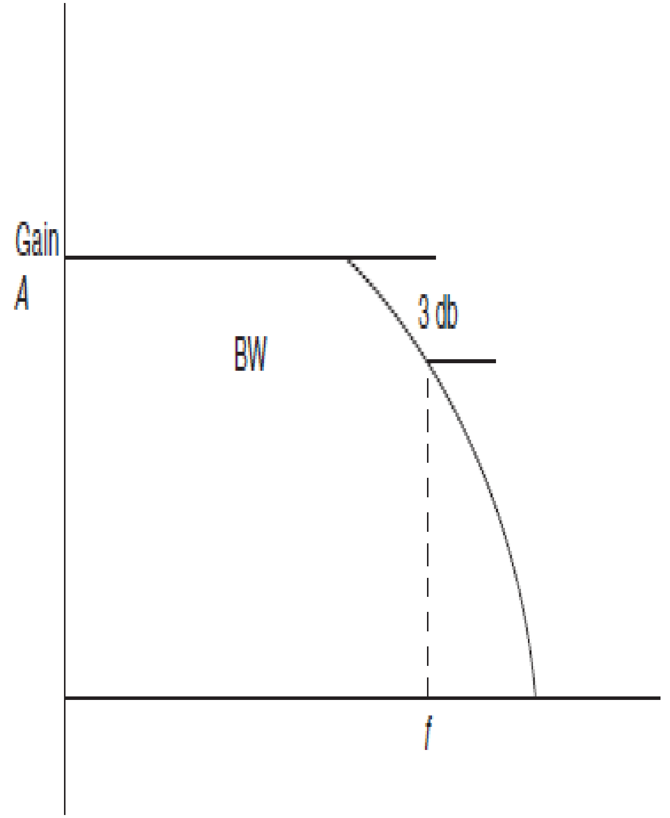


Figure 14-8 Frequency response graphs

Characteristics of a HF CRO

- The vertical amplifier must be designed both for high B.W. and high sensitivity or gain. Making the vertical amplifier a fixed gain amplifier simplifies the design. The input to the amplifier is brought to the required level by means of an attenuator circuit. The final stages is the push-pull stage.
- The LF CRT is replaced by an HF CRT.

- A probe is used to connect the signals, e.g. a high Z passive probe acts like a compensated attenuator.

- By using a triggered sweep, for fast rising signals, and by the use of delay lines between the vertical plates, for improvement of HF characteristics.

- New fluorescent materials that increase the brightness of the display are used.

Characteristics of a HF CRO

Features:

- Highest Sensitivity up to 1mV/div (After Expand)
- Full band Trig Auto Sweep Circuit
- Flex Trig mode (Select either CH1 or CH2 Signal / External Signal)
- Alt-Trig View 2 in relative Signal
- Ext Trig Input
- Power Supply : AC 200 ±10%V

TYPES OF THE CATHODE-RAY OSCILLOSCOPES

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.

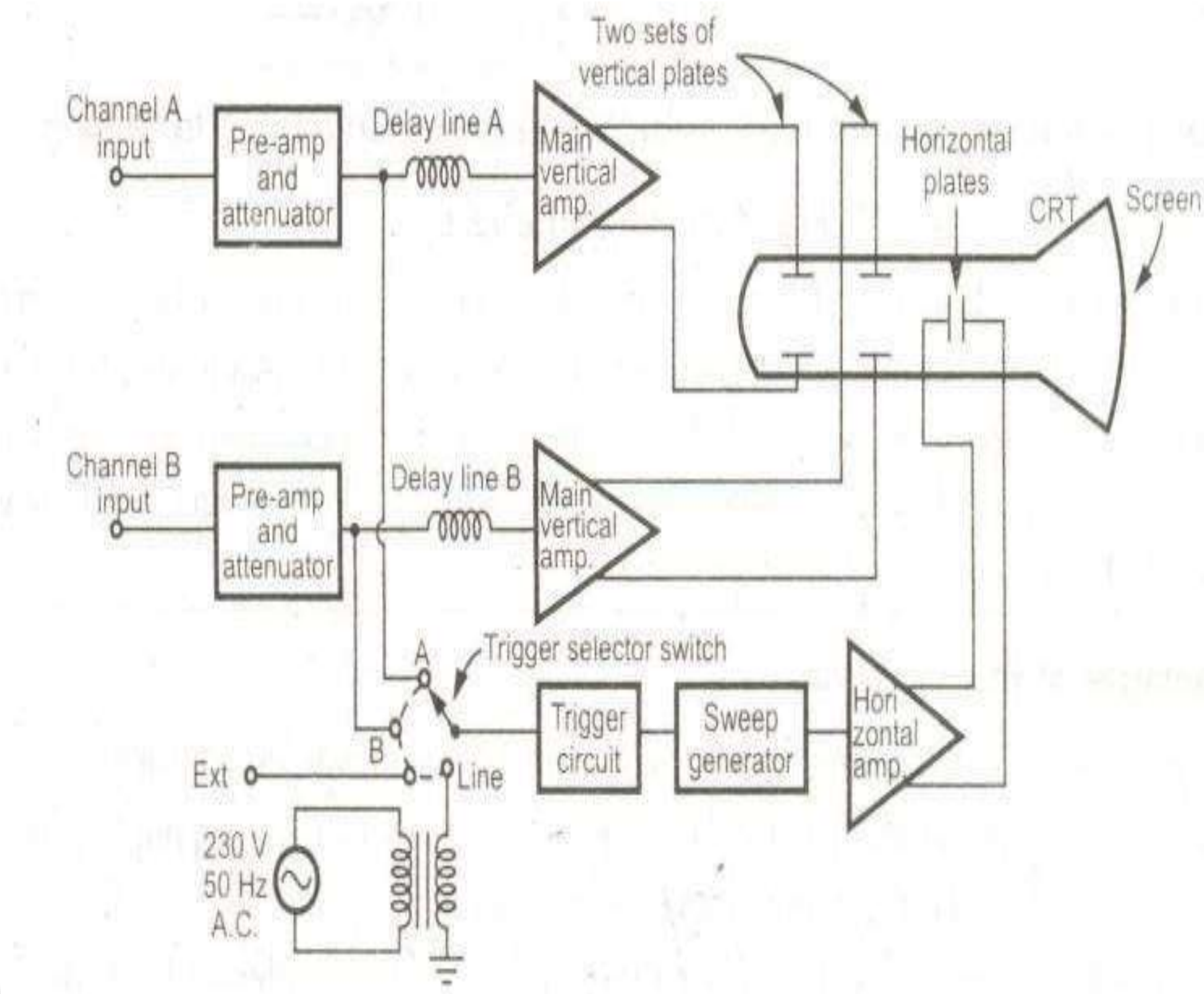
TYPES OF THE CATHODE-RAY OSCILLOSCOPES

3.<u>Storage CRO:</u> 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.

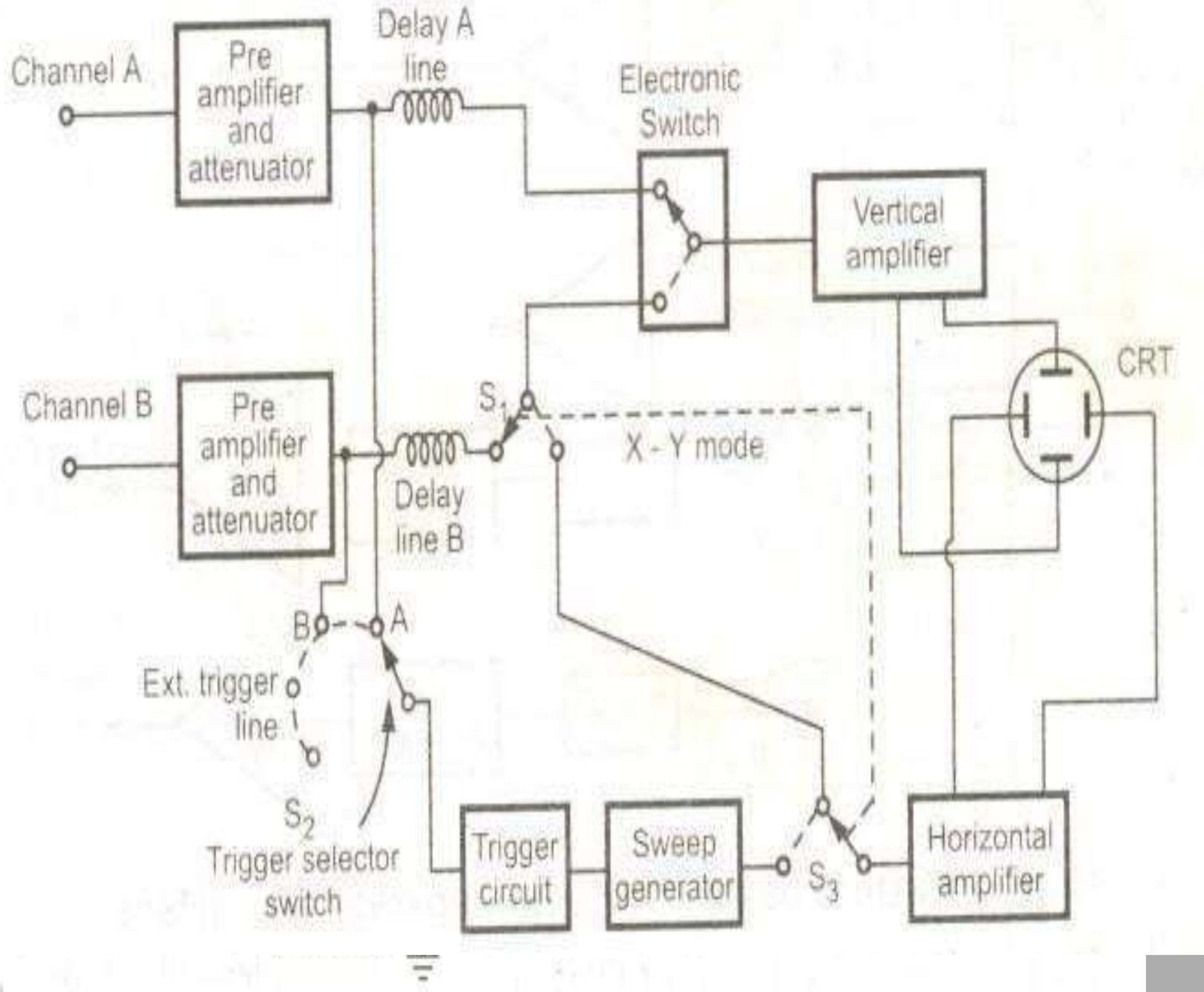
4.<u>Dual-Beam CRO:</u> In the dual-beam CRO two electron beams fall on a single CRT. The dual-gun CRT generates two different beams.

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.

DUAL BEAM OSCILLOSCOPE



DUAL TRACE OSCILLOSCOPE



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SPECIAL PURPOSEOSCILLOSCOPES

Following are the **special purpose oscilloscopes**.

- Dual Beam Oscilloscope
- Dual Trace Oscilloscope
- Digital Storage Oscilloscope

SPECIAL PURPOSEOSCILLOSCOPES

The graph, usually called the **trace**, is drawn by a beam of electrons striking the phosphor coating of the screen making it emit light, usually green or blue. This is similar to the way a television picture is produced.

WHY DUAL TRACE?

Unlike single trace oscilloscope, dual trace oscilloscope can display two traces on the screen, allowing you to easily compare the input and output .

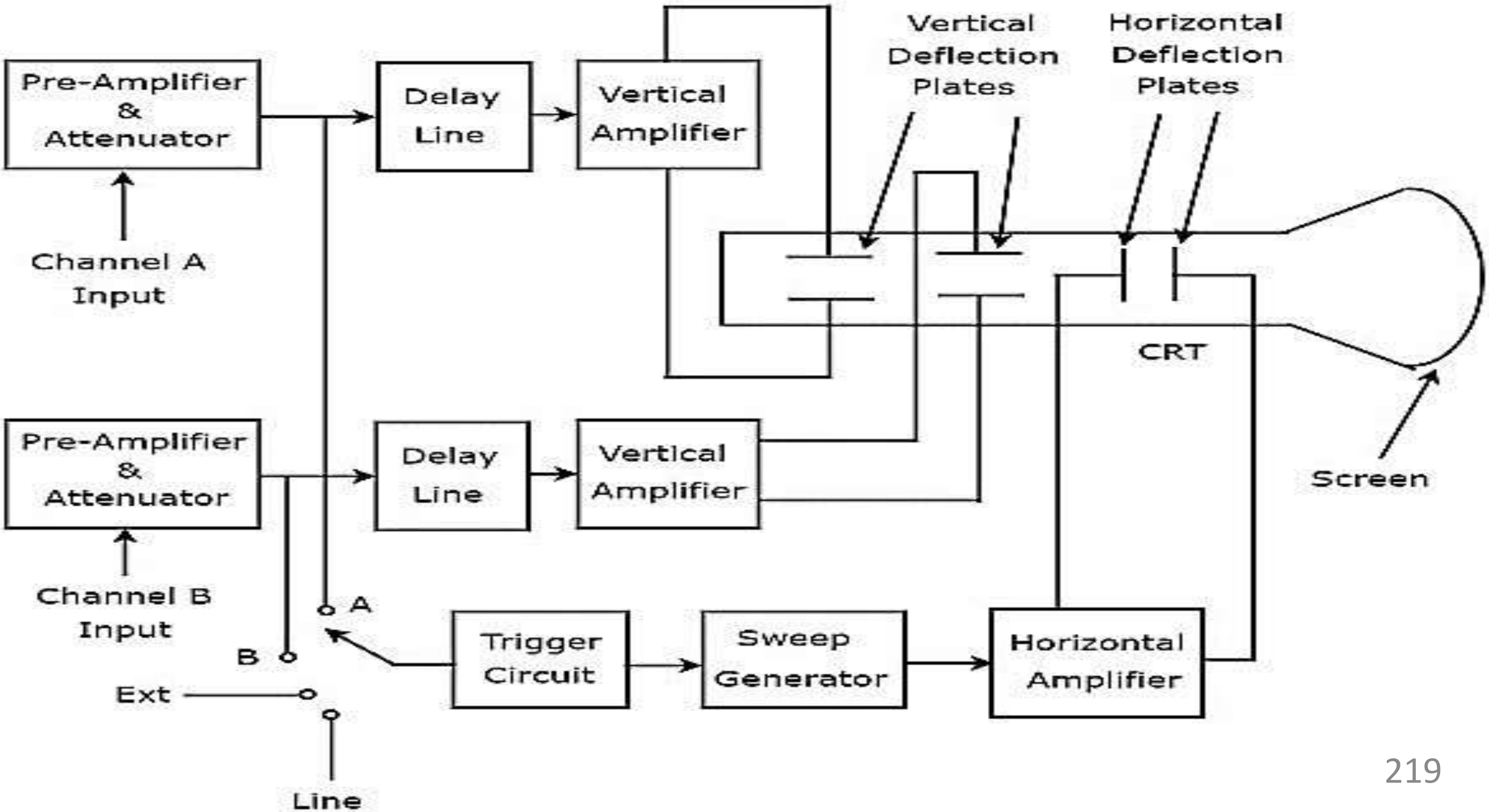
FOR EXAMPLE: input and output of an amplifier.

DUAL BEAM OSCILLOSCOPE

The Oscilloscope, which displays two voltage waveforms is called Dual Beam Oscilloscope

DUAL BEAM OSCILLOSCOPE

The Oscilloscope, which displays two voltage waveforms is called Dual Beam Oscilloscope



DUAL BEAM OSCILLOSCOPE

CRT of Dual Beam Oscilloscope consists of two sets of vertical deflection plates and one set of horizontal deflection plates.

The combination of the following blocks together is called a **channel**.

- ❖ Pre-Amplifier & Attenuator
- ❖ Delay Line
- ❖ Vertical Amplifier
- ❖ A set of Vertical Deflection Plates

DUAL BEAM OSCILLOSCOPE

- There are two channels in Dual Beam Oscilloscope. So, we can apply the two signals, namely A & B as input of channel A & Channel B respectively.

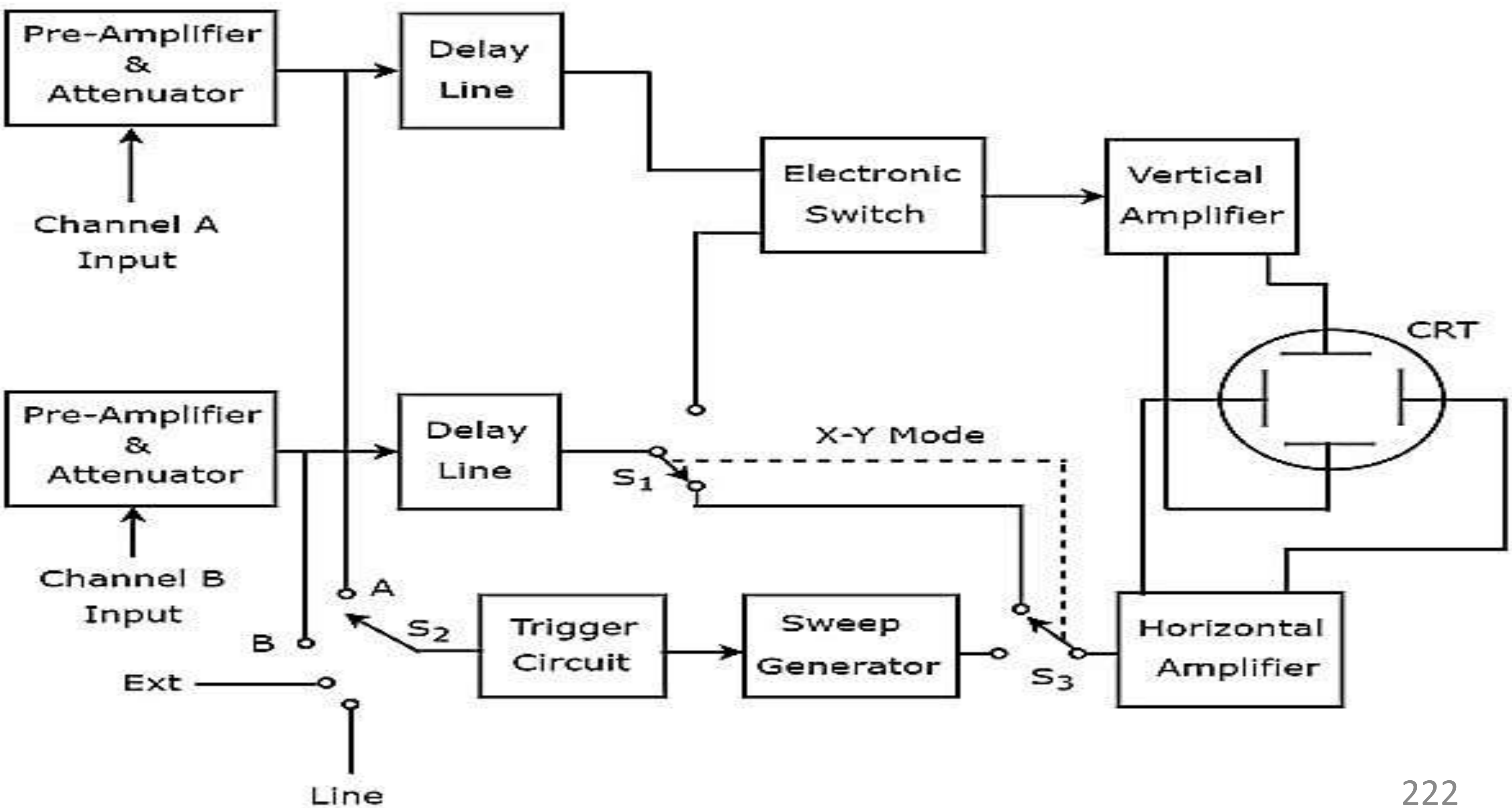
- We can choose any one of these four signals as **trigger input** to the trigger circuit by using a switch. Those are input signals A & B, External signal (Ext) and Line input.

- This oscilloscope will produce two vertically deflected beams, since there are two pairs of vertical deflection plates. In this oscilloscope, the blocks which are useful for deflecting the beam in horizontal direction is common for both the input signals.

- Finally, this oscilloscope will produce the **two input signals** simultaneously on the screen of CRT.

DUAL TRACE OSCILLOSCOPE

The oscilloscope, which stores the waveform digitally is known as digital storage oscilloscope.



DUAL TRACE OSCILLOSCOPE

- CRT of Dual Trace Oscilloscope consists of a set of vertical deflection plates and another set of horizontal deflection plates. channel consists of four blocks, i.e. pre-Amplifier & attenuator, delay line, vertical amplifier and vertical deflection plates.

- In above block diagram, the first two blocks are separately present in both channels. The last two blocks are common to both the channels.

- Hence, with the help of **electronic switch** we can connect the delay line output of a specific channel to vertical amplifier.

.

DUAL TRACE OSCILLOSCOPE

- We can choose any one of these four signals as trigger input to the **trigger circuit** by using a switch. Those are input signals A & B, External signal (Ext) and Line input.

- This oscilloscope uses same electron beam for deflecting the input signals A & B in vertical direction by using an electronic switch, and produces **two traces**. the blocks that deflect the beam horizontally is common for both the input signals.

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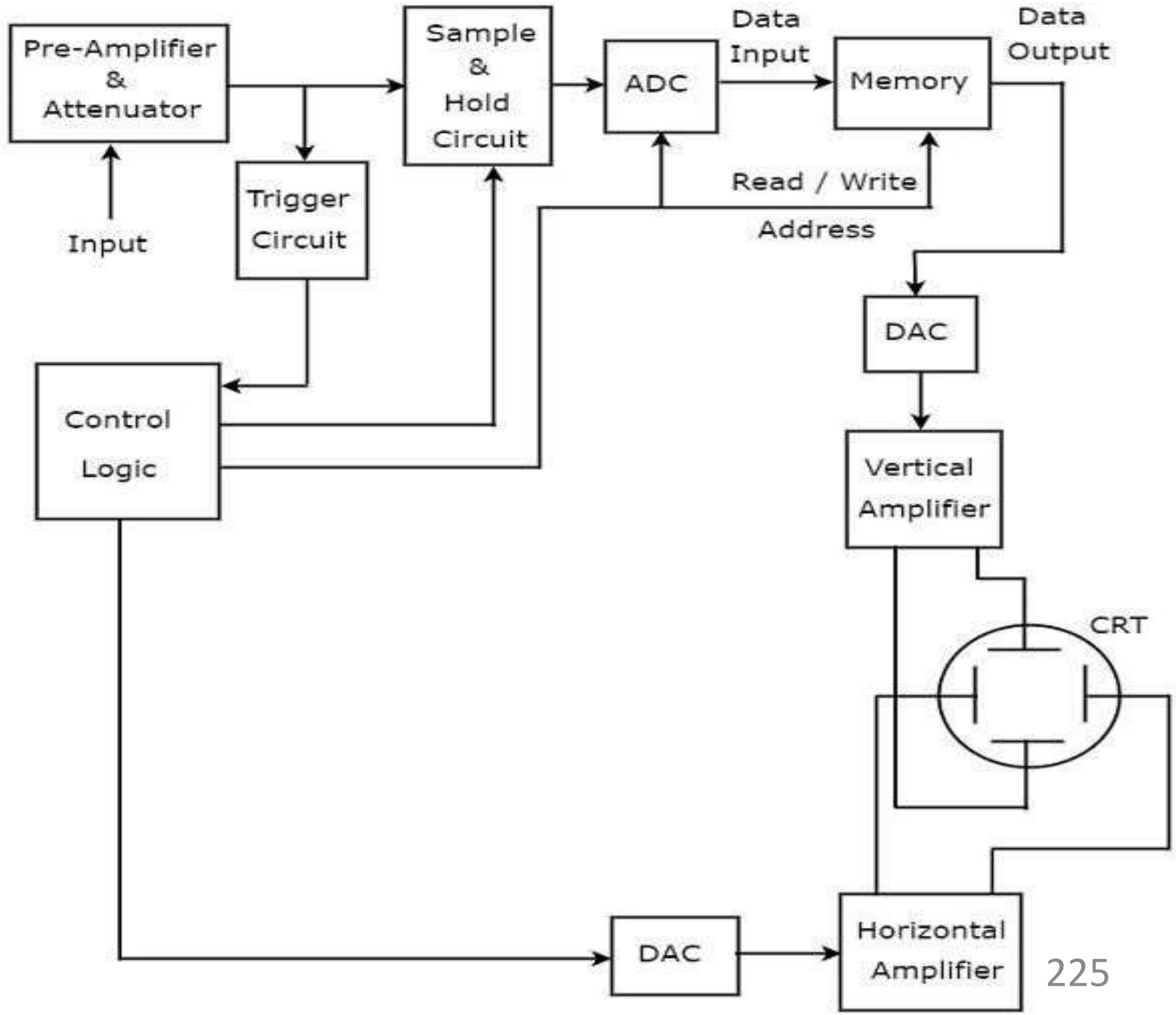
Digital Storage Oscilloscope

The oscilloscope, which stores the waveform digitally is known as digital storage oscilloscope.



Digital Storage Oscilloscope

- Additional blocks required for digital data storage are added to a basic oscilloscope to make it convert it into a Digital Storage Oscilloscope.
- The blocks that are required for **storing of digital data** are lies between the pre-amplifier & attenuator and vertical amplifier in Digital Storage Oscilloscope.
- Those are Sample and Hold circuit, Analog to Digital Converter (ADC), Memory & Digital to Analog Converter.
- Control logic controls the first three blocks by sending various control signals. The blocks like control logic and Digital to Analog Converter are present between the trigger circuit and horizontal amplifier in Digital Storage Oscilloscope

Digital Storage Oscilloscope

- Control logic controls the first three blocks by sending various control signals. The blocks like control logic and Digital to Analog Converter are present between the trigger circuit and horizontal amplifier in Digital Storage Oscilloscope

- The Digital Storage Oscilloscope stores the data in digital before it displays the waveform on the screen. Whereas, the basic oscilloscope doesn’t have this feature.

Sampling Oscilloscope

- The sampling oscilloscope is a special type of digital sampling oscilloscope which is used to examine a very fast signal.

- In other words, The sampling oscilloscope receives various electrical signal and then to getherly display the signals on the screen.

- It works on the principle of stroboscopic light in which sample is taken at different portions of the waveform, over successive cycles, and then the total picture is stretched, amplified by relatively low bandwidth amplifiers, and display as the continuous wave on the screen.

Sampling Oscilloscope

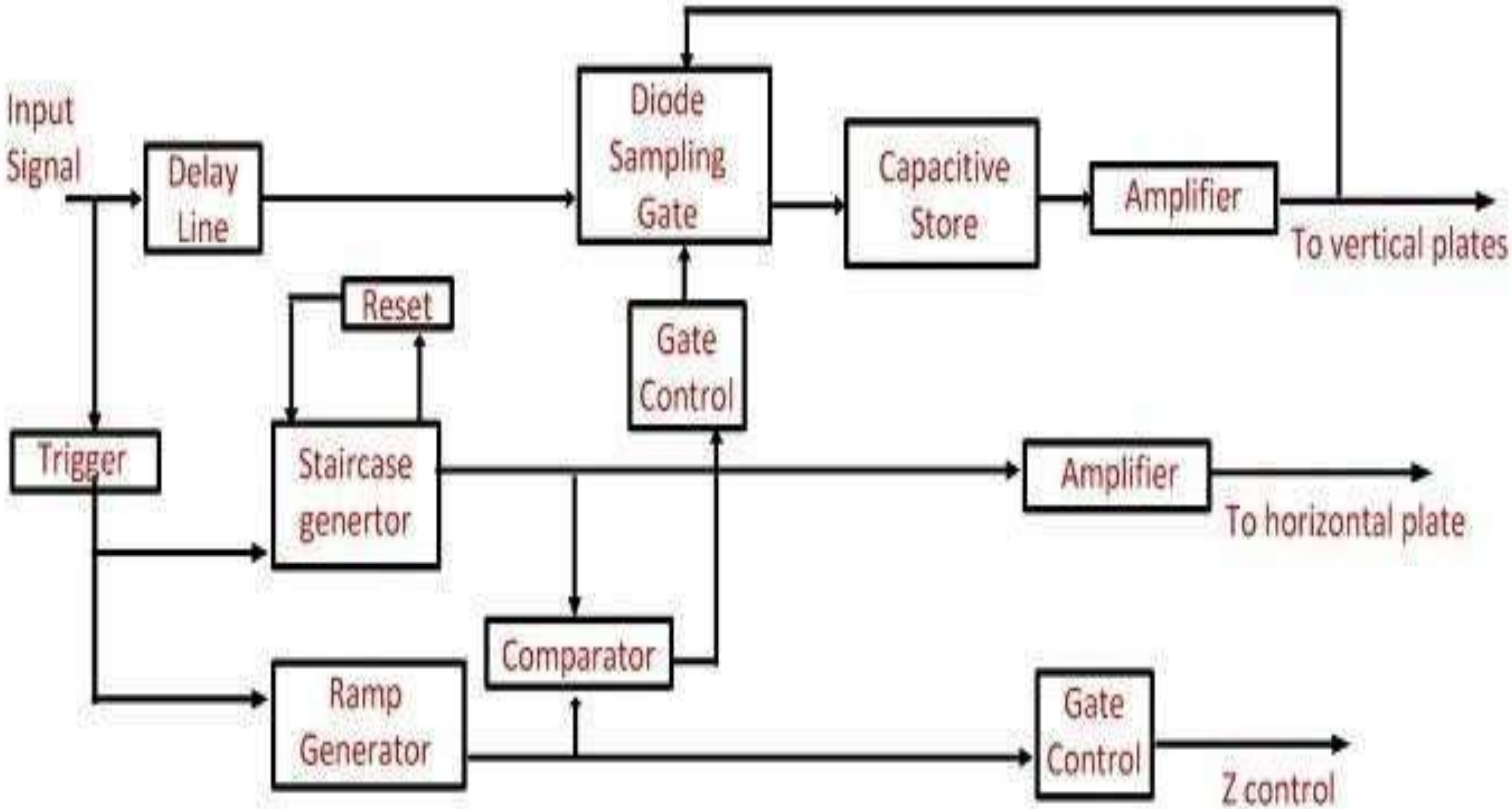
- The advantage of the sampling oscilloscope is that it can measure the very high-speed event with the help of the instrument having lower bandwidth.

- The disadvantage of the oscilloscope is are that it can only measure the repetitive or continuous signal. The frequency range of the oscilloscopes depends on their design.

- The sampling techniques of the oscilloscope convert the input signal into the low-frequency domain. The low-frequency signal has a highly efficient domain.

- The sampling oscilloscopes in not used for displaying the transient signals.

Block Diagram of Sampling Oscilloscope



Sampling Oscilloscope Block Diagram

Circuit Globe

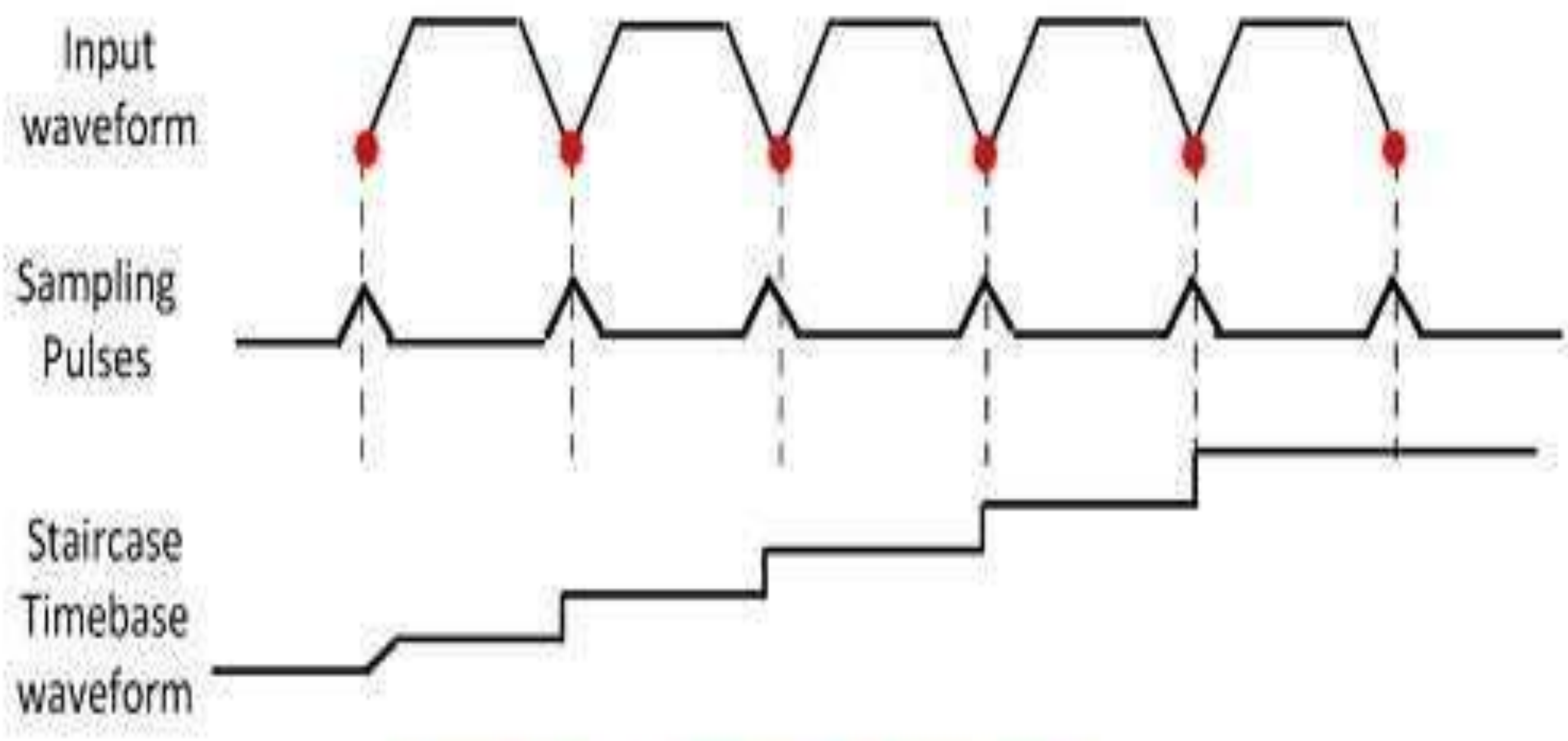
Block Diagram of Sampling Oscilloscope

- The single feedback is used from the amplifier to the diode gate. The feedback shows that the voltage stored on the capacitor increases only by the change in internal signal between each sample.

- The staircase waveform is shown in the figure below. The waveform shows that it is reset after several numbers of steps. Thus, more than 1000 points are used on the screen for creating the waveform.

- The staircase waveform is used in the cathode ray tube. It is used for removing the spot on the screen.

Sampling Oscilloscope



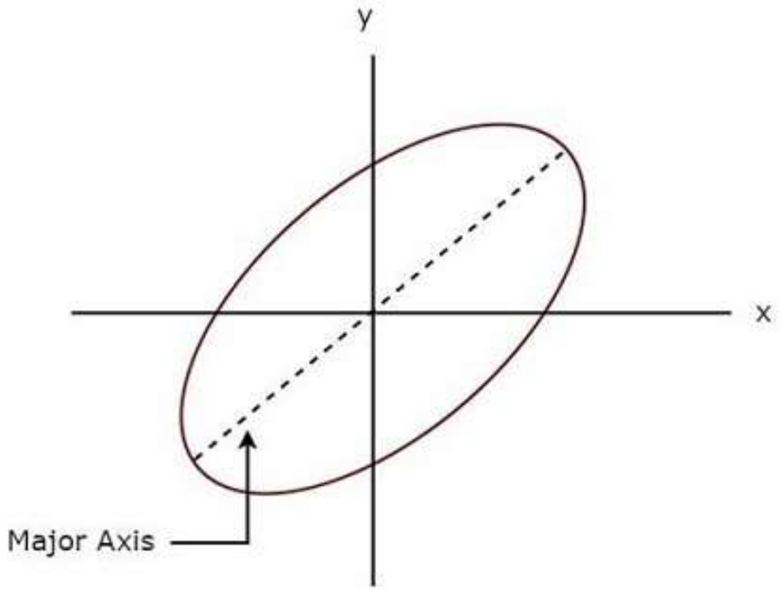
Principle of Sampling Oscilloscopes

•

Lissajous Figures
and
CRO Probes

LISSAJOUS FIGURES

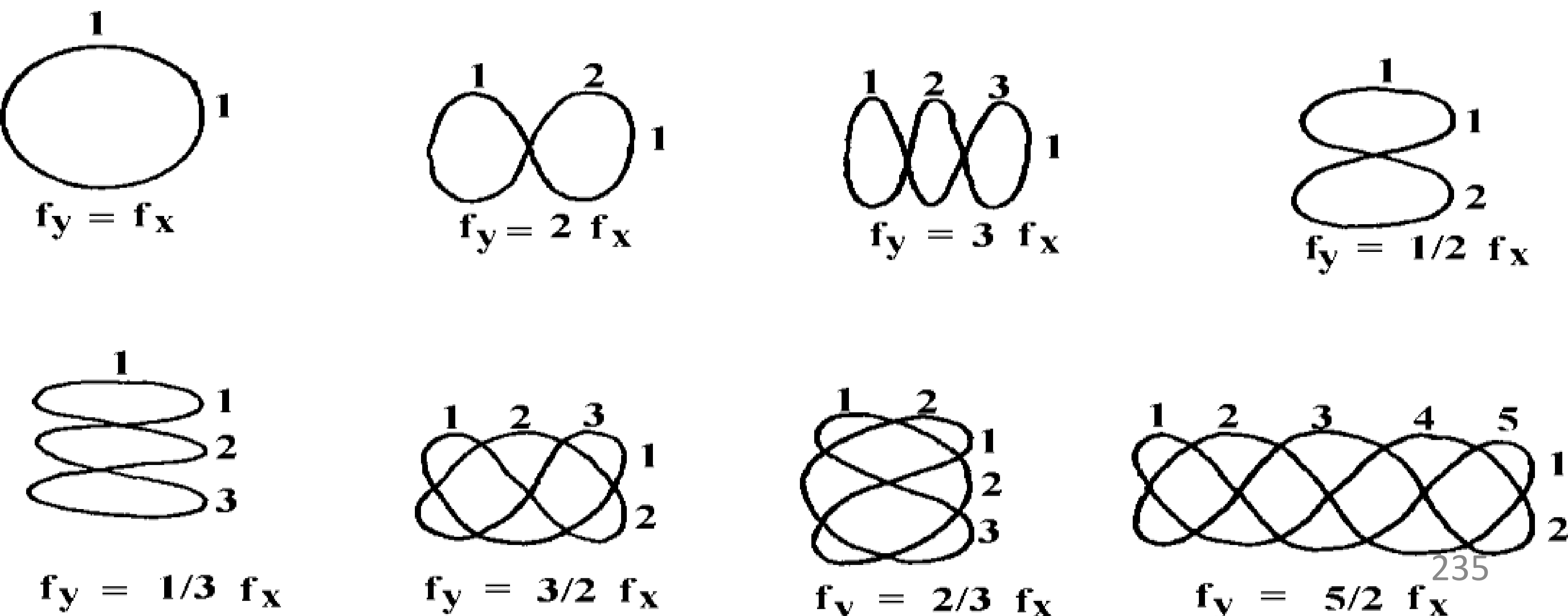
- Lissajous figure can be displayed by applying two a.c. signals simultaneously to the X-plates and Y-plates of an oscilloscope.
- As the frequency, amplitude and phase difference are altered, different patterns are seen on the screen of the CRO.



Frequency can be determined from:

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

where, f_v and f_h are the frequencies of the vertical and the horizontal signals, respectively.



LISSAJOUS FIGURES

- An ordinary oscilloscope has a B.W. of 10 MHz the HF performance can be improved by means of sampling the input waveform and reconstructing its shape from the sample, i.e. the signal to be observed is sampled and after a few cycles sampling point is advanced and another sample is taken.

- The shape of the wave form is reconstructed by joining the sample levels together. The sampling frequency may be as low as 1/10th of the input signal frequency (if the input signal frequency is 100 MHz, the bandwidth of the CRO vertical amplifier can be as low as 10 MHz).
- As many as 1000 samples are used to reconstruct the original waveform.

Measurements using Lissajous Figures

We can do the following **two measurements** from a Lissajous figure.

- Frequency of the sinusoidal signal
- Phase difference between two sinusoidal signals

Measurement of Frequency

- Lissajous figure will be displayed on the screen, when the sinusoidal signals are applied to both horizontal & vertical deflection plates of CRO.
- Hence, apply the sinusoidal signal, which has standard **known frequency** to the horizontal deflection plates of CRO.
- Similarly, apply the sinusoidal signal, whose **frequency** is **unknown** to the vertical deflection plates of CRO
- Let, fH and fV are the frequencies of sinusoidal signals, which are applied to the horizontal & vertical deflection plates of CRO respectively. The relationship between fH and fV can be **mathematically** represented as below.

LISSAJOUS FIGURES

$$fV/fH=nH/nV$$

From above relation, we will get the frequency of sinusoidal signal, which is applied to the vertical deflection plates of CRO as,

$$fV=(nH/nV)fH$$

Where,

nH is the number of horizontal tangencies

nV is the number of vertical tangencies

We can find the values of nH and nV from Lissajous figure. So, by substituting the values of nH, nV and fH in Equation , we will get the value of fV, i.e. the **frequency of sinusoidal signal** that is applied to the vertical deflection plates of CRO.

Measurement of Phase Difference

A Lissajous figure is displayed on the screen when sinusoidal signals are applied to both horizontal & vertical deflection plates of CRO. Hence, apply the sinusoidal signals, which have **same amplitude and frequency** to both horizontal and vertical deflection plates of CRO.

For few Lissajous figures based on their shape, we can directly tell the phase difference between the two sinusoidal signals.

- If the Lissajous figure is a **straight line** with an inclination of 45∘45∘ with positive x-axis, then the **phase difference** between the two sinusoidal signals will be 0∘0∘. That means, there is no phase difference between those two sinusoidal signals..

LISSAJOUS FIGURES

Measurement of Phase Difference

- If the Lissajous figure is a **straight line** with an inclination of 135∘ with positive x-axis, then the **phase difference** between the two sinusoidal signals will be 180∘. That means, those two sinusoidal signals are out of phase.

- If the Lissajous figure is in **circular shape**, then the phase difference between the two sinusoidal signals will be 90∘ or 270∘

Measurement of Phase Difference

We can calculate the phase difference between the two sinusoidal signals by using formulae, when the Lissajous figures are of **elliptical shape**.

- If the major axis of an elliptical shape Lissajous figure having an inclination angle lies between 0∘ and 90∘ with positive x-axis, then the phase difference between the two sinusoidal signals will be.

$$\phi=\sin^{-1}(x1/x2)=\sin^{-1}(y1/y2)$$

- If the major axis of an elliptical shape Lissajous figure having an inclination angle lies between 90∘ and 180∘ with positive x-axis, then the phase difference between the two sinusoidal signals will be.

$$\phi=180-\sin^{-1}(x1/x2)=180-\sin^{-1}(y1/y2)$$

Measurement of Phase Difference

Where,

x_1 is the distance from the origin to the point on x-axis, where the elliptical shape Lissajous figure intersects

x_2 is the distance from the origin to the vertical tangent of elliptical shape Lissajous figure

y_1 is the distance from the origin to the point on y-axis, where the elliptical shape Lissajous figure intersects

y_2 is the distance from the origin to the horizontal tangent of elliptical shape Lissajous figure

CRO Probes

We can connect any test circuit to an oscilloscope through a probe. As CRO is a basic oscilloscope, the probe which is connected to it is also called **CRO probe**.

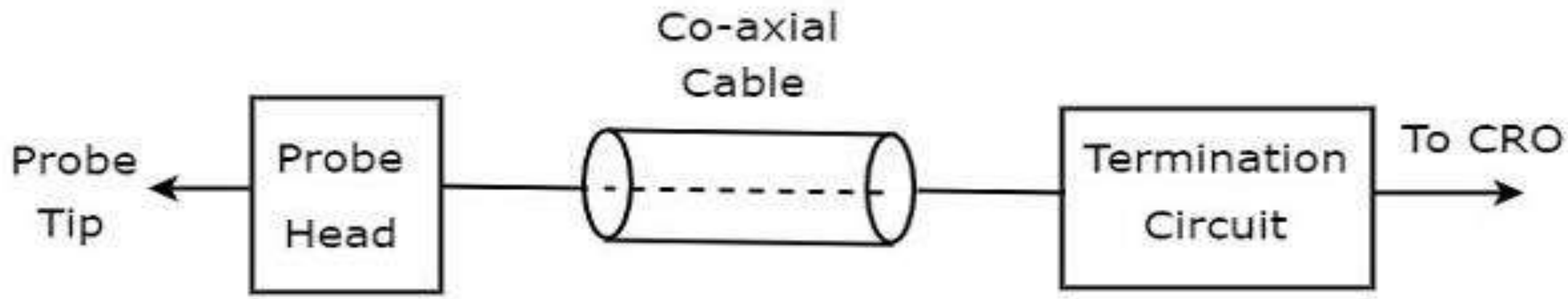
We should select the probe in such a way that it should not create any loading issues with the test circuit. So that we can analyze the test circuit with the signals properly on CRO screen.

CRO probes should have the following **characteristics**.

- High impedance
- High bandwidth

CRO Probes

The **block diagram** of CRO probe is shown in below figure.



As shown in the figure, CRO probe mainly consists of three blocks. Those are probe head, co-axial cable and termination circuit. Co-axial cable simply connects the probe head and termination circuit.

Types of CRO Probes

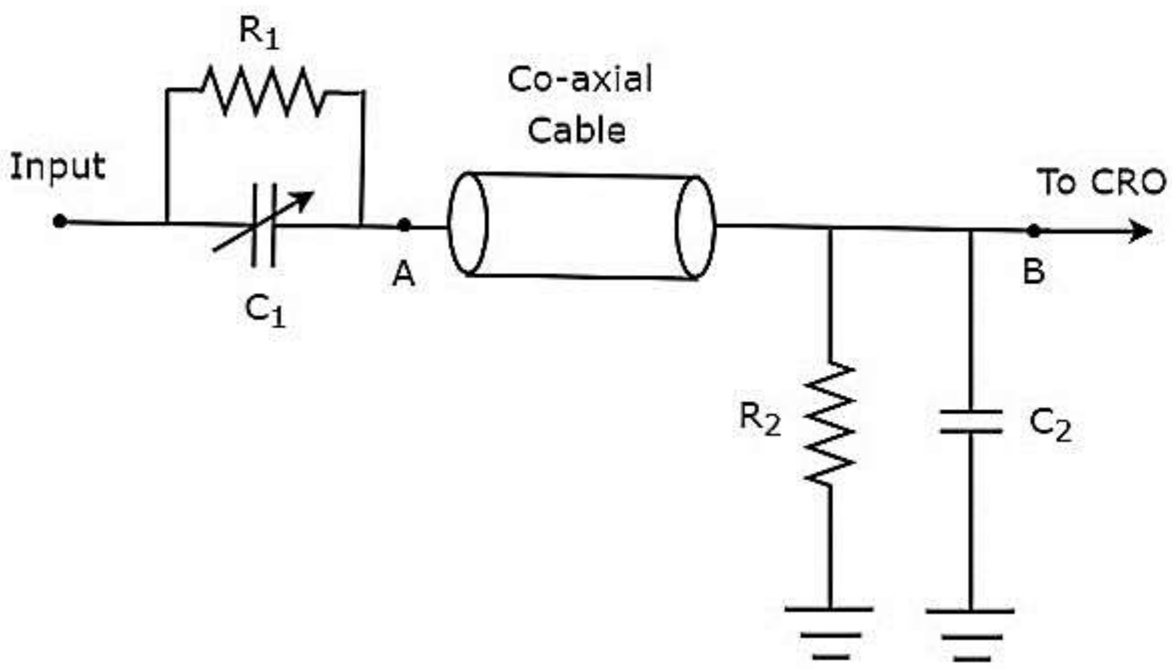
CRO probes can be classified into the following **two types**.

- Passive Probes
- Active Probes

Passive Probes

If the probe head consists of passive elements, then it is called **passive probe**. The circuit diagram of passive probe is shown in below figure.

.



Active Probes

If the probe head consists of active electronic components, then it is called **active probe**. The block diagram of active probe is shown in below figure.

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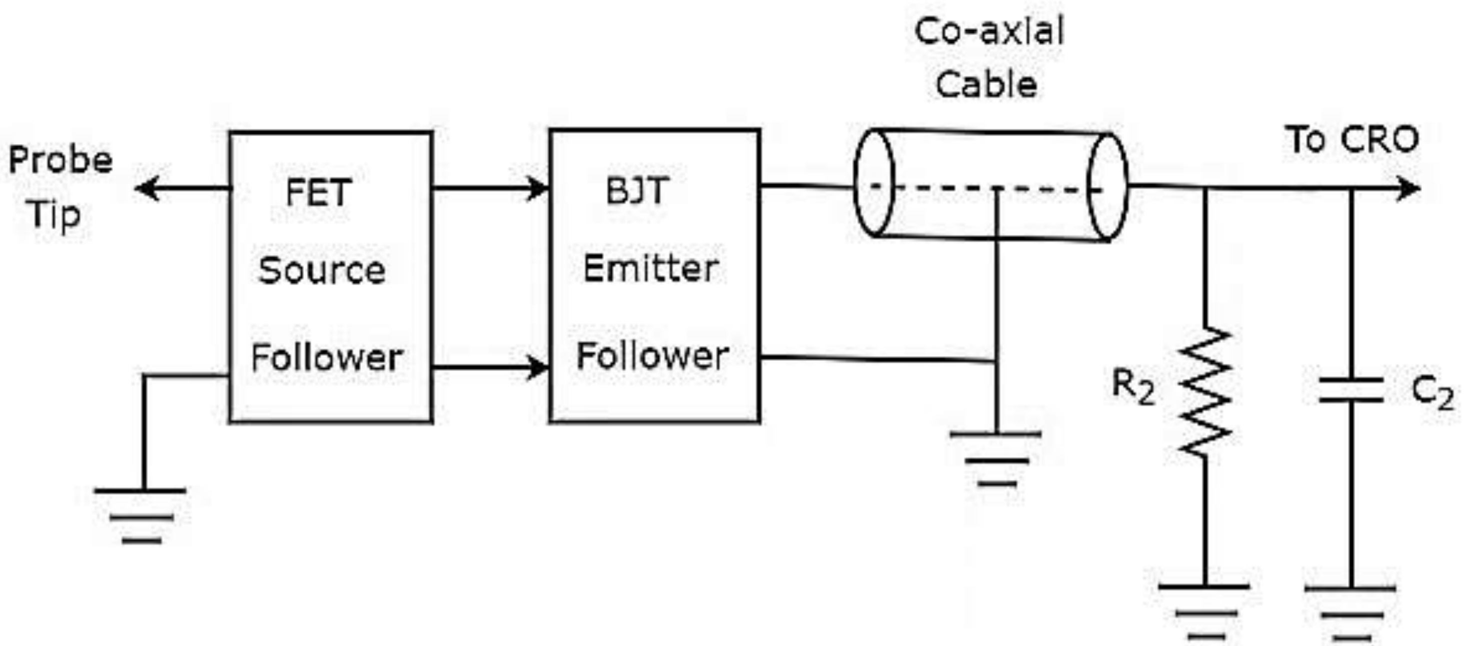
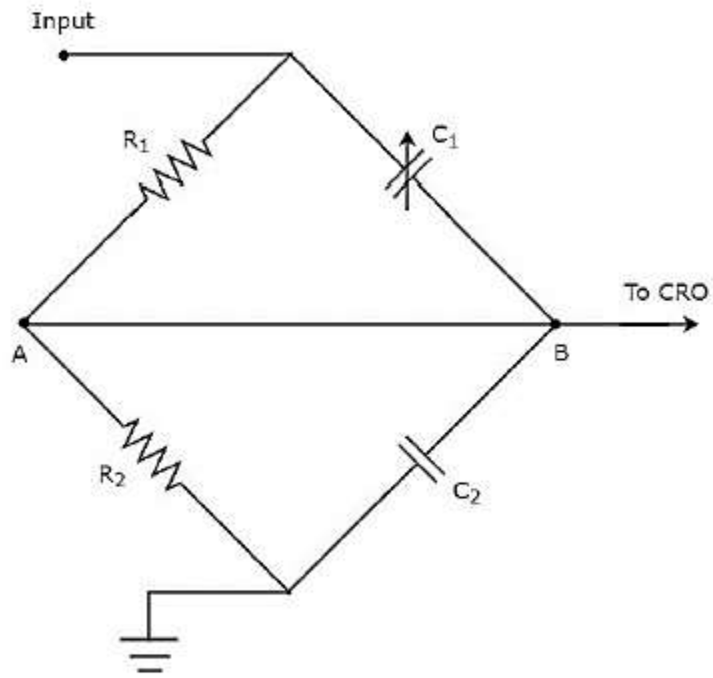


Passive Probes

As shown in the figure, the probe head consists of a parallel combination of resistor, R1 and a variable capacitor, C1. Similarly, the termination circuit consists of a parallel combination of resistor, R2 and capacitor, C2.



Passive Probes

We can balance the bridge, by adjusting the value of variable capacitor, c1. We will discuss the concept of bridges in the following chapters. For the time being, consider the following **balancing condition of AC bridge**.

$$Z1\ Z4 = Z2\ Z3$$

Substitute, the impedances Z1,Z2,Z3 and Z4 as R1,1/jωC1,R2 and 1/jωC2 respectively in above equation.

$$R1(1/j\omega C2) = (1/j\omega C1)R2$$

$$\Rightarrow R1C1 = R2C2$$ ---------------**Equation 1**

By voltage division principle, we will get the **voltage across resistor,** R2 as

$$V0 = Vi(R2/R1+R2)$$

Passive Probes

attenuation factor is the ratio of input voltage, Vi and output voltage, $V0$.

So, from above equation we will get the attenuation factor, α as,

$$\alpha = Vi/V0 = R1 + R2/R2$$

$$\Rightarrow \alpha = 1 + (R1/R2)$$

$$\Rightarrow \alpha - 1 = R1R2$$

$\Rightarrow R1=(\alpha-1)R2$ --------------**Equation 2**

From above Equation 2 , we can conclude that the value of R1 is greater than or equal to the value of $R2$ for integer values of $\alpha>1$

Passive Probes

Substitute above Equation 2 in Equation 1.

$$(\alpha-1)R2C1=R2C2$$

$$\Rightarrow(\alpha-1)C1=C2$$

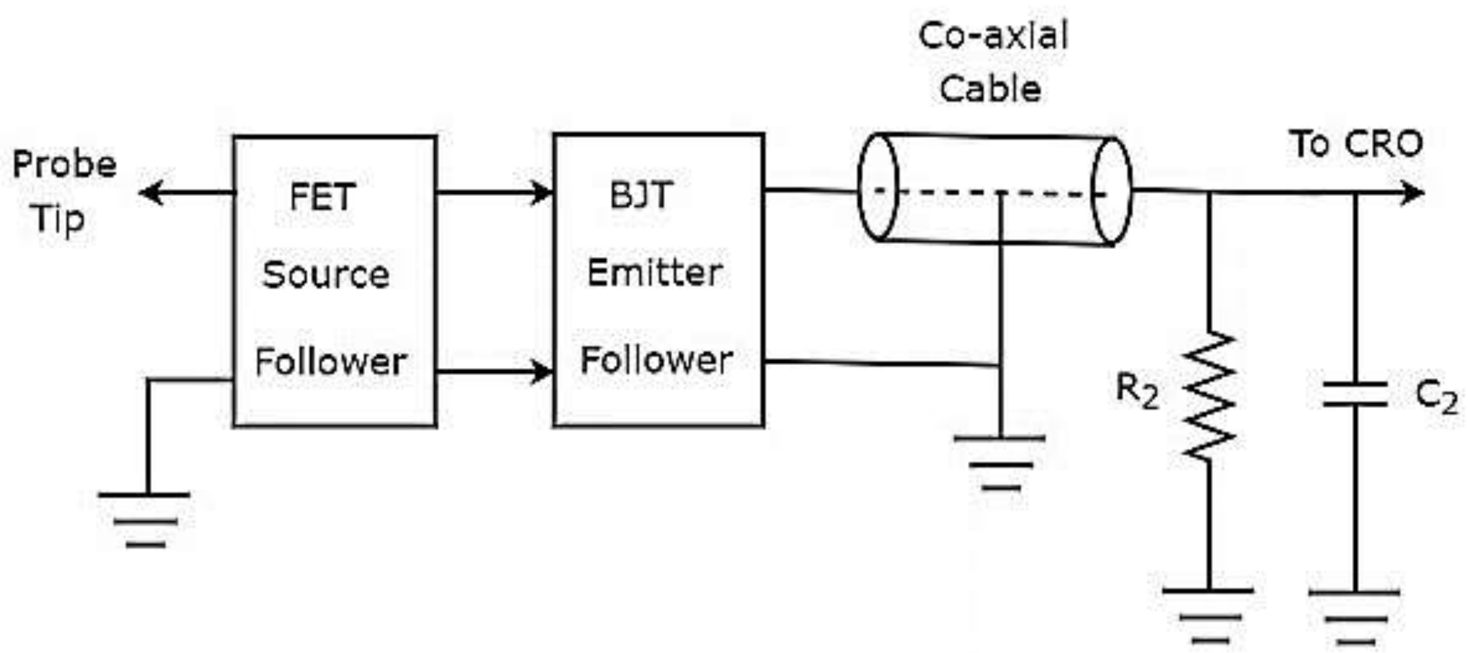
$$\Rightarrow C1=C2/(\alpha-1)$$

From Equation 3, we can conclude that the value of C1 is less than or equal to the value of C2 for integer values of $\alpha>1$

Active Probes

If the probe head consists of active electronic components, then it is called **active probe**. The block diagram of active probe is shown in below figure.

.



Active Probes

- As shown in the figure, the probe head consists of a FET source follower in cascade with BJT emitter follower.
- The FET source follower provides high input impedance and low output impedance. Whereas, the purpose of BJT emitter follower is that it avoids or eliminates the impedance mismatching.
- The other two parts, such as co-axial cable and termination circuit remain same in both active and passive probes.

MODULE-III

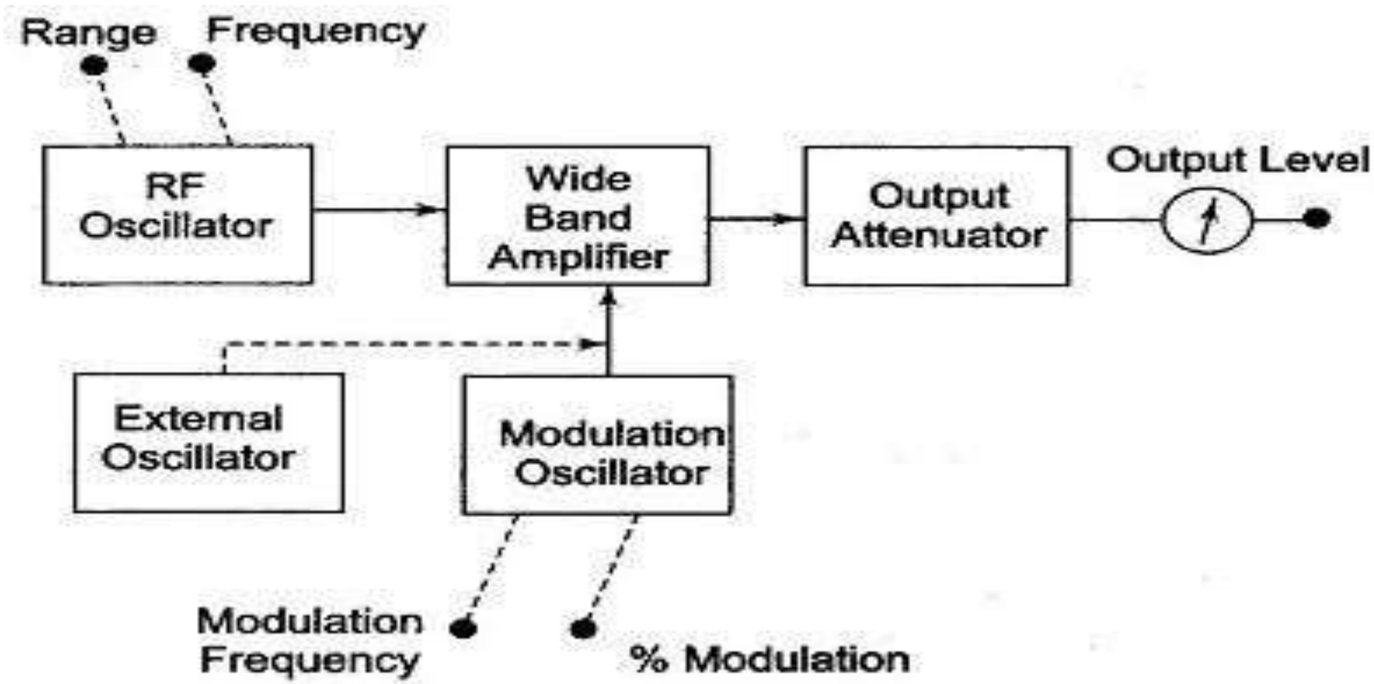
SIGNAL GENERATOR AND SIGNAL ANALYZERS

Standard Signal Generator

- A standard signal generator produces known and controllable voltages.
- It is used as power source for the measurement of gain, signal to noise ratio (S/N), bandwidth, standing wave ratio and other properties. It is extensively used in the testing of radio receivers and transmitters.
- The instrument is provided with a means of modulating the carrier frequency, which is indicated by the dial setting on the front panel.

Standard Signal Generator

- 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.



Conventional Standard Signal Generator

Standard Signal Generator

- The carrier frequency is generated by a very stable RF oscillator using an LC tank circuit, having a constant output over any frequency range.

- The frequency of oscillations is indicated by the frequency range control and the vernier dial setting. AM is provided by an internal sine wave generator or from an external source.

- (Modulation is done in the output amplifier circuit. This amplifier delivers its output, that is, modulation carrier, to an attenuator. The output voltage is read by an output meter and the attenuator output setting.)

Standard Signal Generator

- Frequency stability is limited by the LC tank circuit design of the master oscillator.

- Since range switching is usually accomplished by selecting appropriate capacitors, any change in frequency range upsets the circuit design to some extent and the instrument must be given time to stabilize at the new resonant frequency.

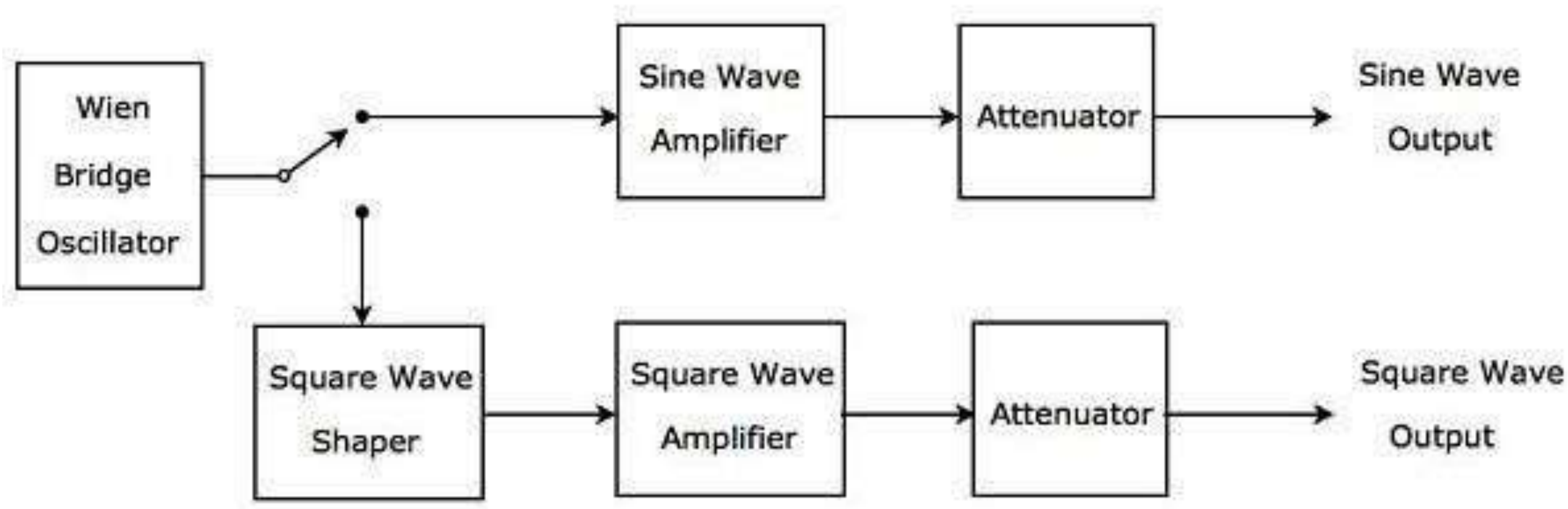
- In high frequency oscillators, it is essential to isolate the oscillator circuit from the output circuit. This isolation is necessary, so that changes occurring in the output circuit do not affect the oscillator frequency, amplitude and distortion characteristics. Buffer amplifiers are used for this purpose.

SIGNAL GENERATORS

- **Signal generator** is an electronic equipment that provides standard test signals like sine wave, square wave, triangular wave and etc.
- It is also called an oscillator, since it produces periodic signals.
- The signal generator, which produces the periodic signal having a frequency of Audio Frequency (AF) range is called **AF signal generator**.
- The range of audio frequencies is 20Hz to 20KHz.

AF Sine and Square Wave Generator

The AF signal generator, which generates either sine wave or square wave in the range of audio frequencies based on the requirement is called AF Sine and Square wave generator. Its **block diagram** is shown in below figure.



AF Sine and Square Wave Generator

- The above block diagram consists of mainly **two paths**. Those are upper path and lower path.

- Upper path is used to produce AF sine wave and the lower path is used to produce AF square wave.

- **Wien bridge oscillator** will produce a sine wave in the range of audio frequencies. Based on the requirement, we can connect the output of Wien bridge oscillator to either upper path or lower path by a switch.

AF Sine and Square Wave Generator

- The upper path consists of the blocks like sine wave amplifier and attenuator.

- If the switch is used to connect the output of Wien bridge oscillator to upper path, it will produce a desired **AF sine wave** at the output of upper path.

- The lower path consists of the following blocks: square wave shaper, square wave amplifier, and attenuator.

- The square wave shaper converts the sine wave into a square wave.

AF Sine and Square Wave Generator

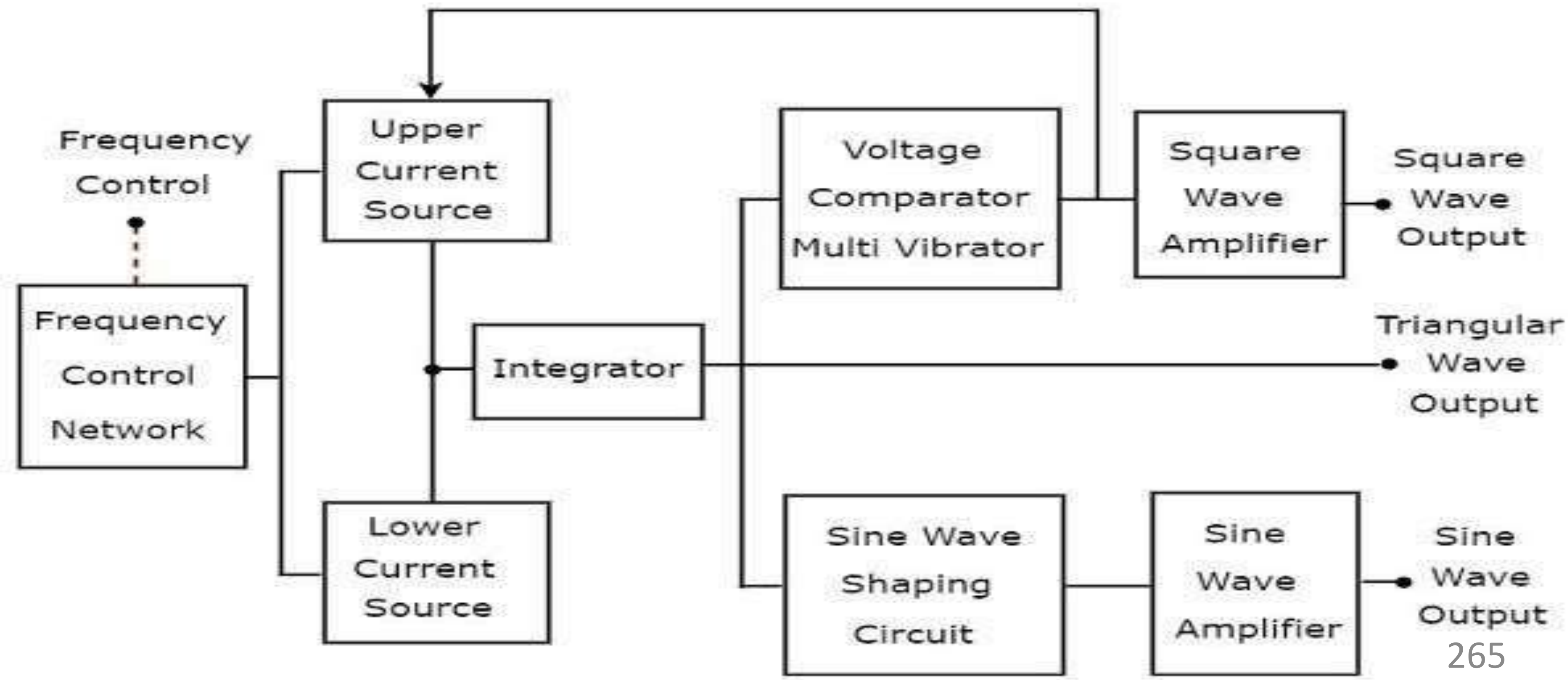
- If the switch is used to connect the output of Wien bridge oscillator to lower path, then it will produce a desired **AF square wave** at the output of lower path.

- In this way, the block diagram that we considered can be used to produce either AF sine wave or AF square wave based on the requirement.

Function Generators

Function Generator

- Function generator is a signal generator, which generates three or more periodic waves. A Function generator, which will produce periodic waves like triangular wave, square wave and sine wave.



Function Generator

- There are two **current sources**, namely upper current source and lower current source in above block diagram.

- These two current sources are regulated by the frequency-controlled voltage.

Triangular Wave

- **Integrator** present in the above block diagram, gets constant current alternately from upper and lower current sources for equal amount of time repeatedly.

- So, the integrator will produce two types of output for the same time repeatedly –

- So, the integrator will produce two types of output for the same time repeatedly –
  - The output voltage of an integrator **increases linearly** with respect to time for the period during which integrator gets current from upper current source.
  - The output voltage of an integrator **decreases linearly** with respect to time for the period during which integrator gets current from lower current source.

In this way, the integrator present in above block diagram will produce a **triangular wave**.

Square Wave & Sine Wave

- The output of integrator, i.e. the triangular wave is applied as an input to two other blocks as shown in above block diagram in order to get the square wave and sine wave respectively. Let us discuss about these two one by one.

Square Wave

- The triangular wave has positive slope and negative slope alternately for equal amount of time repeatedly.
- So, the **voltage comparator multivibrator** present in above block diagram will produce the following two types of output for equal amount of time repeatedly.

Function Generator

- One type of constant **(higher) voltage** at the output of voltage comparator multivibrator for the period during which the voltage comparator multivibrator gets the positive slope of the triangular wave.

- Another type of constant **(lower) voltage** at the output of voltage comparator multivibrator for the period during which the voltage comparator multi vibrator gets the negative slope of the triangular wave.

The voltage comparator multivibrator present in above block diagram will produce a **square wave**.

Function Generator

- If the amplitude of the square wave that is produced at the output of voltage comparator multivibrator is not sufficient, then it can be amplified to the required value by using a square wave amplifier.

Sine Wave

- The **sine wave shaping circuit** will produce a sine wave output from the triangular input wave. Basically, this circuit consists of a diode resistance network.

- If the amplitude of the sine wave produced at the output of sine wave shaping circuit is insufficient, then it can be amplified to the required value by using sine wave amplifier.

Arbitrary waveform generators (AWGs)

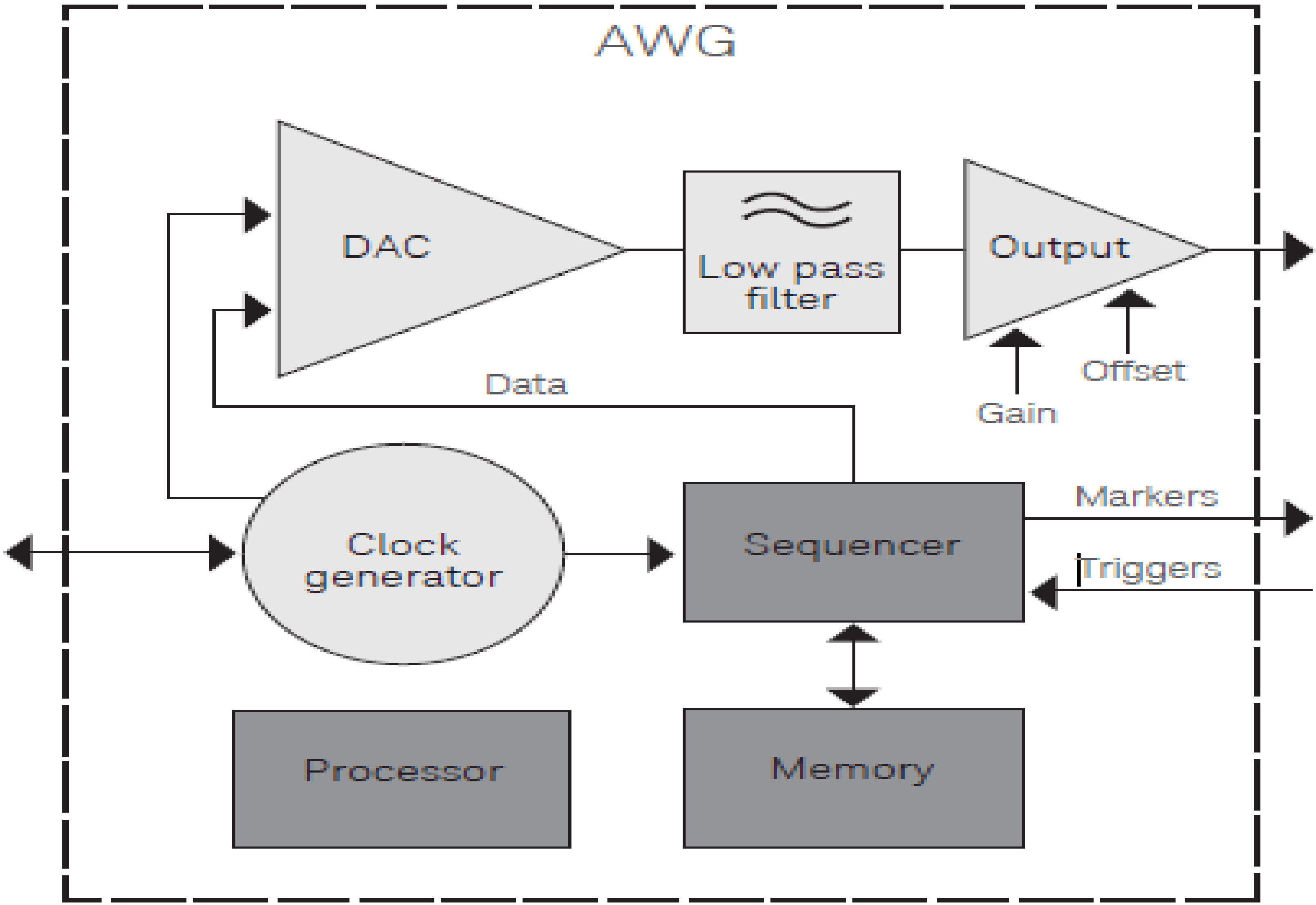
- Arbitrary waveform generators (AWGs) are the most versatile signal generators available.

- An AWG can generate any mathematically-characterized signal, including sine wave, pulse, modulated, multitone, polarized, and rotated signals.

- The AWG is commonly seen as the workhorse piece of test equipment and can perform the functions of any other generator type.

- A typical block diagram of an AWG is shown below.

Arbitrary waveform generators (AWGs)



Arbitrary waveform generators (AWGs)

- The signal flow through the functional blocks starts with a numeric description of a waveform stored in memory.
- Then the selected waveform samples are sent to a digital-to-analog converter (DAC), filtered, conditioned, amplified and output as an analog waveform.

AWG-Functional Block

1. Memory

- A digital representation of a waveform is loaded into AWG memory through a variety of software applications, such as MATLAB, LabView, Visual Studio Plus, IVI, and SCPI.

- The memory is clocked at the highest sampling rate supported by the AWG.

- The size of the memory will dictate the amount of signal playback time available.

- A rule of thumb to determine the playback time is: memory depth divided by sample rate equals playback time. The faster your sample rate, the quicker you will use up the available memory.

2. Sequencer

- The sequencer circuitry can solve memory depth limitations by arranging (sequencing) the waveform into segments to create your desired waveform.

- Memory sequencing (or memory ping-pong) does this by only enabling memory during critical waveform portions and then shutting off.

- You can think about it like this: when recording a round of golf, imagine how much recording time you would save if you only recorded the players striking the ball and not all the walking and setup time.

AWG-Functional Block

2. Sequencer

- The sequencer does the same thing by only recording waveform transitions and not idle time.

- Synchronization is maintained by the trigger generator, which enables the waveform.

- Trigger events can be internal, external, or linked to another AWG.

AWG-Functional Block

3. Markers and Triggers

- Marker outputs are useful for triggering external equipment. Trigger inputs are used to alter sequencer operation, resulting in the desired waveform entering the DAC.
- Hardware or software triggers can be used for applications requiring exact timing, like wideband chirp signals.
- They can also be used where multiple AWGs are synchronized together and need to be triggered simultaneously.

4. Clock Generator

- The timing of the waveform is controlled by an internal or external clock source.
- The memory controller keeps track of waveform events in memory and then outputs them in the correct order to the DAC.
- The memory controller saves space by looping on repetitive elements so that the elements are listed only once in the waveform memory.
- Clocking circuitry controls both the DAC and the sequencer.

5. Digital-to-Analog Converter (DAC)

- Waveform memory contents are sent to the DAC. Here the digital voltage values are converted into analog voltages.
- The number of bits within the DAC will impact the AWG's vertical resolution.
- The higher the number of bits, the higher the vertical resolution and the more detailed the output waveform will be. DACs can use interpolation to reach an even higher update rate than what was supplied by the waveform memory.

AWG-Functional Block

6. Low Pass Filter

- Because the DAC output is a series of voltage stair steps, it is harmonic-rich and requires filtering for a smooth sinusoidal analog waveform.

7. Output Amplifier

- After the signal passes through the filter, it will enter an amplifier. The amplifier controls both gain and offset. This gives you the flexibility to adjust output gain and offset depending on your application.

- For example, you may need high dynamic ranges for radar and satellite solutions or high bandwidth for high-speed and coherent optical solutions.

Advantages and disadvantages of AFG

Arbitrary function generator advantages

- ***Sub Hz frequency resolution:*** By using a long word length phase accumulator in the phase accumulator of the DDS, it is possible to achieve sub-Hertz frequency resolution levels.

- ***Down sampling:*** Waveforms are automatically truncated by sampling to allow repetition rates above the clock frequency.

- ***Digital modulation:*** It is possible to add digital modulation words to the phase accumulator to provide a means of providing digital modulation.

Advantages and disadvantages of AFG

Arbitrary function generator disadvantages

- ***Waveform jitter:*** Waveform jitter is an issue with arbitrary function generators because frequencies are up-sampled or down-sampled and this results in missing samples and hence jitter. Only frequencies equal to the clock frequency divided by the waveform length and its sub multiples are not sampled and therefore they do not suffer from this problem.

- ***Single waveform capability:*** It is only possible to generate a single waveform at a time because memory segmentation and waveform sequencing is not possible using a DDS arbitrary function generator

Signal (or) Wave Analyzers

Introduction:

- Any complex waveform is made up of a fundamental frequency and its harmonics. It is often required to measure the amplitude of each harmonic and fundamental frequency individually. This can be done using instrument known as wave analyzer.

- Wave analyzers are also referred to as frequency selective voltmeter, carrier frequency voltmeter and selective level voltmeter.

- The wave analyzers are tuned to the frequency of the component, whose amplitude is to be measured.

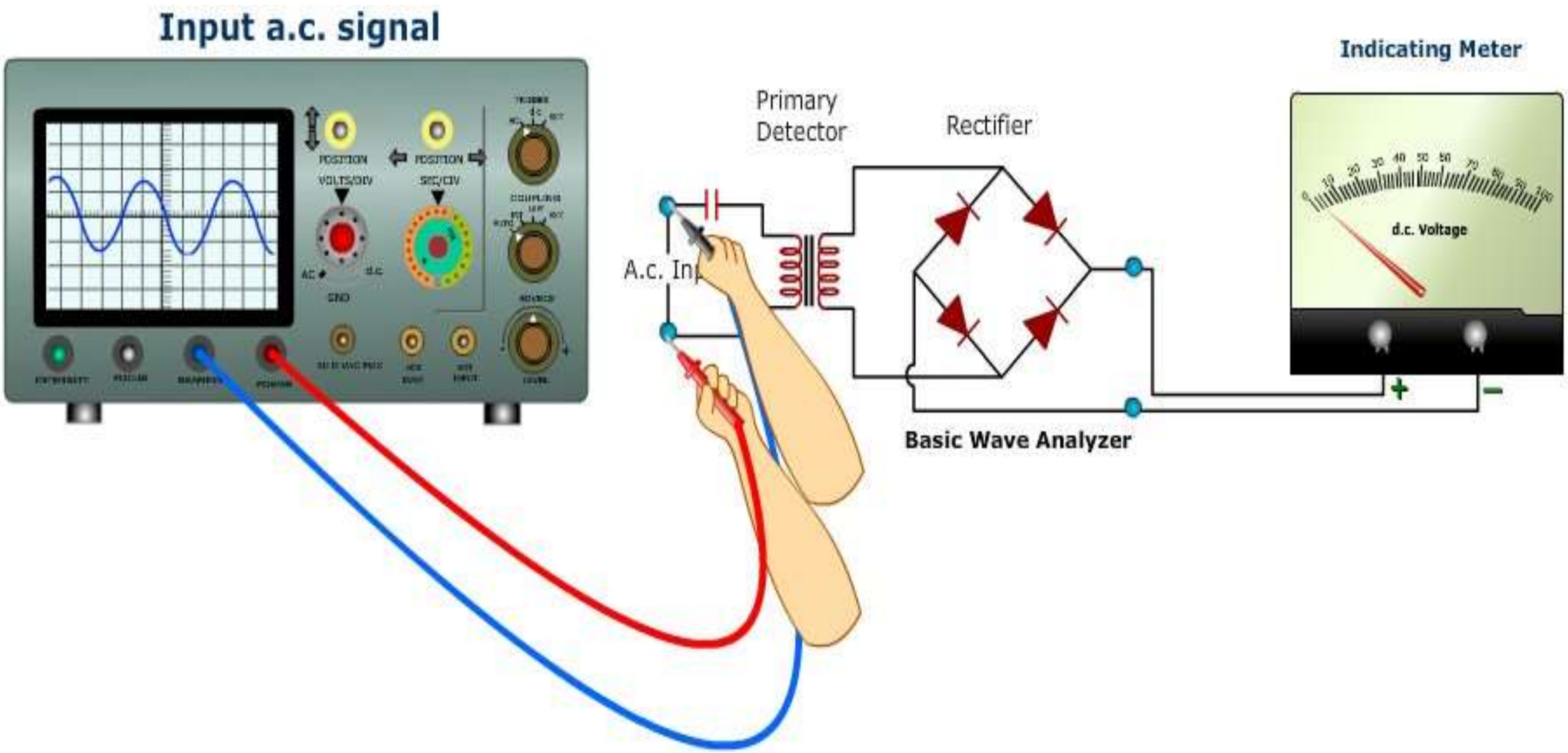
Signal (or) Wave Analyzers

- The electronic instrument used to analyze waves is called **wave analyzer**. It is also called signal analyzer, since the terms signal and wave can be interchangeably used frequently.

- We can represent the **periodic signal** as sum of the following two terms.
  - DC component
  - Series of sinusoidal harmonics

- So, analyzation of a periodic signal is analyzation of the harmonics components presents in it.

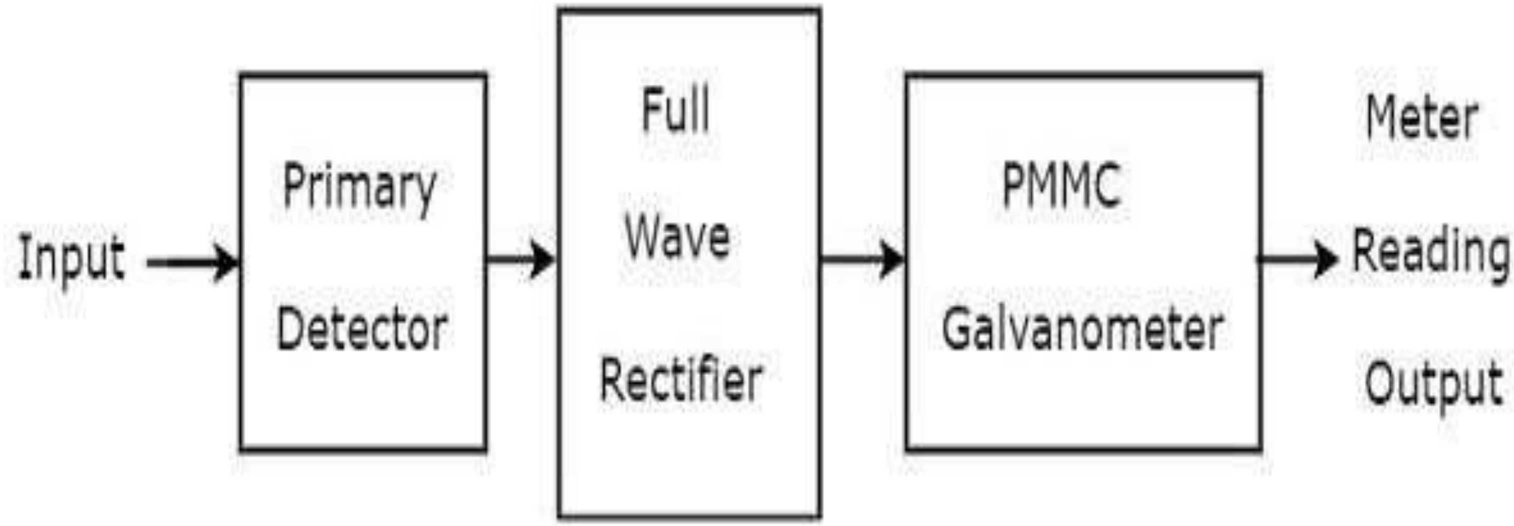
Signal (or) Wave Analyzers



Basic Wave Analyzer

Basic Signal (or) Wave Analyzers

- Basic wave analyzer mainly consists of three blocks – the primary detector, full wave rectifier, and PMMC galvanometer. The **block diagram** of basic wave analyzer is shown in below figure –



Basic Signal (or) Wave Analyzers

- The **function** of each block present in basic wave analyzer is mentioned below.

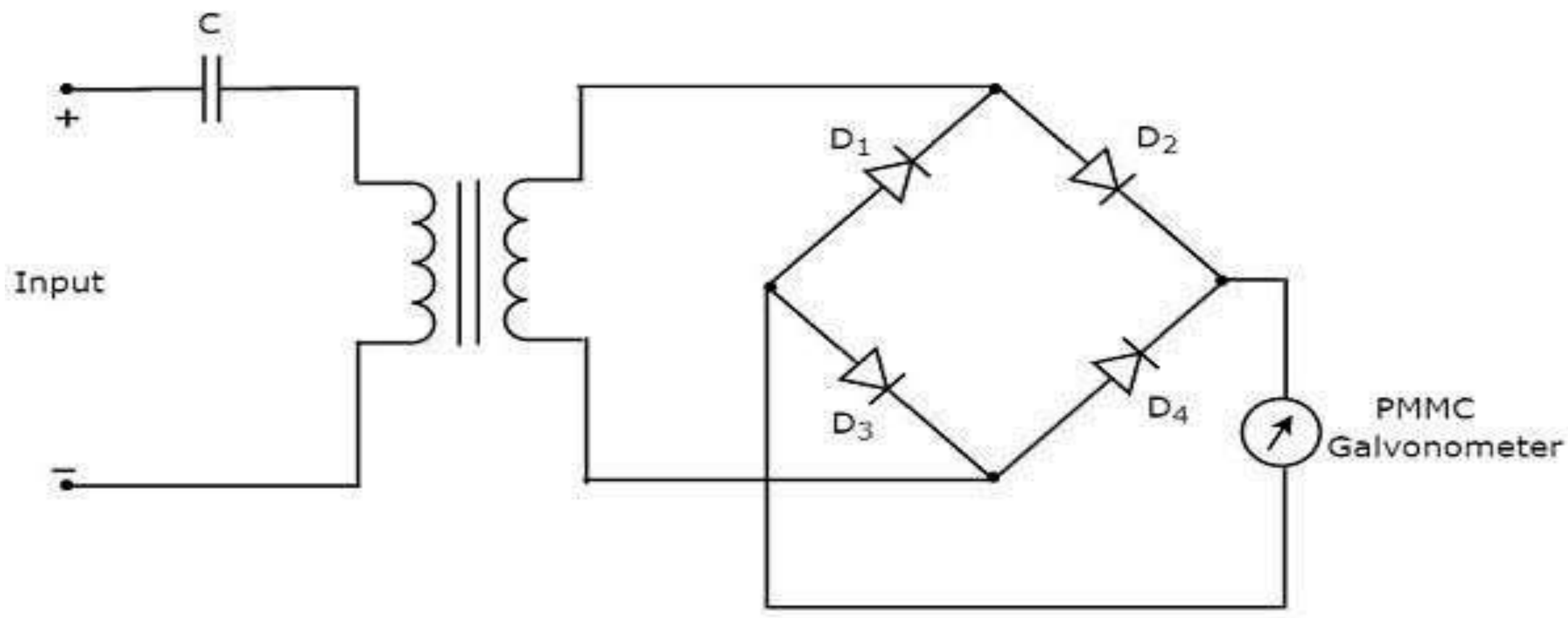
- **Primary Detector** − It consists of an LC circuit. We can adjust the values of inductor, L and capacitor, C in such a way that it allows only the desired harmonic frequency component that is to be measured.

- **Full Wave Rectifier** − It converts the AC input into a DC output.

- **PMMC Galvanometer** − It shows the peak value of the signal, which is obtained at the output of Full wave rectifier.

Basic Signal (or) Wave Analyzers

- We will get the corresponding circuit diagram, just by replacing each block with the respective component(s) in above block diagram of basic wave analyzer.
- So, the **circuit diagram** of basic wave analyzer will look like as shown in the following figure −



Basic Signal (or) Wave Analyzers

- This basic wave analyzer can be used for analyzing each and every harmonic frequency component of a periodic signal.

- The wave analyzer, used for analyzing the signals are of AF range is called frequency selective wave analyzer.

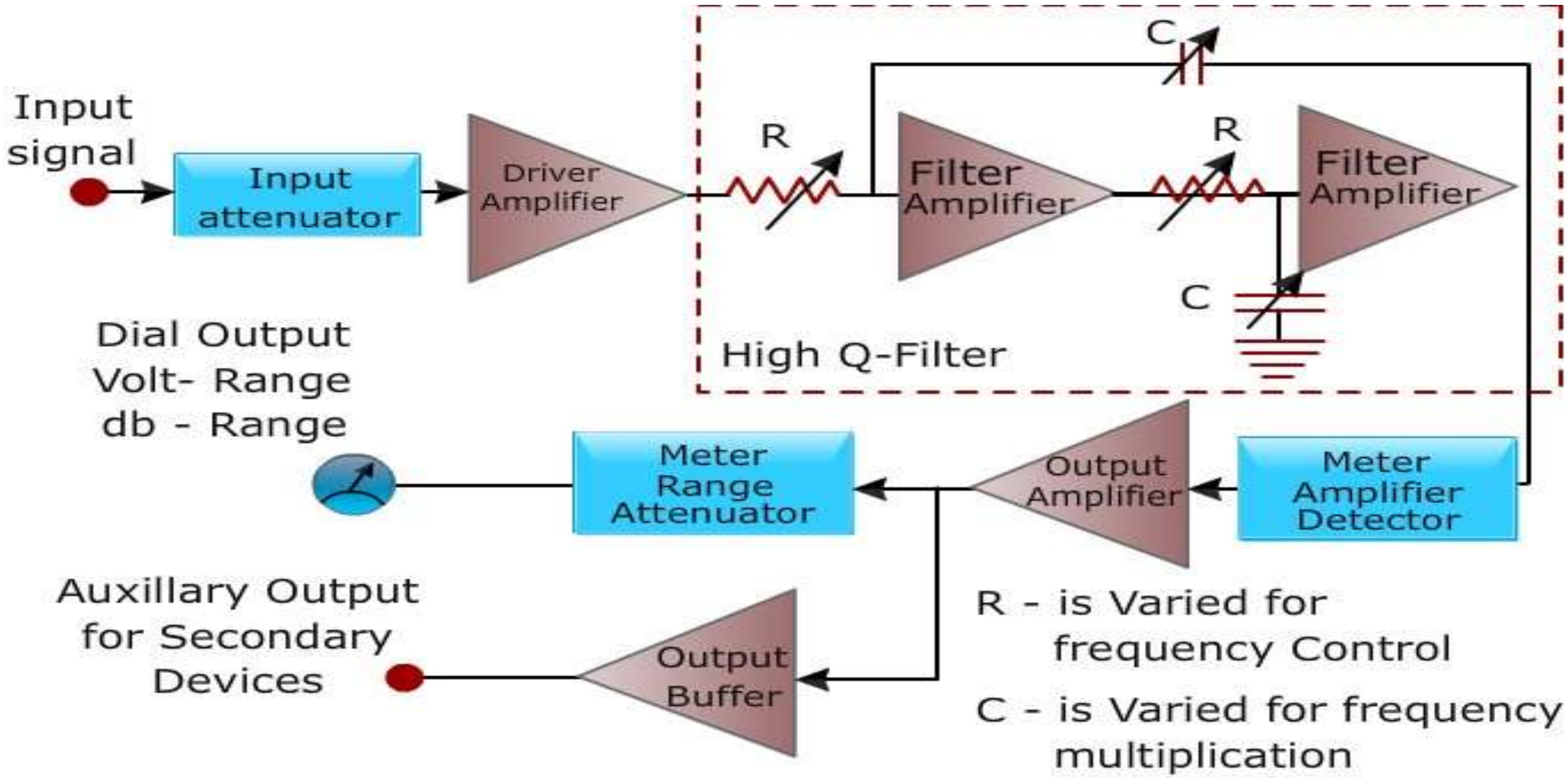
Types of Wave Analyzers

Wave analyzers can be classified into the following **two types**.

- **Frequency Selective Wave Analyzer**
- **Super heterodyne Wave Analyzer**

Frequency Selective Wave Analyzer

- The **block diagram** of frequency selective wave analyzer is shown in below figure.



Frequency Selective Wave Analyzer

Frequency Selective Wave Analyzer

Frequency selective wave analyzer consists a set of blocks. The **function** of each block is mentioned below.

- **Input Attenuator** − The AF signal, which is to be analyzed is applied to input attenuator. If the signal amplitude is too large, then it can be attenuated by input attenuator.

- **Driver Amplifier** − It amplifies the received signal whenever necessary.

- **Meter Range Attenuator** − It gets the selected AF signal as an input & produces an attenuated output, whenever required.

- **Meter Circuit** − It displays the reading of selected AF signal. We can choose the meter reading in volt range or decibel range.

Frequency Selective Wave Analyzer

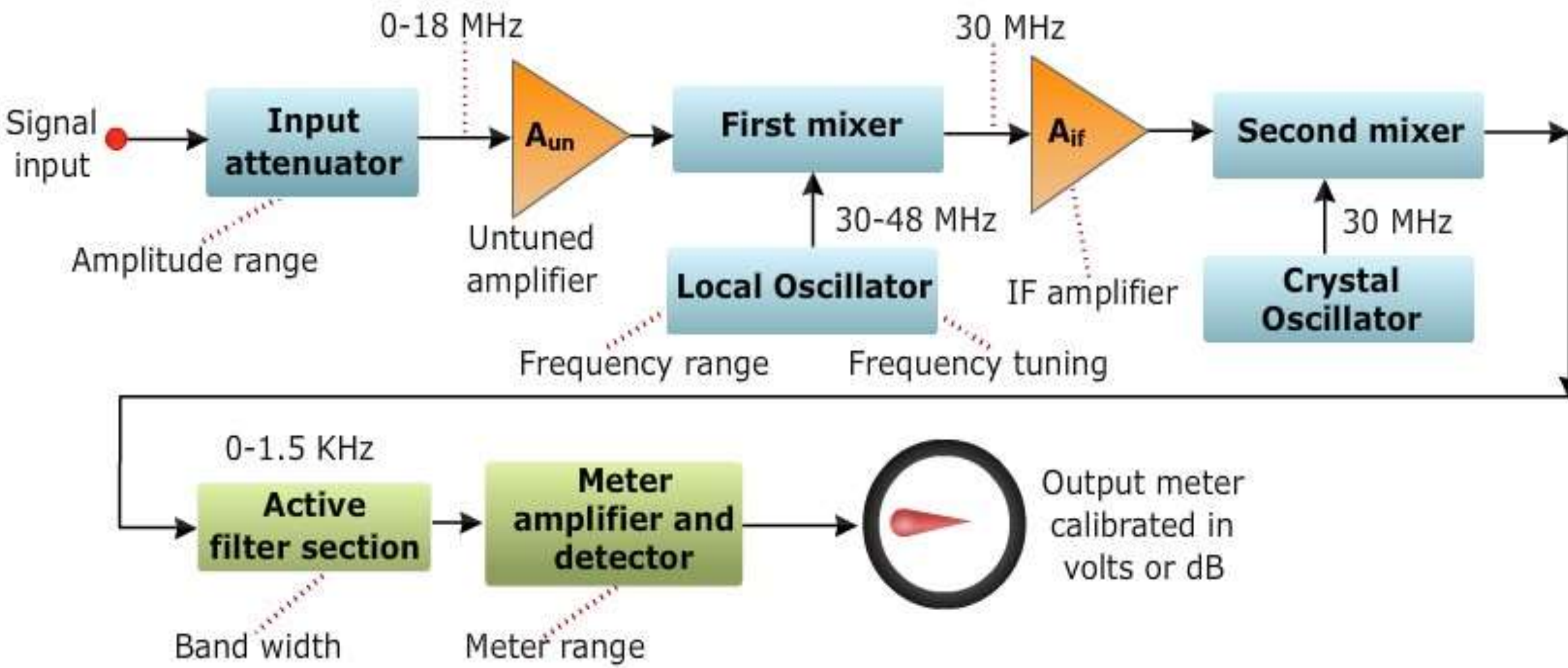
- **High Q-filter** − It is used to select the desired frequency and reject unwanted frequencies. It consists of two RC sections and two filter amplifiers & all these are cascaded with each other.

- We can vary the capacitance values for changing the range of frequencies in powers of 10. Similarly, we can vary the resistance values in order to change the frequency within a selected range.

- **Output Amplifier** − It amplifies the selected AF signal if necessary.
- **Output Buffer** − It is used to provide the selected AF signal to output devices.

Super heterodyne Wave Analyzer

➢ The wave analyzer, used to analyze the signals of RF range is called super heterodyne wave analyzer.



Block Diagram of Heterodyne Wave Analyzer

Super heterodyne Wave Analyzer

- The **working** of super heterodyne wave analyzer is mentioned below.
- The RF signal, which is to be analyzed is applied to the input attenuator. If the signal amplitude is too large, then it can be attenuated by **input attenuator**.
- **Untuned amplifier** amplifies the RF signal whenever necessary and it is applied to first mixer.
- The frequency ranges of RF signal & output of Local oscillator are 0-18 MHz & 30-48 MHz respectively.
- So, **first mixer** produces an output, which has frequency of 30 MHz. This is the difference of frequencies of the two signals that are applied to it.

Super heterodyne Wave Analyzer

- **IF amplifier** amplifies the Intermediate Frequency (IF) signal, i.e. the output of first mixer. The amplified IF signal is applied to second mixer.

- The frequencies of amplified IF signal & output of Crystal oscillator are same and equal to 30MHz.

- So, the **second mixer** produces an output, which has frequency of 0 Hz. This is the difference of frequencies of the two signals that are applied to it.

- The cut off frequency of **Active Low Pass Filter (LPF)** is chosen as 1500 Hz. Hence, this filter allows the output signal of second mixer.

Super heterodyne Wave Analyzer

- **Meter Circuit** displays the reading of RF signal. We can choose the meter reading in volt range or decibel range.

- So, we can choose a particular wave analyzer based on the frequency range of the signal that is to be analyzed.

Harmonic Distortion Analyzer

- The application of purely sinusoidal input signal to an amplifier should result in purely sinusoidal signal at the output.

- But practically output waveform is not exact replica of the input. This is because of presence of various types of distortions.

- Such distortions are due to the inherent nature of amplifier or non linear characteristics of various components used.

- The distortion caused due to non linear behavior of the circuit element is called harmonic distortion.

- In case of sine wave which is harmonically distorted, it consist of a fundamental frequency ‘f’ and the harmonic multiple of fundamental frequency 2f, 3f…etc..

Harmonic Distortion Analyzer

- 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

$$D_2 = \frac{B_2}{B_1}, \quad D_3 = \frac{B_3}{B_1}, \quad D_4 = \frac{B_4}{B_1}$$

Where Dn represents the distortions of the nth harmonic. Bn represents the amplitude of the nth harmonic and B1 represents the amplitude of the fundamental frequency component.

- The total harmonic distortion or distortion factor is defined as

$$THD = \frac{\left[\Sigma(Harmonics)^2\right]^{\frac{1}{2}}}{Fundamental} = \frac{\sqrt{B^2{}_2 + B_3^2 + B_4^2 + ---}}{B_1}$$

Harmonic Distortion Analyzer

- ➢The total harmonic distortion or distortion factor is defined as

$$THD = \frac{\left[\Sigma(Harmonics)^2\right]^{\frac{1}{2}}}{Fundamental} = \frac{\sqrt{B^2{}_2 + B_3^2 + B_4^2 + ---}}{B_1}$$

$$THD = \sqrt{D_2^2 + D_3^2 + D_4^2 + ---}$$

Different types of harmonic distortion analyzers are there, in that we are going to see Fundamental Suppression type.

Fundamental Suppression type

- A distortion analyzer measures the total harmonic power present in the test wave rather than the distortion caused by each component.

- The simplest method is to suppress the fundamental frequency by means of a high pass filter whose frequency is a little above the fundamental frequency.

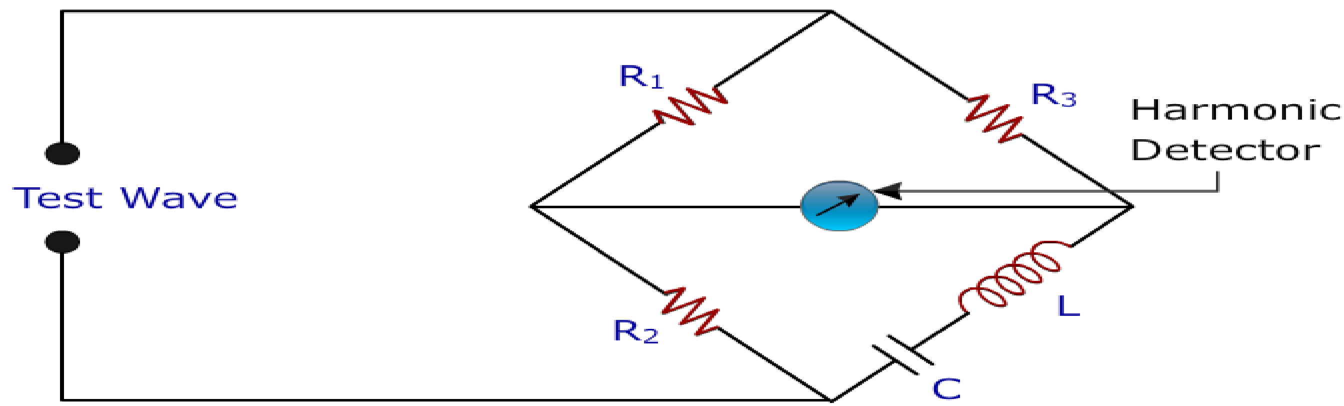
- This high pass allows only the harmonics to pass and the total harmonic distortion can then be measured.

Fundamental Suppression type

(a) Employing Resonance Bridge

➢The bridge is balanced for fundamental frequency, i.e. L and C are tuned to the fundamental frequency.

➢The bridge is unbalanced for the harmonics, i.e. only harmonic power will be available at the output terminal and can be measured.



Resonance Bridge

(a) Employing Resonance Bridge

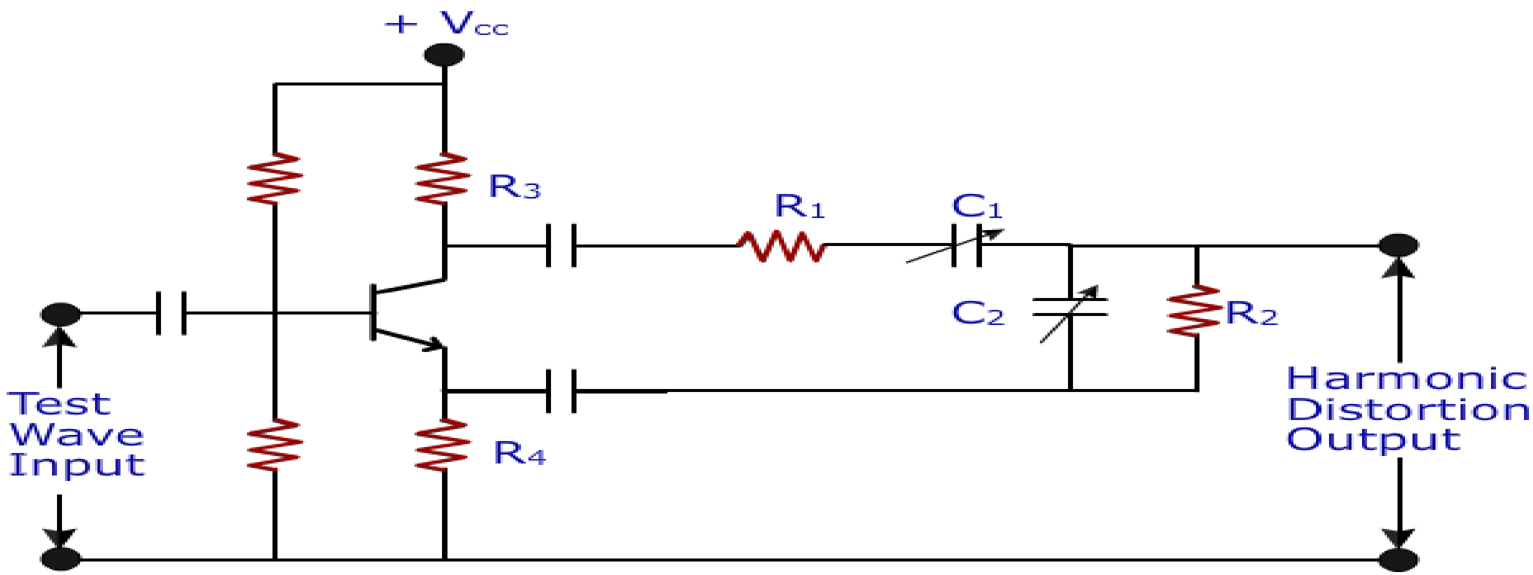
- The bridge is unbalanced for the harmonics, i.e. only harmonic power will be available at the output terminal and can be measured.

- If the fundamental frequency is changed, the bridge must be balanced again. If L& C are fixed components, then this method is suitable only when the test wave has a fixed frequency.

- Indicators can be thermocouples or square law VTVM's. This indicates the RMS value of all harmonics.

- When a continuous adjustment of the fundamental frequency is desired, a wien bridge arrangement is used.

(b) Wien's Bridge Method



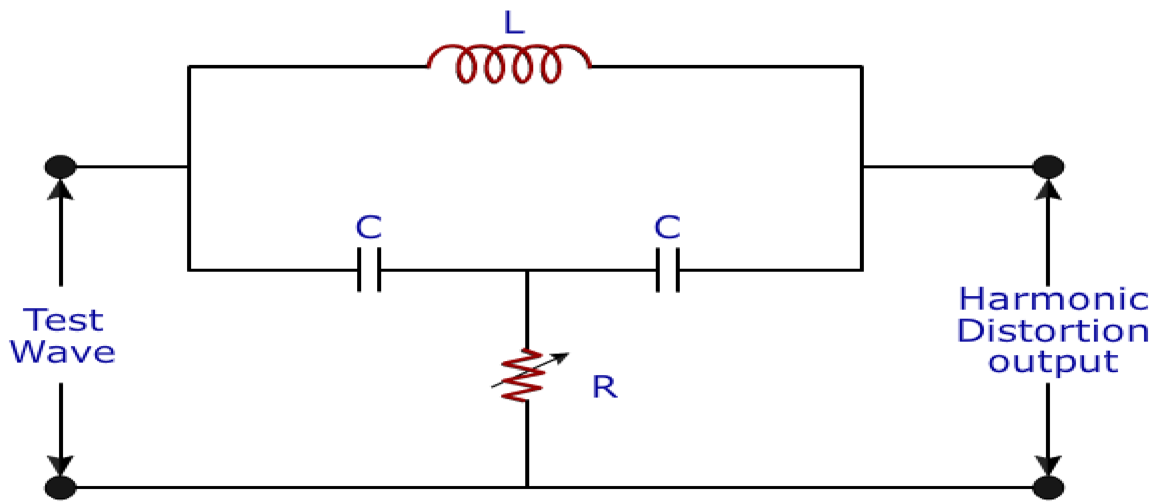
Wien's Bridge Method

➢The bridge is balanced for the fundamental frequency. The fundamental energy is dissipated in the bridge circuit elements. Only the harmonic components reach the output terminals.

➢The harmonic distortion output can then be measured with a meter. For balance at the fundamental frequency

$C_1 = C_2 = C$, $R_1 = R_2 = R$, $R_3 = 2R_4$.

(C) Bridged T-Network

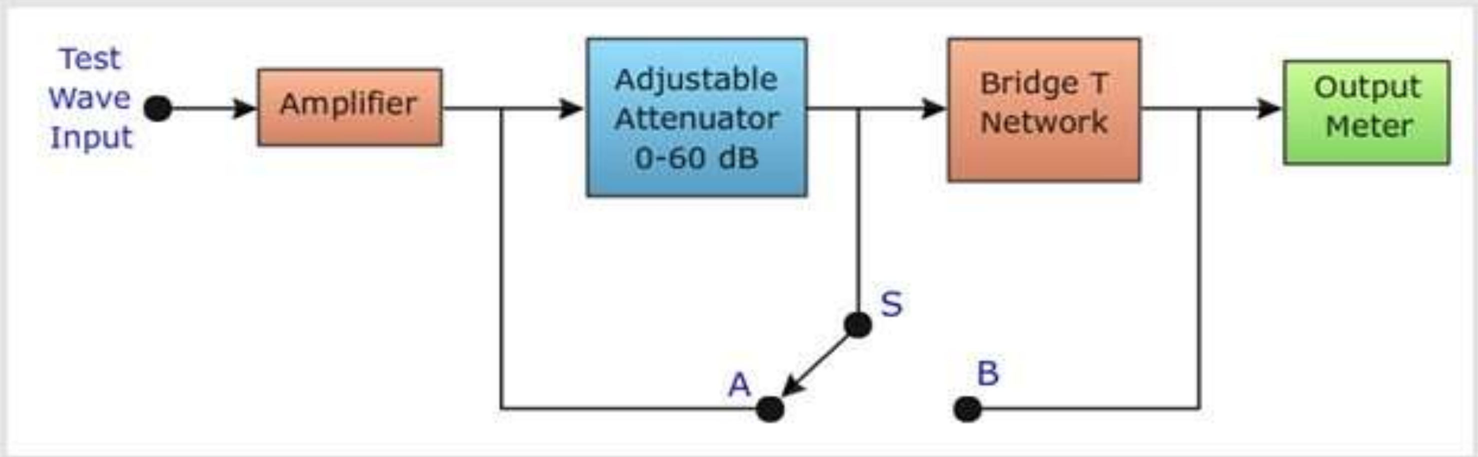


Bridged T-Network Method

- From the figure L and C's are tuned to the fundamental frequency, and R is adjusted to bypass fundamental frequency.

- The tank circuit being tuned to the fundamental frequency, the fundamental energy will circulate in the tank and is bypassed by the resistance. Only harmonic components will reach the output terminals and the distorted output can be measured by the meter.

HDA Using Bridged T-Network



Harmonic Distortion Analyzer Using Bridged T-Network

- From the figure, The switch S is first connected to point A so that the attenuator is excluded and the bridge T-network is adjusted for full suppression of the fundamental frequency, i.e. Minimum output indicates that the bridged T network is tuned to the fundamental frequency and that fundamental frequencies is fully suppressed.

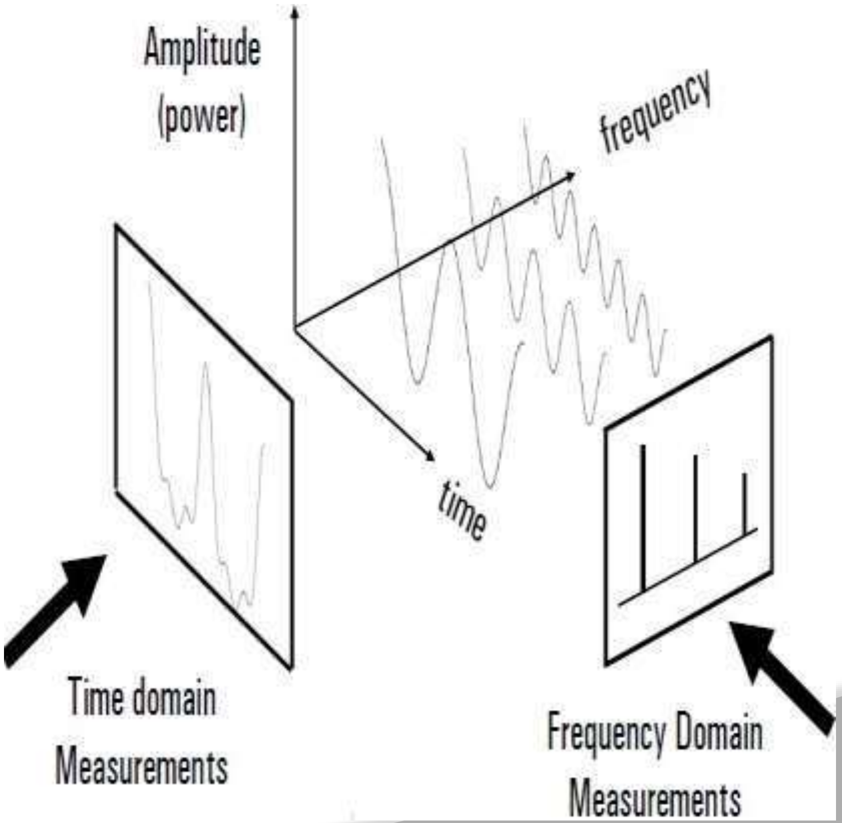
spectrum analyzer

Introduction

- A **spectrum analyzer** measures the amplitude of an input signal versus frequency within the full frequency range of the instrument
- The spectrum analyzer is to the frequency domain where as the oscilloscope is to the time domain

•In the frequency domain, complex signals are separated into their frequency components, and the level at each frequency is displayed

•Spectrum analyzer greatly reduces the amount of noise present in the measurement and also ensure there's no interference from neighbouring frequencies.



Types of Spectrum Analyzers

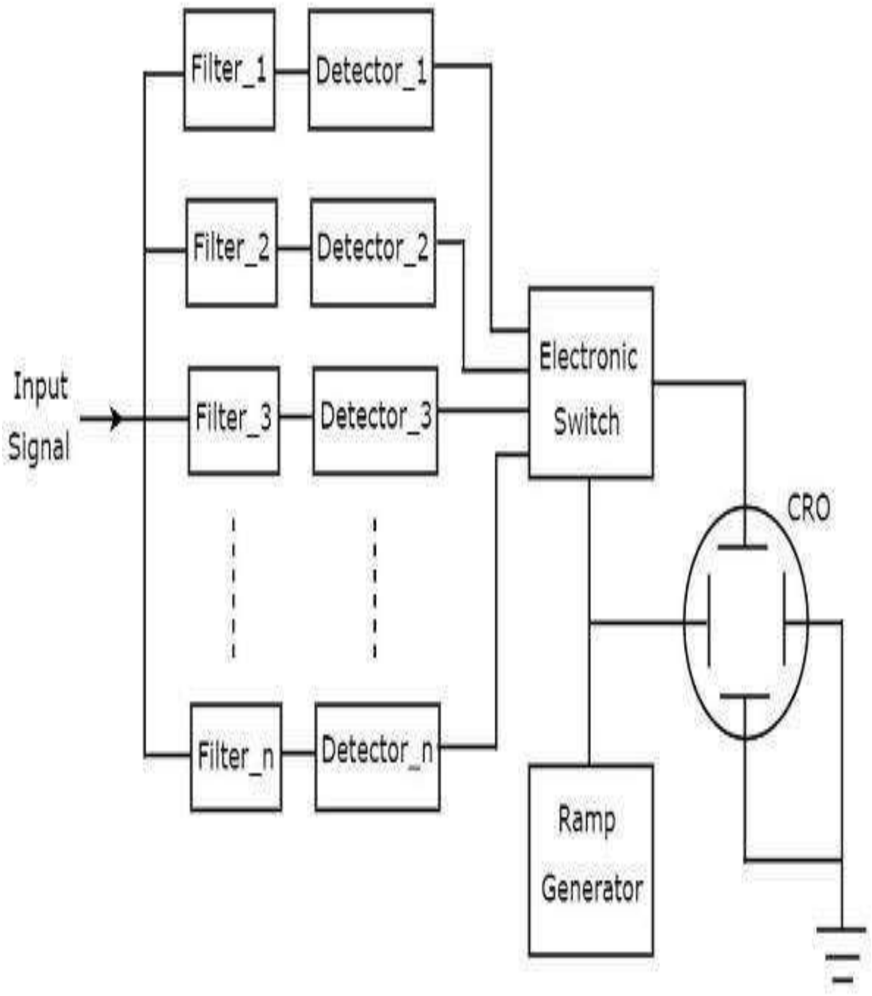
- The most common spectrum analyzer measurements are: **modulation, distortion,** and **noise**

➢ We can classify the spectrum analyzers into the following two types.
  - ➢ **Filter Bank Spectrum Analyzer**
  - ➢ **Super heterodyne Spectrum Analyzer**

Filter Bank Spectrum Analyzer

The spectrum analyzer, used for analyzing the signals are of AF range is called filter bank spectrum analyzer, or real time spectrum analyzer because it shows (displays) any variations in all input frequencies.

Filter Bank Spectrum Analyzer



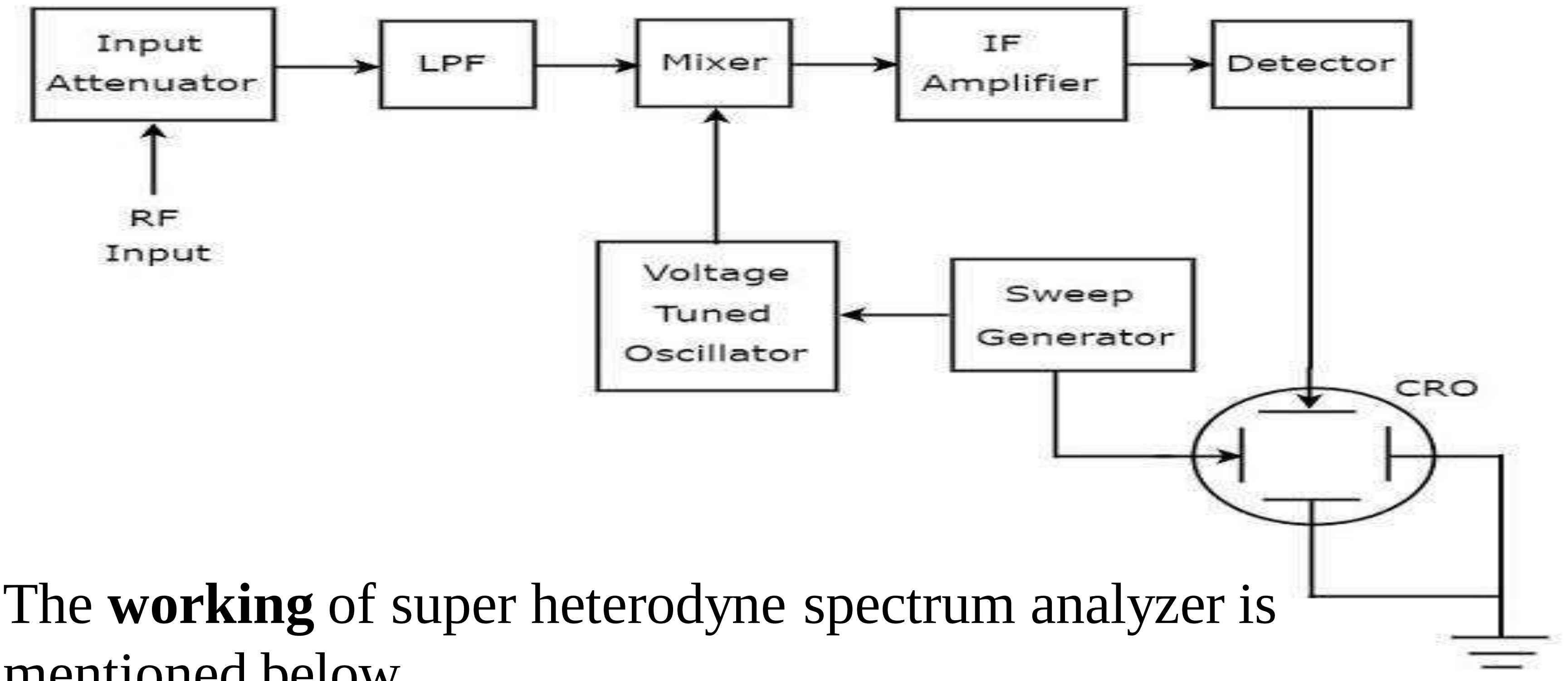
- ➢The **working** of filter bank spectrum analyzer is mentioned below.

It has a set of band pass filters and each one is designed for allowing a specific band of frequencies. The output of each band pass filter is given to a corresponding detector.

All the detector outputs are connected to Electronic switch. This switch allows the detector outputs sequentially to the vertical deflection plate of CRO. So, CRO displays the frequency **spectrum of AF signal** on its CRT screen.

Super heterodyne Spectrum Analyzer

The spectrum analyzer, used for analyzing the signals are of RF range is called **super heterodyne spectrum analyzer**.



The **working** of super heterodyne spectrum analyzer is mentioned below.

The RF signal, which is to be analyzed is applied to input attenuator. If the signal amplitude is too large, then it can be attenuated by an **input attenuator**.

Super heterodyne Spectrum Analyzer

Low Pass Filter (LPF) allows only the frequency components that are less than the cut-off frequency.

Mixer gets the inputs from Low pass filter and voltage tuned oscillator. It produces an output, which is the difference of frequencies of the two signals that are applied to it.

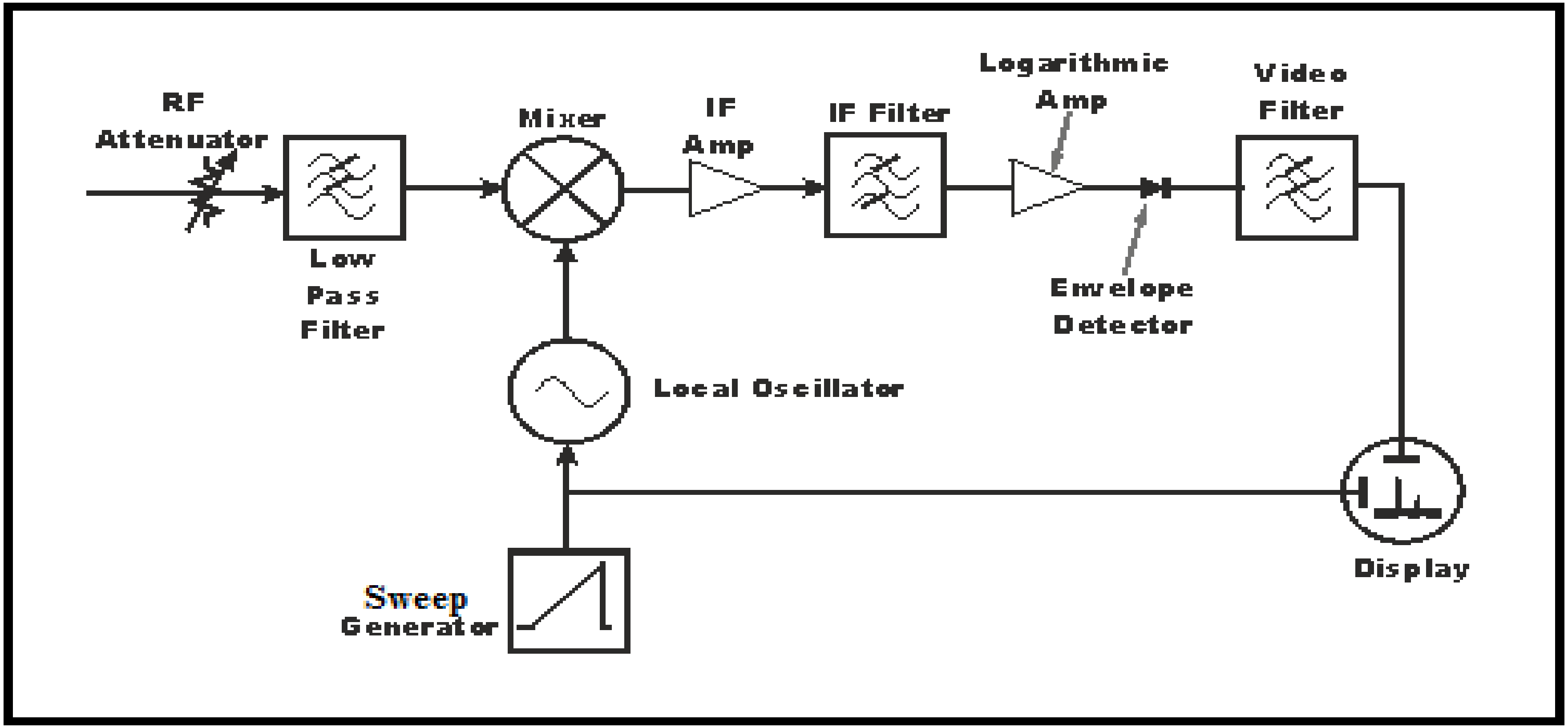
IF amplifier amplifies the Intermediate Frequency (IF) signal, i.e. the output of mixer. The amplified IF signal is applied to detector.

The output of detector is given to vertical deflection plate of CRO. So, CRO displays the frequency **spectrum of RF signal** on its CRT screen.
So, we can choose a particular spectrum analyzer based on the frequency range of the signal that is to be analyzed.

Types

- Spectrum analyzer types are:
  - **Swept tuned spectrum analyzer** : It sweeps across the frequency range, displaying all the frequency components present. This enables measurements to be made over a large dynamic range and wide frequency range.
  - **FFT based spectrum analyzer** : The FFT analyzer takes a time-domain signal, digitizes it using digital sampling, and then applies the mathematics required to convert it to the frequency domain. The result is displayed as a spectrum.

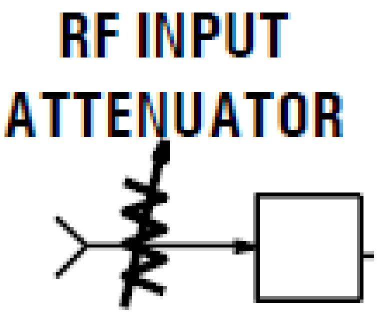
Swept tuned spectrum analyzer



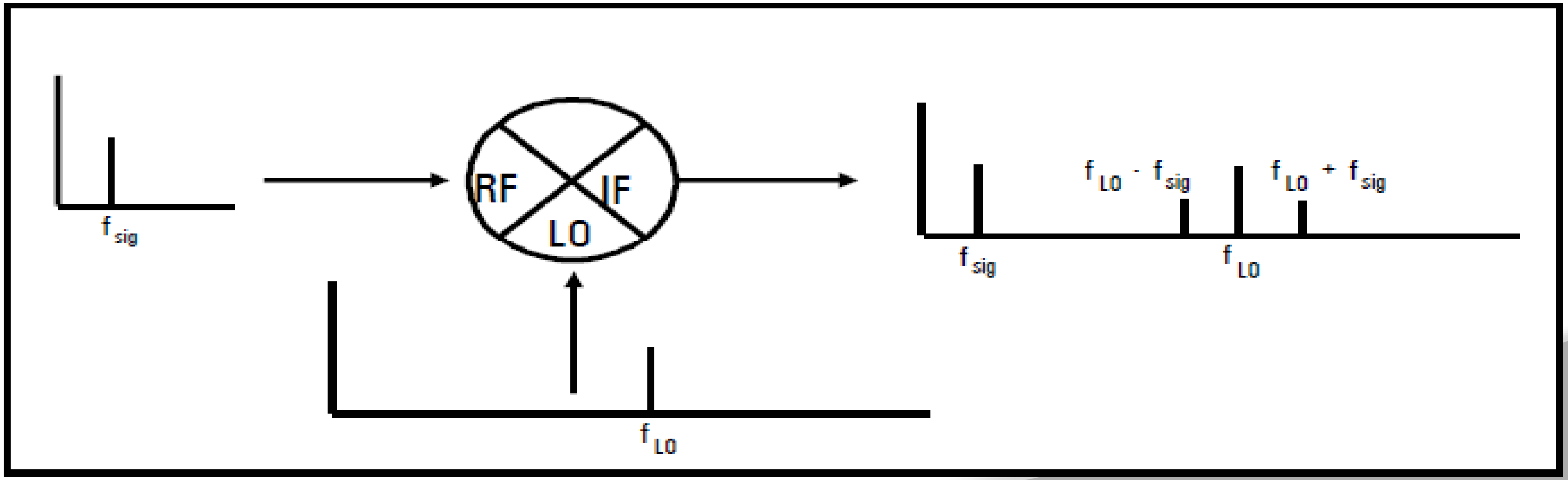
•The major components in a spectrum analyzer are the RF input attenuator, mixer, IF (Intermediate Frequency) gain, IF filter, detector, video filter, local oscillator, sweep generator, and LCD display.

Input attenuator and mixer

•Its purpose is to adjust the level of the signal entering the mixer to its optimum level. If the signal level is too high, the readings fall outside the display, but also the mixer performance may not be optimum.



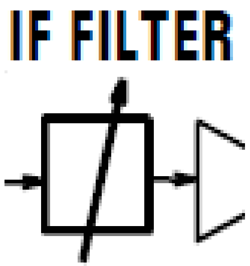
•A mixer is a three-port device that converts a signal from one frequency to another (sometimes called a frequency translation device)



Gain , filter and detector

- IF stages provide the required level of gain. It has to be used in conjunction with the RF gain control. Too high a level of IF gain will increase the front end noise level which may result in low level signals being masked.

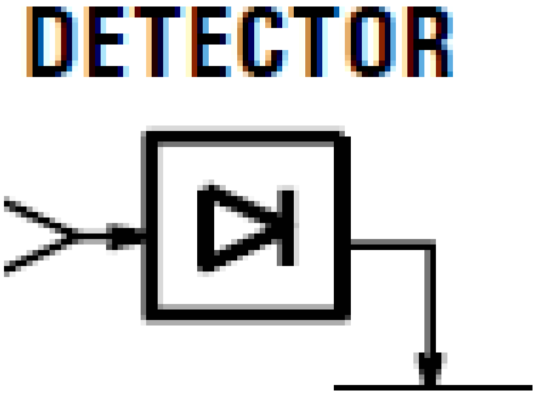
- The IF filter is a band pass filter which is used as the "window" for detecting signals. It's bandwidth is also called the resolution bandwidth (RBW) of the analyzer and can be changed via the front panel of the analyzer.



Gain , filter and detector

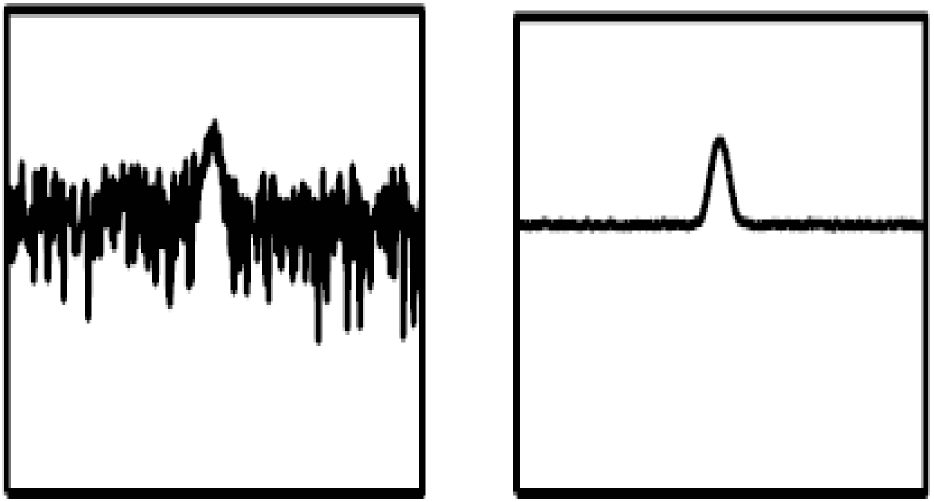
- The analyzer must covert the IF signal to a baseband or video signal so it can be digitized and then viewed on the analyzer display.

- This is accomplished with an envelope detector whose video output is then digitized with an analog-to digital converter (ADC).



Video filter, LO, SG and ADC

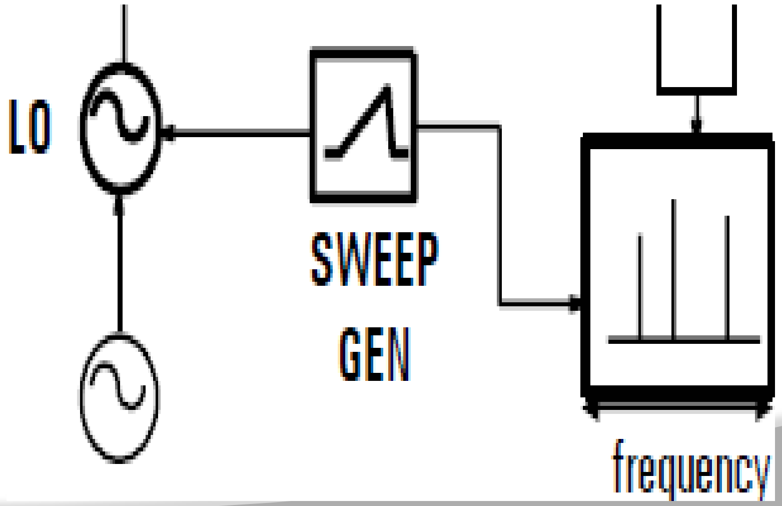
- The video filter is a low-pass filter that is envelope detector and before the ADC. This filter determines the bandwidth of the video amplifier, and is used to average or smooth the trace seen on the screen.



Video filter, LO, SG and ADC

•The local oscillator (LO) must be capable of being tuned over a very wide range of frequencies to enable the analyzer to scan over the required range.

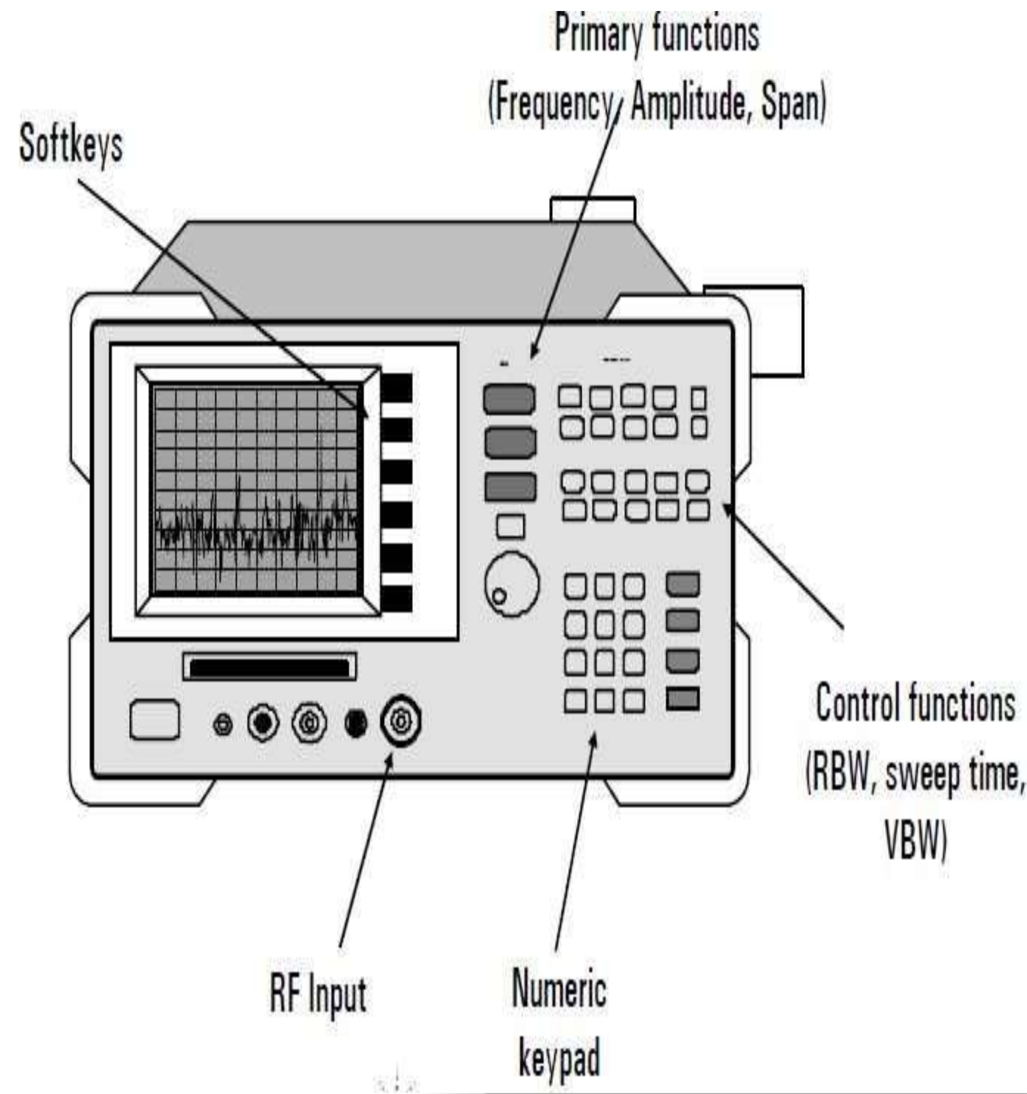
•The sweep generator actually tunes the LO so that its frequency changes in proportion to the ramp voltage. The video signal by the ADC is also synchronized with the sweep generator to create the frequency domain on the x-axis.



Front Panel

•The three primary hard keys on any spectrum analyzer are: frequency, amplitude, and span

•Other important control functions include setting the resolution- bandwidth, sweep



Advantages and disadvantages

- Advantages :
  - Able to operate over wide frequency range
  - Wide bandwidth
  - Not as expensive as other spectrum analyzer technologies

- Disadvantages:
  - Cannot measure phase
  - Cannot measure transient events

Power Analyzer

These instruments are used for

a) Testing and verifying correct operation of motors.
b) Checking transformer efficiency
c) Verifying power supply performance
d) Measuring the effect of neutral current

- These features include harmonic analysis, power measurements and Pulse width modulation motor drive triggering.

- These instruments can also be used as oscilloscopes. which enable trouble shooting and verification of complicated electronic control circuits controlling the high-voltage power electronic circuits.

MODULE-IV
DC & AC BRIDGES

Bridges

- If the electrical components are arranged in the form a bridge or ring structure, then that electrical circuit is called a **bridge**.

- In general, bridge forms a loop with a set of four arms or branches. Each branch may contain one or two electrical components.

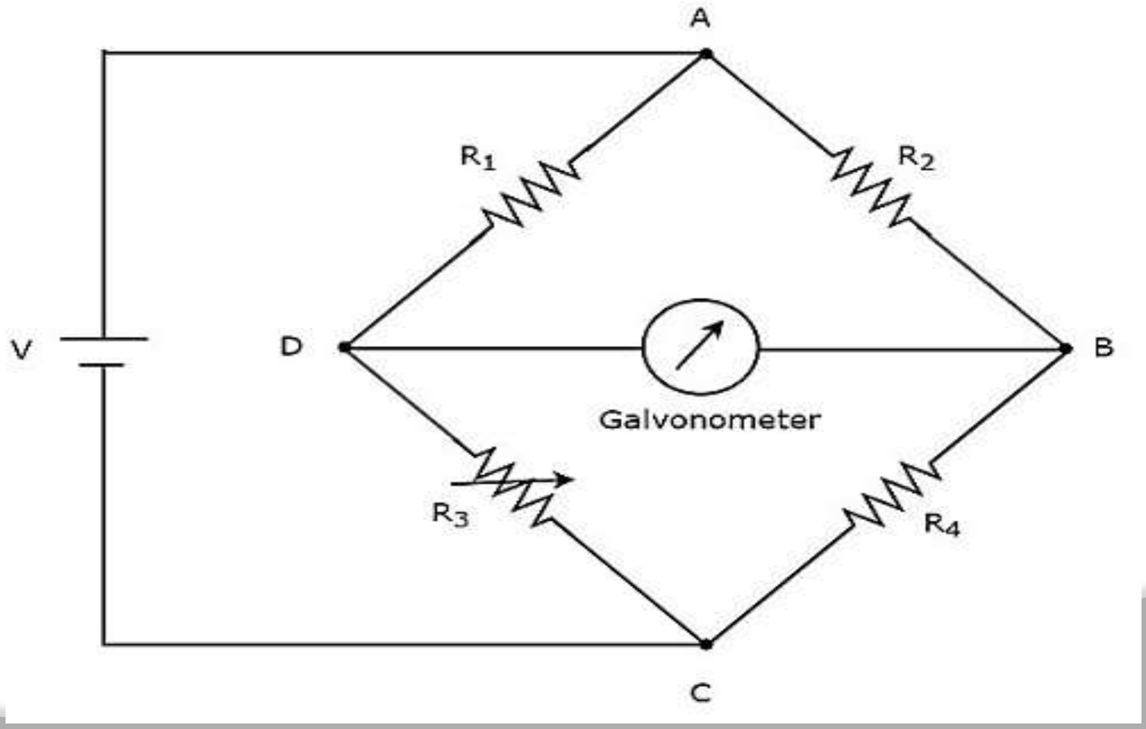
Types of Bridges

We can classify the bridge circuits or bridges into the following two categories based on the voltage signal with which those can be operated.

- DC Bridges
- AC Bridges

DC Bridges

- If the bridge circuit can be operated with only DC voltage signal, then it is a DC bridge circuit or simply **DC bridge**.
- DC bridges are used to measure the value of unknown resistance. The **circuit diagram** of DC bridge looks like as shown in below figure.



DC Bridges

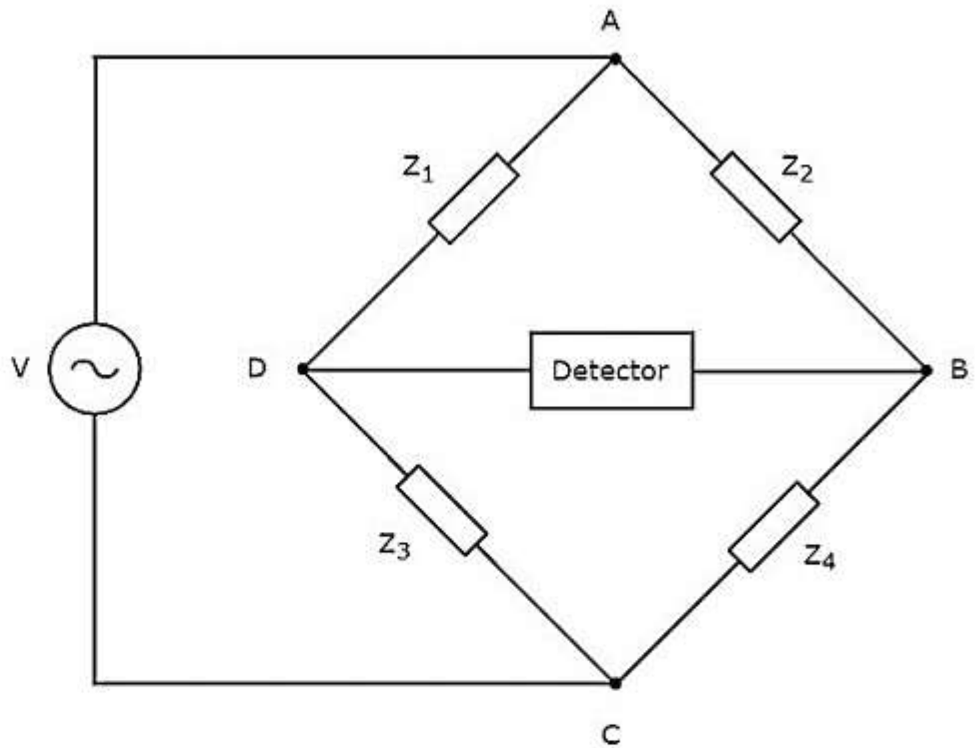
- The above DC bridge has **four arms** and each arm consists of a resistor. Among which, two resistors have fixed resistance values, one resistor is a variable resistor and the other one has an unknown resistance value.

- The above DC bridge circuit can be excited with a **DC voltage source** by placing it in one diagonal. The galvanometer is placed in other diagonal of DC bridge. It shows some deflection as long as the bridge is unbalanced.

- Vary the resistance value of variable resistor until the galvanometer shows null (zero) deflection. Now, the above DC bridge is said to be a balanced one. So, we can find the value of **unknown resistance** by using nodal equations.

AC Bridges

- If the bridge circuit can be operated with only AC voltage signal, then it is said to be AC bridge circuit or simply **AC bridge**. AC bridges are used to measure the value of unknown inductance, capacitance and frequency.



AC Bridges

- The circuit diagram of AC bridge is similar to that of DC bridge. The above AC bridge has **four arms** and each arm consists of some impedance.

- That means, each arm will be having either single or combination of passive elements such as resistor, inductor and capacitor.

- Among the four impedances, two impedances have fixed values, one impedance is variable and the other one is an unknown impedance.

- The above AC bridge circuit can be excited with an **AC voltage source** by placing it in one diagonal.

AC Bridges

- A detector is placed in other diagonal of AC bridge. It shows some deflection as long as the bridge is unbalanced.

- The above AC bridge circuit can be excited with an **AC voltage source** by placing it in one diagonal.

- A detector is placed in other diagonal of AC bridge. It shows some deflection as long as the bridge is unbalanced.

- Vary the impedance value of variable impedance until the detector shows null (zero) deflection. Now, the above AC bridge is said to be a balanced one.

- So, we can find the value of **unknown impedance** by using balanced condition.

Types of DC Bridges

- **DC bridges** can be operated with only DC voltage signal. DC bridges are useful for measuring the value of unknown resistance, which is present in the bridge.

- Wheatstone's Bridge and Kelvin's are the examples of DC bridge.

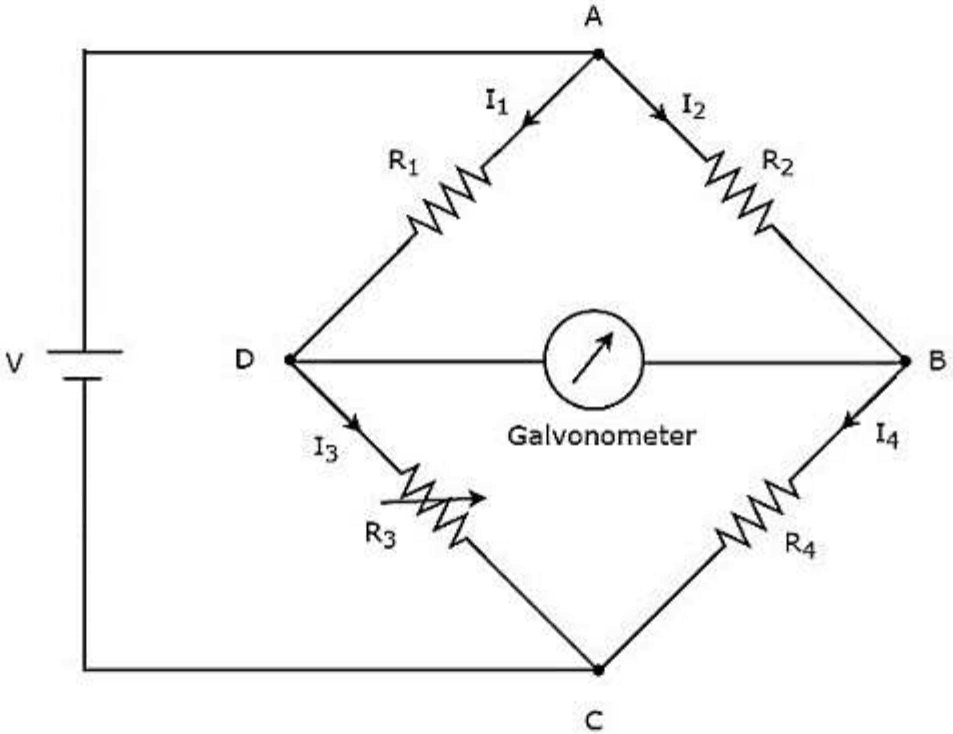
Wheatstone's Bridge

- Wheatstone's bridge is a simple DC bridge, which is mainly having four arms. These four arms form a rhombus or square shape and each arm consists of one resistor.

- To find the value of unknown resistance, we need the galvanometer and DC voltage source.

Wheatstone’s Bridge

- Hence, one of these two are placed in one diagonal of Wheatstone’s bridge and the other one is placed in another diagonal of Wheatstone’s bridge.



Wheatstone's Bridge

- In above circuit, the arms AB, BC, CD and DA together form a **rhombus** or square shape. They consist of resistors R2, R4, R3 and R1 respectively.

- Let the current flowing through these resistor arms is I2, I4, I3 and I1 respectively and the directions of these currents are shown in the figure.

- The diagonal arms DB and AC consists of galvanometer and DC voltage source of V volts respectively.

- Here, the resistor, R3 is a standard variable resistor and the resistor, R4 is an unknown resistor. We can balance the bridge, by varying the resistance value of resistor, R3.

Wheatstone's Bridge

- The above bridge circuit is balanced when no current flows through the diagonal arm, DB. That means, there is **no deflection** in the galvanometer, when the bridge is balanced.

- The bridge will be balanced, when the following **two conditions** are satisfied.

- The voltage across arm AD is equal to the voltage across arm AB. i.e.,

$$V_{AD} = V_{AB}$$

$$\Rightarrow I_1 R_1 = I_2 R_2 \qquad \text{Equation 1}$$

Wheatstone's Bridge

- The voltage across arm DC is equal to the voltage across arm BC. i.e.,

$$V_{DC} = V_{BC}$$

$$\Rightarrow I_3 R_3 = I_4 R_4 \qquad \text{Equation 2}$$

- From above two balancing conditions, we will get the following two conclusions.
- The current flowing through the arm AD will be equal to that of arm DC. i.e.,

$$I_1 = I_3$$

The current flowing through the arm AB will be equal to that of arm BC. i.e.,

$$I_2 = I_4$$

Wheatstone's Bridge

Take the ratio of Equation 1 and Equation 2.

$$\frac{I_1 R_1}{\ } = \frac{I_2 R_2}{I_4 R_4}$$ Equation 3

Substitute, $I_1 = I_3$ and $I_2 = I_4$ in Equation 3.

$$\frac{I_3 R_1}{I_3 R_3} = \frac{I_4 R_2}{I_4 R_4}$$

$$\Rightarrow \frac{R_1}{R_3} = \frac{R_2}{R_4}$$

$$\Rightarrow R_4 = \frac{R_2 R_3}{R_1}$$

By substituting the known values of resistors R_1, R_2 and R_3 in above equation, we will get the **value of resistor,** R_4

Kelvin Bridge

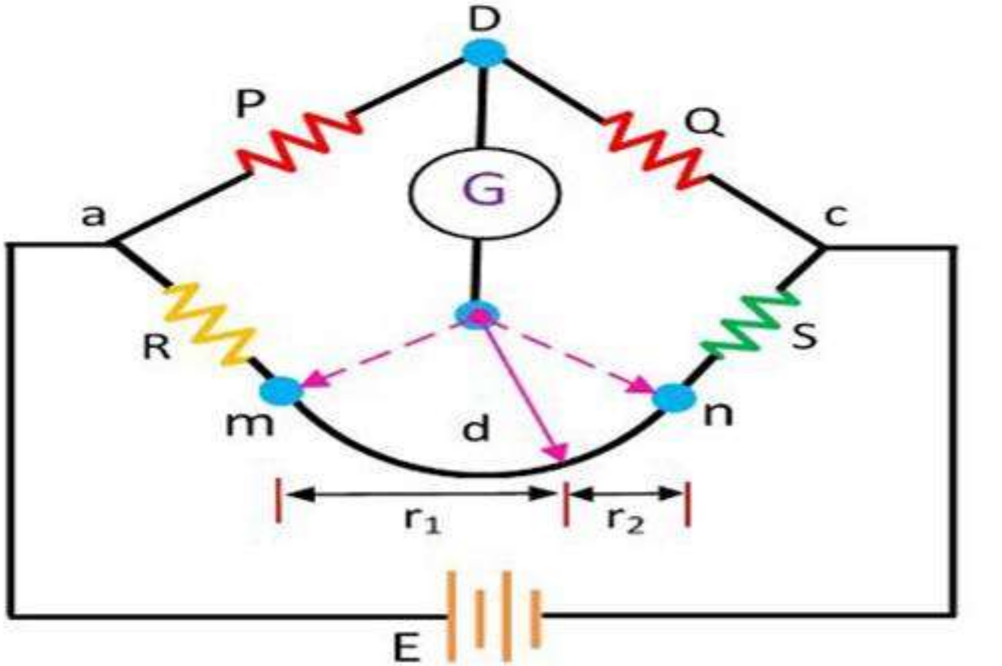
- **Definition:** The Kelvin bridge or Thompson bridge is used for measuring the unknown resistances having a value less than 1Ω. It is the modified form of the Wheatstone Bridge.
- **What is the need of Kelvin Bridge?**
- Wheatstone bridge use for measuring the resistance from a few ohms to several kilo-ohms. But error occurs in the result when it is used for measuring the low resistance.

- This is the reason because of which the Wheatstone bridge is modified, and the Kelvin bridge obtains. The Kelvin bridge is suitable for measuring the low resistance.

Kelvin Bridge

Modification of Wheatstone Bridge

In Wheatstone Bridge, while measuring the low-value resistance, the resistance of their lead and contacts increases the resistance of their total measured value. This can easily be understood with the help of the circuit diagram.



Prinicple of Kelvin's Bridge

Kelvin Bridge

- The **r** is the resistance of the contacts that connect the **unknown resistance** **R** to the **standard resistance** **S**. The **'m'** and **'n'** show the range between which the galvanometer is connected for obtaining a null point.
- When the galvanometer is connected to point 'm', the lead resistance r is added to the standard resistance S. Thereby the very low indication obtains for unknown resistance R.
- And if the galvanometer is connected to point n then the r adds to the R, and hence the high value of unknown resistance is obtained.
- Thus, at point n and m either very high or very low value of unknown resistance is obtained.

Kelvin Bridge

- So, instead of connecting the galvanometer from point, m and n we chose any intermediate point say d where the resistance of lead r is divided into two equal parts, i.e., r_1 and r_2

$$\frac{r_1}{r_2} = \frac{P}{Q} \ldots\ldots\ldots equ(1)$$

The presence of r_1 causes no error in the measurement of unknown resistance

$$R + r_1 = \frac{P}{Q}.(S + r_2)$$

From equation (1), we get

Kelvin Bridge

$$\frac{r_1}{r_1 + r_2} = \frac{P}{P + Q}$$

$$r_1 = \frac{P}{P + Q} . r$$

then

$$r_1 + r_2 = r$$

$$r_2 = \frac{Q}{P + Q} . r$$

then

$$R + \frac{P}{P + Q} . r = \frac{P}{Q}\left(S + \frac{Q}{P + Q} r\right)$$

$$R = \frac{P}{Q} . S$$

Kelvin Bridge

- The above equation shows that if the galvanometer connects at point d then the resistance of lead will not affect their results.

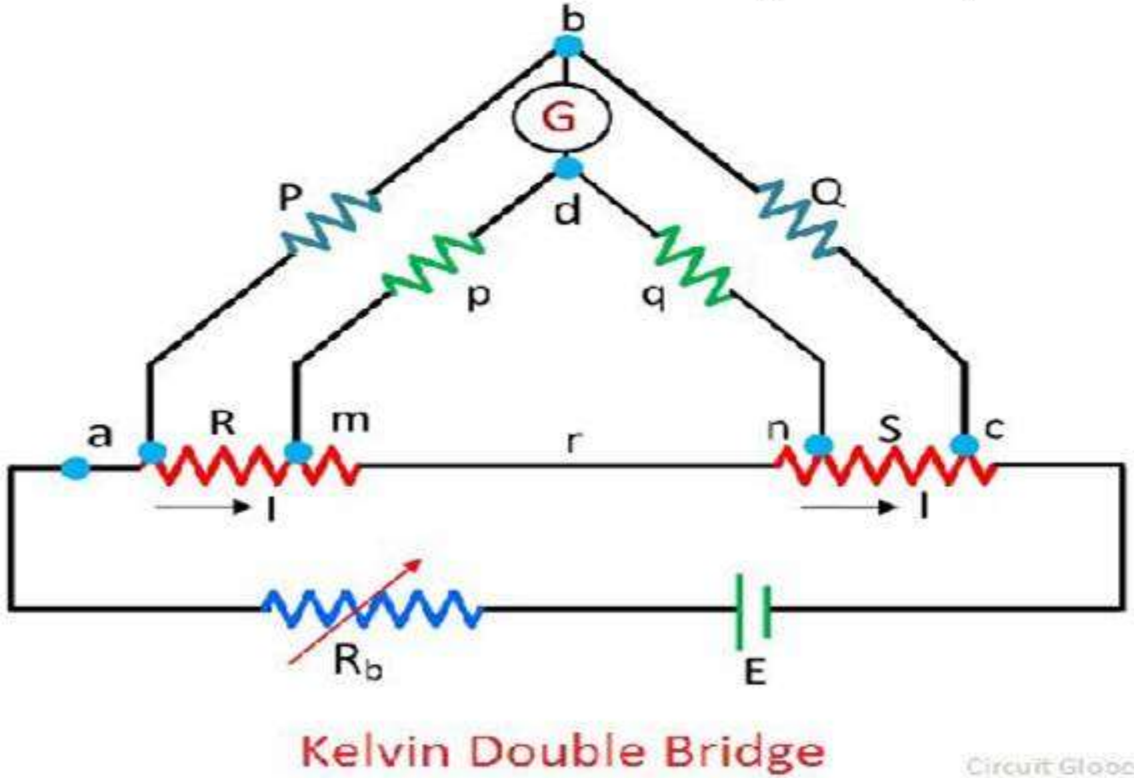
- The above mention process is practically not possible to implement.

- For obtaining the desired result, the actual resistance of exact ratio connects between the point m and n and the galvanometer connects at the junction of the resistor.

Kelvin Double Bridge Circuit

- The ratio of the arms p and q are used to connect the galvanometer at the right place between the point j and k. The j and k reduce the effect of connecting lead.

- **The P and Q is the first ratio of the arm and p and q is the second arm ratio.**



Kelvin Double Bridge Circuit

- The galvanometer is connected between the arms p and q at a point d. The point d places at the centre of the resistance r between the point m and n for removing the effect of the connecting lead resistance which is placed between the **unknown resistance R** and standard **resistance S.**

- The ratio of p/q is made equal to the P/Q. Under balance condition zero current flows through the galvanometer. The potential difference between the point a and b is equivalent to the voltage drop between the points E_{amd}.

- Now,

$$E_{ab} = \frac{P}{P+Q} E_{ac}$$

Kelvin Double Bridge Circuit

$$E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right] \ldots\ldots\ldots\ldots equ(1)$$

$$E_{amd} = I\left[R + \frac{p}{(p+q)}\left\{\frac{(p+q)r}{p+q+r}\right\}\right]$$

$$E_{ac} = I\left[\frac{pr}{p+q+r}\right] \ldots\ldots\ldots\ldots equ(2)$$

For zero galvanometer deflection,

$$E_{ac} = E_{amd}$$

$$\frac{P}{P+Q}.I\left[R + \frac{p}{(p+q)}\left\{\frac{(p+q)r}{p+q+r}\right\}\right] = I\left[\frac{pr}{p+q+r}\right]$$

Kelvin Double Bridge Circuit

$$R = \frac{P}{Q}.S + \frac{pr}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$$

As we known, **P/Q = p/q** then above equation becomes

$$R = \frac{P}{Q}.S$$

The above equation is the working equations of the Kelvins bridge.

The equation shows that the result obtains from the Kelvin double bridge is free from the impact of the connecting lead resistance.

Kelvin Double Bridge Circuit

- For obtaining the appropriate result, it is very essentials that the ratio of their arms is equal.

- The unequal arm ratio causes the error in the result. Also, the value of resistance r should be kept minimum for obtaining the exact result.

- The thermo-electric EMF induces in the bridge during the reading. This effect can be reduced by measuring the resistance with the reverse battery connection.

- The real value of the resistance obtains by takings the means of the two.

Kelvin Double Bridge Circuit

Limitations of Kelvins Bridge

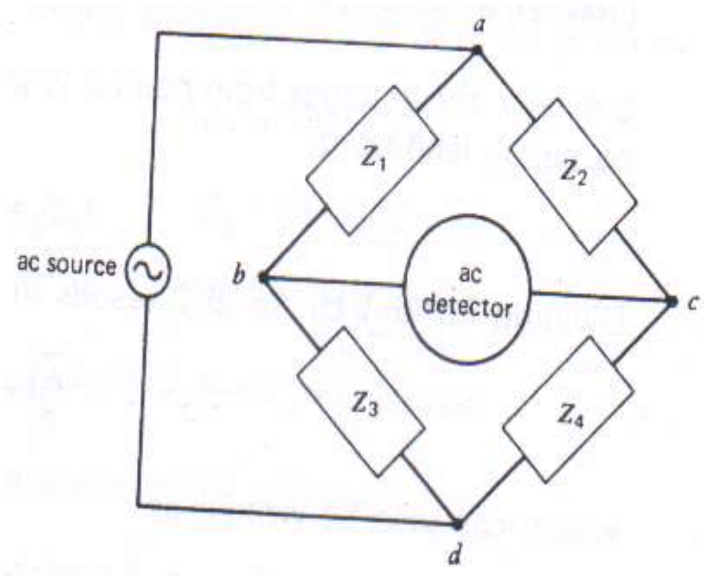
- The sensitive galvanometer is used for detecting the balance condition.
- The high measurement current is required for obtaining the good sensitivity.
- Nowadays the kelvins bridge is replaced by the Kelvin Bridge Ohmmeter.

AC BRIDGES

AC BRIDGES

In general, AC bridge has a similar circuit design as DC bridge, except that the bridge arms are impedances.

The impedances can be either *pure resistances* or *complex impedances* (*resistance* + *inductance* or *resistance* + *capacitance*). Therefore, AC bridges are used to measure *inductance* and *capacitance.*



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AC BRIDGES

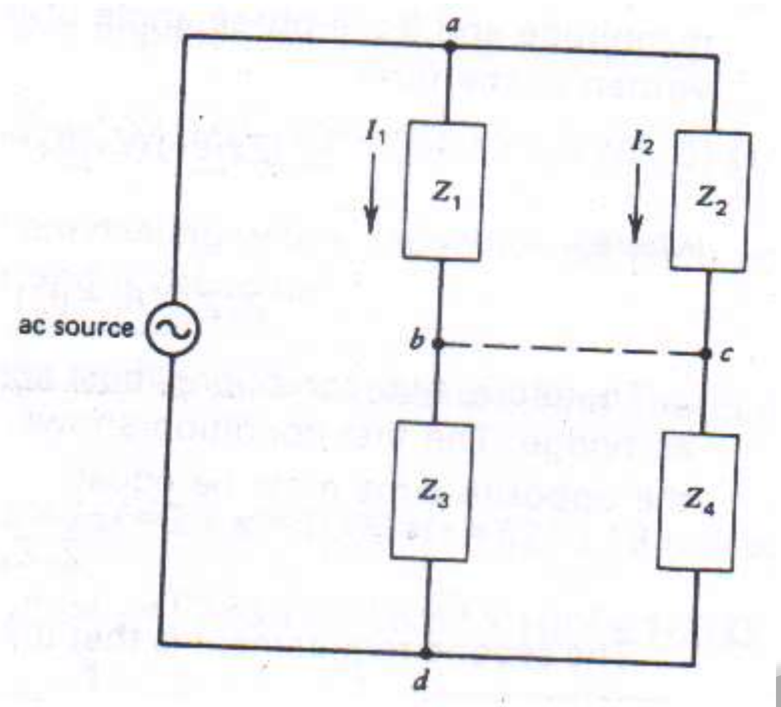
- Some impedance bridge circuits are *frequency-sensitive* while others are not.
- The frequency-sensitive types may be used as frequency measurement devices if all component values are accurately known
- The usefulness of AC bridge circuit is not restricted to the measurement of an unknown impedance. These circuits find other application in many *communication systems* and *complex electronic circuits*, such as for:
  - shifting phase, providing feedback paths for oscillators or amplifiers;
  - filtering out undesired signals;
  - measuring the frequency of audio signals.

AC BRIDGES

- AC bridge is excited by an *AC source* and its galvanometer is replaced by a *detector*. The detector can be a sensitive electromechanical meter movements, oscilloscopes, headphones, or any other device capable of registering very small AC voltage levels.
- AC bridge circuits work on the same basic principle as DC bridge circuits: that a balanced ratio of impedances (rather than resistances) will result in a "balanced" condition as indicated by the null-detector.
- When an AC bridge is in **null** or **balanced** condition, **the detector current becomes zero**. This means that **there is no voltage difference across the detector** and the bridge circuit in can be redrawn as

The dash line in the figure indicates that *there is no potential difference* and *no current* between points *b* and *c*. The voltages from point *a* to point *b* and from point *a* to point *c* must be equal, which allows us to obtain:

$$I_1 Z_1 = I_2 Z_2$$



Similarly, the voltages from point *d* to point *b* and point *d* to point c must also be equal, leading to: ------(2)

$$I_1 Z_3 = I_2 Z_4$$

Dividing Equation (1) by Equation (2) we obtain:

$$\frac{Z_1}{Z_3} = \frac{Z_2}{Z_4}$$

which can also be written as

$$Z_1 Z_4 = Z_2 Z_3$$

If the impedance is written in the form Z = Z∟θ where Z represents the magnitude and θ the phase angle of the complex impedance, can be written in the form

$$(Z_1\angle\theta_1)(Z_4\angle\theta_4)=(Z_2\angle\theta_2)(Z_3\angle\theta_3)$$

or

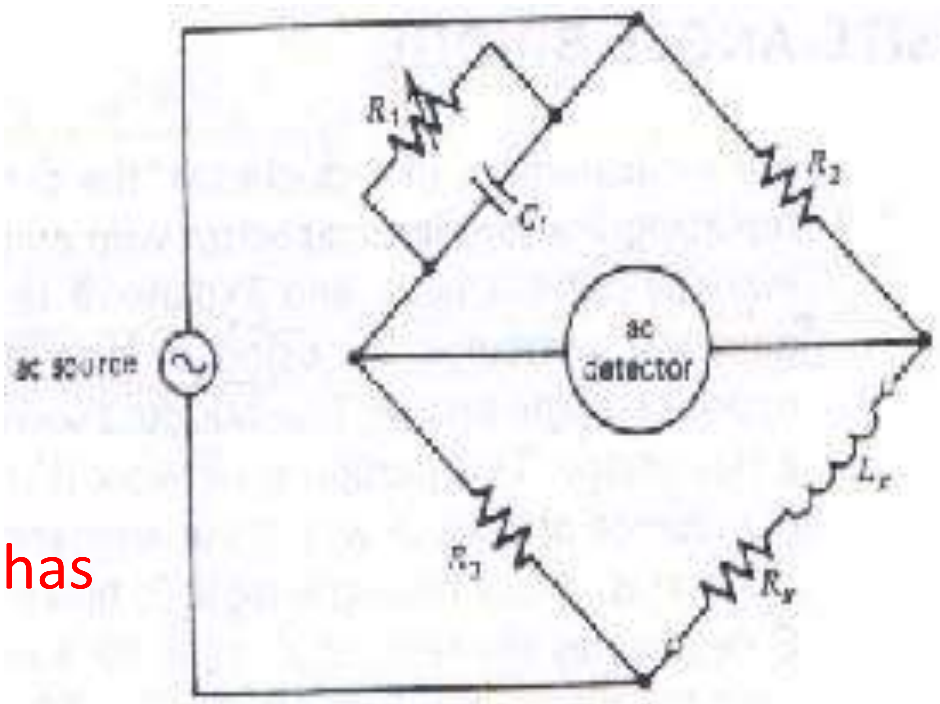
$$Z_1Z_4\angle(\theta_1+\theta_4)=Z_2Z_3\angle(\theta_2+\theta_3) \qquad \text{------(4)}$$

Eq. 4 shows two conditions when ac bridge is balanced;

- First condition shows that the products of the magnitudes of the opposite arms must be equal: $\mathbf{Z_1Z_4 = Z_2Z_3}$
- Second condition shows that the sum of the phase angles of the opposite arms is equal: $\angle\theta_1 + \angle\theta_4 = \angle\theta_2 + \angle\theta_3$

Maxwell Bridge

Maxwell bridge is an ac bridge used to measure an ***unknown inductance*** in terms of a ***known capacitance***. This bridge is sometimes called a **Maxwell-Wien Bridge**.



Using capacitance as a standard has several advantages due to:

- Capacitance of capacitor is influenced by less external fields.
- Capacitor has small size.
- Capacitor is low cost.

Maxwell Bridge

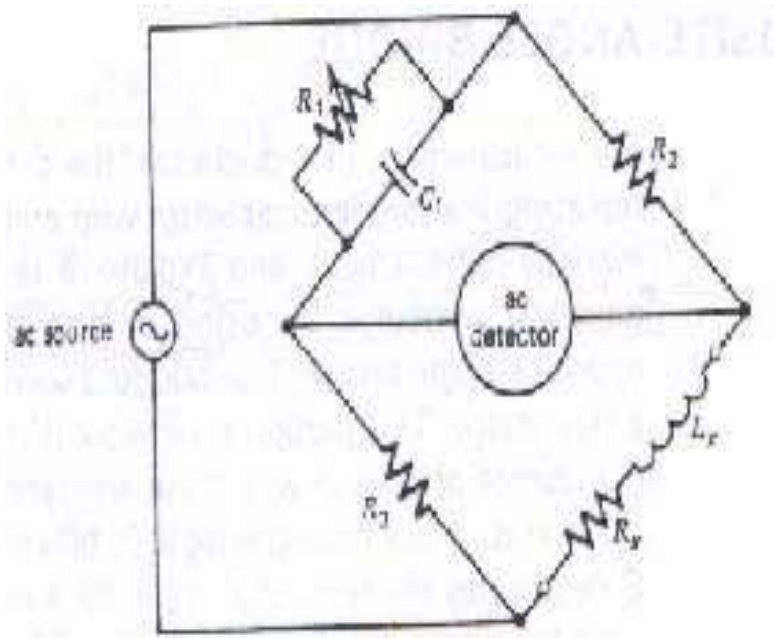
The impedance of the arms of the bridge can be written as

$$Z_1 = \frac{1}{\frac{1}{R_1} + j\omega C_1}$$

$$Z_2 = R_2$$

$$Z_3 = R_3$$

$$Z_4 = R_x + j X_{Lx}$$



The general equation for bridge balance is

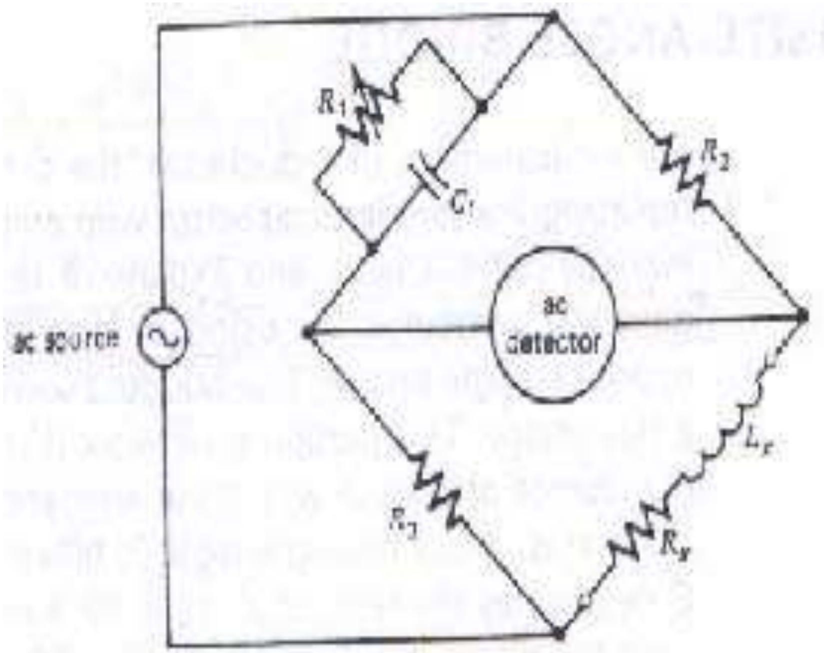
$$Z_1 Z_x = Z_2 Z_3$$

$$\frac{1}{\frac{1}{R_1} + j\omega C_1}\left(R_x + jX_{Lx}\right) = R_2 R_3$$

$$\frac{1}{\frac{1 + j\omega C_1}{R_1}}\left(R_x + jX_{Lx}\right) = R_2 R_3$$

$$\frac{R_x + jX_{Lx}}{1 + j\omega C_1} = \frac{R_2 R_3}{R_1}$$

$$R_x + jX_{Lx} = \frac{R_2 R_3}{R_1} + j\omega R_2 R_3 C_1$$

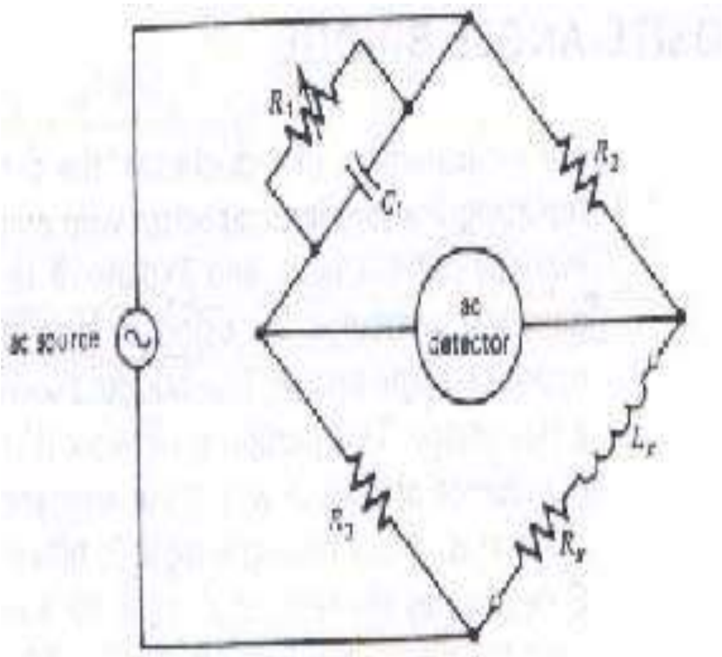


Equating real terms and imaginary terms we have

$$R_x = \frac{R_2 R_3}{R_1}$$

$$j\omega L_x = j\omega R_2 R_3 C_1$$

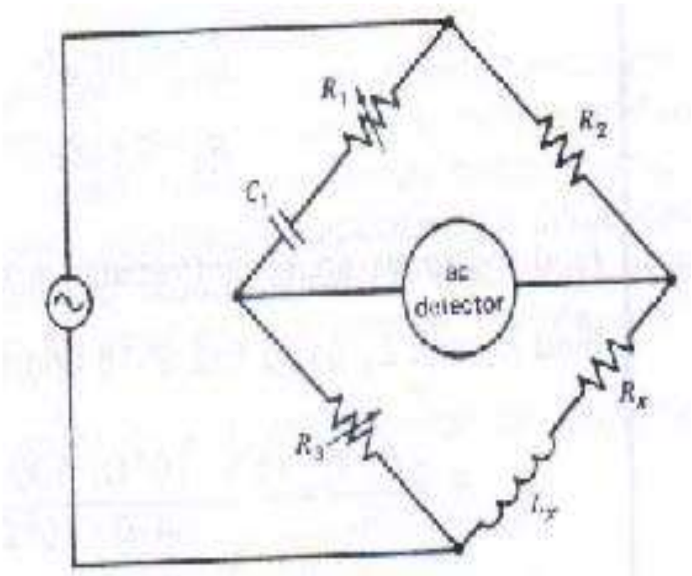
$$L_x = R_2 R_3 C_1$$



Hay's Bridge(Opposite Angle Bridge)

Opposite-angle bridge is an AC bridge for measurement of **inductance**. The construction of this bridge can be done by ***replacing the standard capacitor of the similar-angle with an inductor*** .

Opposite-angle bridge is sometimes known as a **Hay Bridge**. It differs from Maxwell bridge by having a **resistor R_1 in series with a standard capacitor C_1**.
The impedance of the arms of the bridge can be written as



$$Z_1 = R_1 - \frac{j}{\omega C_1} \qquad Z_2 = R_2$$

$$Z_3 = R_3 \qquad Z_x = R_x + j\omega L_x$$

At balance: $Z_1Z_x = Z_2Z_3$, and substituting the values in the balance equation we obtain

$$\left(R_1 - \frac{j}{\omega C_1}\right)\left(R_x + j\omega L_x\right) = R_2R_3$$

$$R_1R_x + \frac{L_x}{C_1} - \frac{jR_x}{\omega C_1} + j\omega L_x R_1 = R_2R_3$$

Equating the real and imaginary terms we have

$$R_1R_x + \frac{L_x}{C_1} = R_2R_3$$

and $$\frac{R_x}{\omega C_1} = \omega L_x R_1 \quad \text{---------(2)}$$

Solving for R_x we have, $R_x = \omega^2 L_x C_1 R_1$.

Substituting for R_x in Eq 2

$$R_1(\omega^2 R_1 C_1 L_x) + \frac{L_x}{C_1} = R_2 R_3$$

$$\omega^2 R_1^2 C_1 L_x + \frac{L_x}{C_1} = R_2 R_3$$

Multiplying both sides by C_1 we get

$$\omega^2 R_1^2 C_1^2 L_x + L_x = R_2 R_3 C_1$$

Therefore,

$$L_x = \frac{R_2 R_3 C_1}{1 + \omega^2 R_1{}^2 C_1{}^2} \quad \text{---------(3)}$$

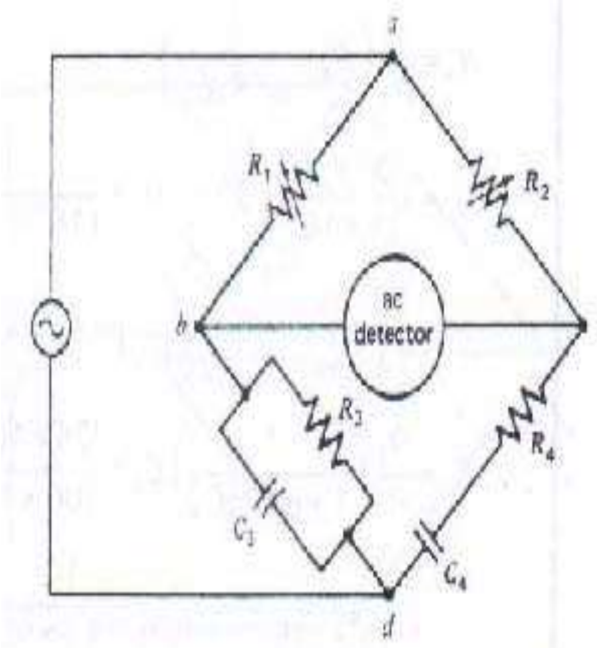
Substituting for L_x in Eq.3 into Eq.2, we obtain

$$R_x = \frac{\omega R_1 R_2 R_3 C_1{}^2}{1 + \omega^2 R_1{}^2 C_1{}^2} \quad \text{---------(4)}$$

The term ω in the expression for both L_x and R_x indicates that the bridge is ***frequency sensitive***.

The Wien bridge is an ac bridge having a series RC combination in one arm and a parallel combination in the adjoining arm.

In its basic form, Wien's bridge is designed to measure either the ***equivalent-parallel components*** or the ***equivalent-series components*** of ***an impedance***.



The impedance of the arms of this bridge can be written as:

$Z_1 = R_1$ $Z_2 = R_2$

The impedance of the parallel arm is

$$Z_3 = \frac{1}{\frac{1}{R_3} + j\omega C_3}$$

The impedance of the series arm is

$$Z_4 = R_4 - \frac{j}{\omega C_4}$$

Using the bridge balance equation, $Z_1Z_4 = Z_2Z_3$ we obtain:

Equivalent parallel components

$$R_3 = \frac{R_1}{R_2}\left(R_4 + \frac{1}{\omega^2 R_4 C_4{}^2}\right) \quad \text{---------(1)}$$

$$C_3 = \frac{R_2}{R_1}\left(\frac{1}{1+\omega^2 R_4{}^2 C_4{}^2}\right)C_4 \quad \text{---------(2)}$$

Equivalent series components

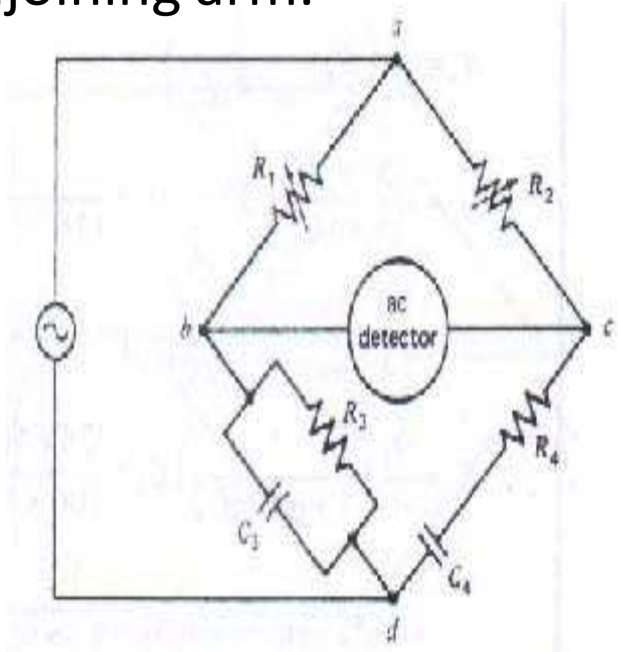
$$R_4 = \frac{R_2}{R_1}\left(\frac{R_3}{1+\omega^2 R_3{}^2 C_3{}^2}\right) \qquad C_3 = \frac{R_2}{R_1}\left(\frac{1}{1+\omega^2 R_4{}^2 C_4{}^2}\right)C_4$$

Knowing the equivalent series and parallel components, Wien’s bridge can also be used for the measurement of a ***frequency***.

$$f = \frac{1}{2\pi\sqrt{R_3 C_3 R_4 C_4}}$$

WEIN BRIDGE

The Wien bridge is an ac bridge having a series RC combination in one arm and a parallel combination in the adjoining arm.



In its basic form, Wien's bridge is designed to measure either the ***equivalent-parallel components*** or the ***equivalent-series components*** of ***an impedance***.

The impedance of the arms of this bridge can be written as:

$Z_1 = R_1$ $Z_2 = R_2$

The impedance of the parallel arm is

$$Z_3 = \frac{1}{\frac{1}{R_3} + j\omega C_3}$$

The impedance of the series arm is

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$$C_3 = \frac{R_2}{R_1}\left(\frac{1}{1+\omega^2 R_4{}^2 C_4{}^2}\right)C_4 \quad \text{---------(2)}$$

Equivalent series components

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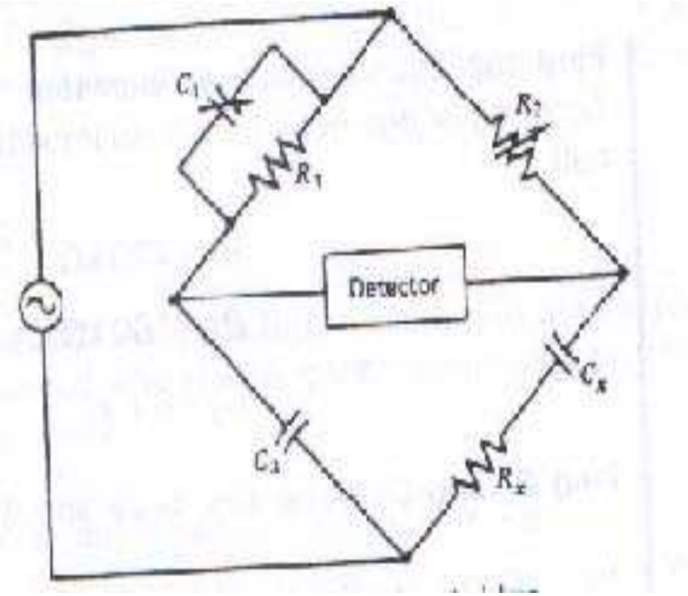
Knowing the equivalent series and parallel components, Wien’s bridge can also be used for the measurement of a ***frequency***.

$$f = \frac{1}{2\pi\sqrt{R_3 C_3 R_4 C_4}}$$

Schering bridge

Schering bridge is a very important AC bridge used for precision measurement of capacitors and their insulating properties. Its basic circuit arrangement given in Figure shows that arm 1 contains a *parallel combination of a resistor* and *a capacitor*.



- The standard capacitor **C_3** is a ***high quality mica capacitor*** for general measurements, or an ***air capacitor* for insulation measurements.**
- A high quality mica capacitor has very low losses (no resistance) and an air capacitor has a very stable value and a very small electric field.

The impedance of the arms of the Schering bridge can be written as

$$Z_1 = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{-jX_{C1}}}$$

$$Z_2 = R_2$$

$$Z_3 = -jX_{C3}$$

$$Z_4 = R_x - jX_x$$

Substituting these values into general balance equation gives:

$$Z_4 = \frac{Z_2 Z_3}{Z_1}$$

$$R_x - jX_x = \frac{R_2(-jX_{C3})}{\dfrac{1}{\dfrac{1}{R_1} + \dfrac{1}{-jX_{C1}}}}$$

$$R_x - \frac{j}{\omega C_x} = R_2(-jX_{C3})\left(\frac{1}{R_1} + \frac{1}{-jX_{C1}}\right)$$

$$R_x - \frac{j}{\omega C_x} = \frac{R_2 C_1}{C_3} - \frac{jR_2}{\omega C_3 R_1}$$

Equating the real and imaginary terms, we find that

$$R_x = R_2 \frac{C_1}{C_3}$$

$$C_x = C_3 \frac{R_1}{R_2}$$

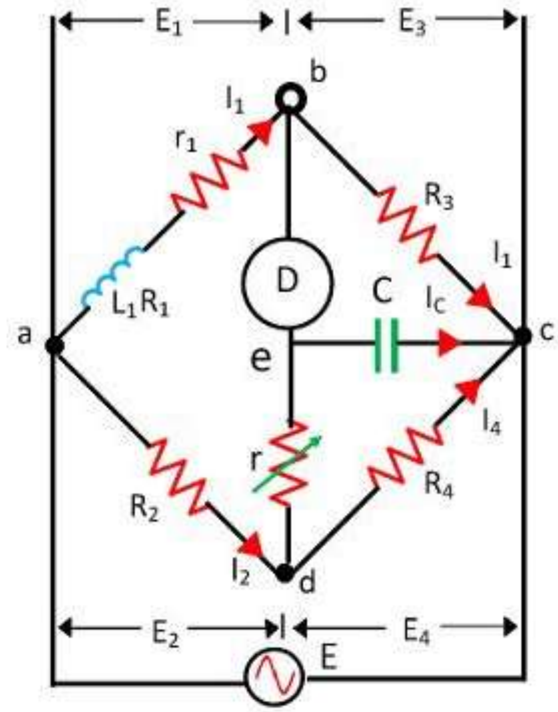
Anderson's bridge

Definition:

The **Anderson's bridge** gives the **accurate measurement** of **self-inductance** of the circuit.

The bridge is the **advanced form** of **Maxwell's inductance capacitance bridge.**

In Anderson bridge, the **unknown inductance** is compared with the **standard fixed capacitance** which is connected between the two arms of the bridge.

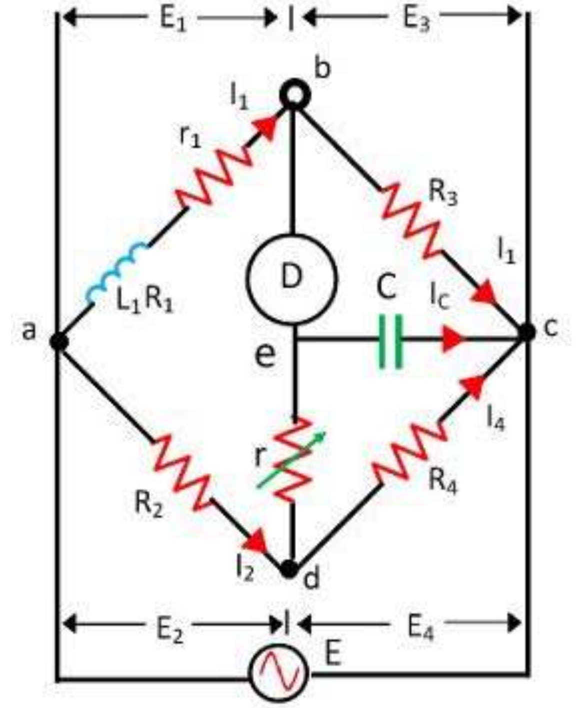


Construction:

The bridge has fours arms **ab, bc, cd,** and **ad.** The arm **ab** consists unknown inductance along with the resistance.

And the other three arms consist the purely resistive arms connected in series with the circuit.

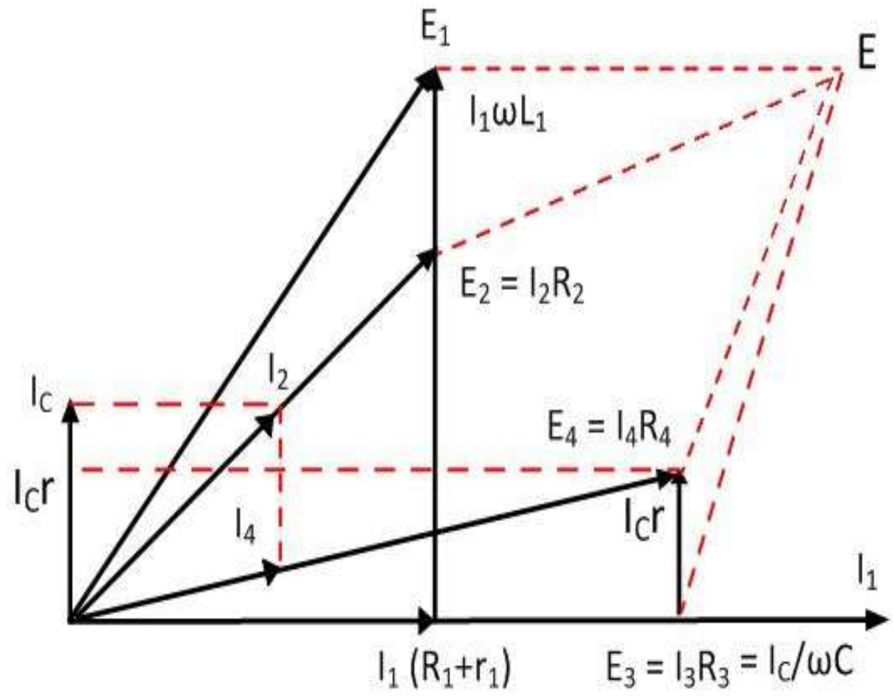
The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.



Phasor Diagram:

The phasor diagram of the Anderson bridge is shown in the figure below.

The current I_1 and the E_3 are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec** are equal.



Advantages of Anderson's Bridge:

1) In Anderson's bridge it is very easy to obtain the balance point as compared to Maxwell's bridge.

2) In this bridge a fixed standard capacitor is used therefore there is no need of costly variable capacitor.

3) This method is very accurate for measurement of capacitance in terms of inductance.

•A serious problem encountered in sensitive ac bridge circuits is that due to stray capacitances.

•Stray capacitances may be formed in an ac bridge between various junction points within the bridge configuration and nearest ground (earthed) object.

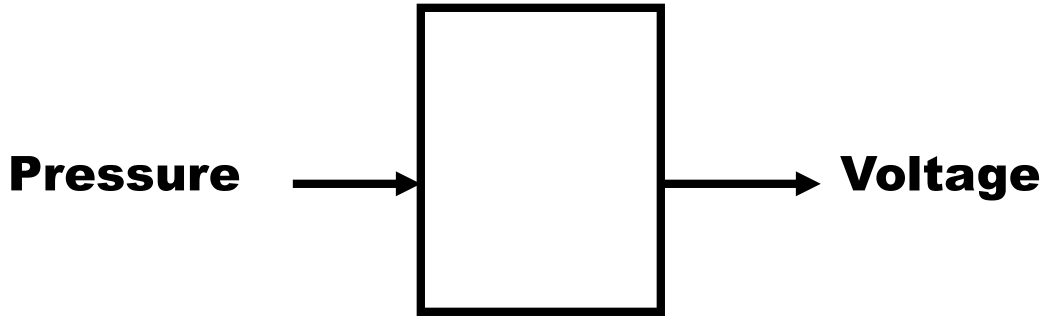
•These stray capacitors affect bridge balance in severe ways since these capacitors carry leakage current when the bridge is operated with ac, especially at high frequencies.

MODULE-V
TRANSDUCERS

INTRODUCTION OF TRANSDUCERS

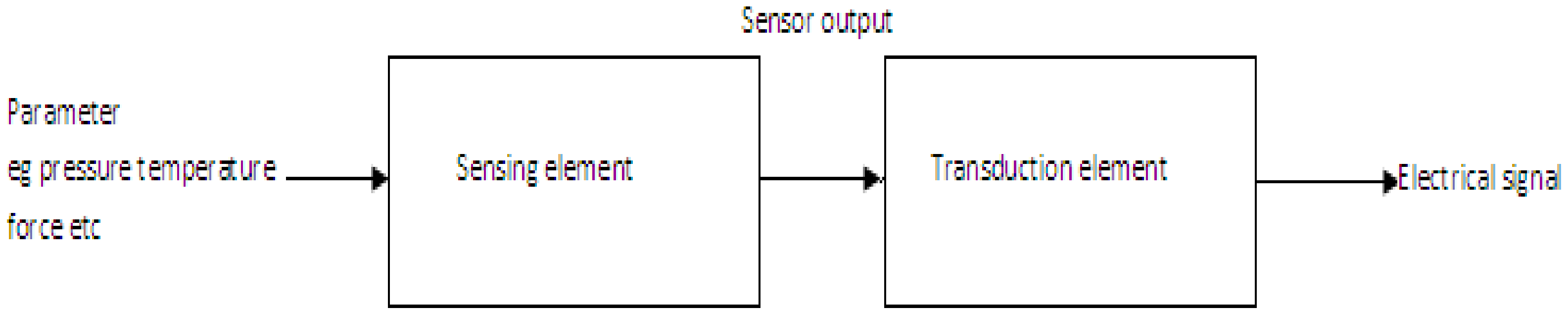
A transducer is a device that convert one form of energy to other form. It converts the measurand to a usable electrical signal.

In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.



BLOCK DIAGRAM OF TRANSDUCERS

- Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.
- The sensing element is called as the sensor. It is device producing measurable response to change in physical conditions.
- The transduction element convert the sensor output to suitable electrical form.



CHARACTERISTICS OF TRANSDUCERS

1. Ruggedness
2. Linearity
3. Repeatability
4. Accuracy
5. High stability and reliability
6. Speed of response
7. Sensitivity
8. Small size

TRANSDUCERS SELECTION FACTORS

1. **Operating Principle:** The transducer are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive , optoelectronic, piezo electric etc.
2. **Sensitivity:** The transducer must be sensitive enough to produce detectable output.
3. **Operating Range:** The transducer should maintain the range requirement and have a good resolution over the entire range.
4. **Accuracy:** High accuracy is assured.

TRANSDUCERS SELECTION FACTORS

4. **Cross sensitivity:** It has to be taken into account when measuring mechanical quantities. There are situation where the actual quantity is being measured is in one plane and the transducer is subjected to variation in another plan.
5. **Errors:** The transducer should maintain the expected input-output relationship as described by the transfer function so as to avoid errors.
6. **Transient and frequency response :** The transducer should meet the desired time domain specification like peak overshoot, rise time, setting time and small dynamic error.

7. **Loading Effects:** The transducer should have a high input impedance and low output impedance to avoid loading effects.
9. **Environmental Compatibility:** It should be assured that the transducer selected to work under specified environmental conditions maintains its input- output relationship and does not break down.
10. **Insensitivity to unwanted signals:** The transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signals.

CLASSIFICATION OF TRANSDUCERS

The transducers can be classified as:

I. Active and passive transducers.
II. Analog and digital transducers.
III. On the basis of transduction principle used.
IV. Primary and secondary transducer
V. Transducers and inverse transducers.

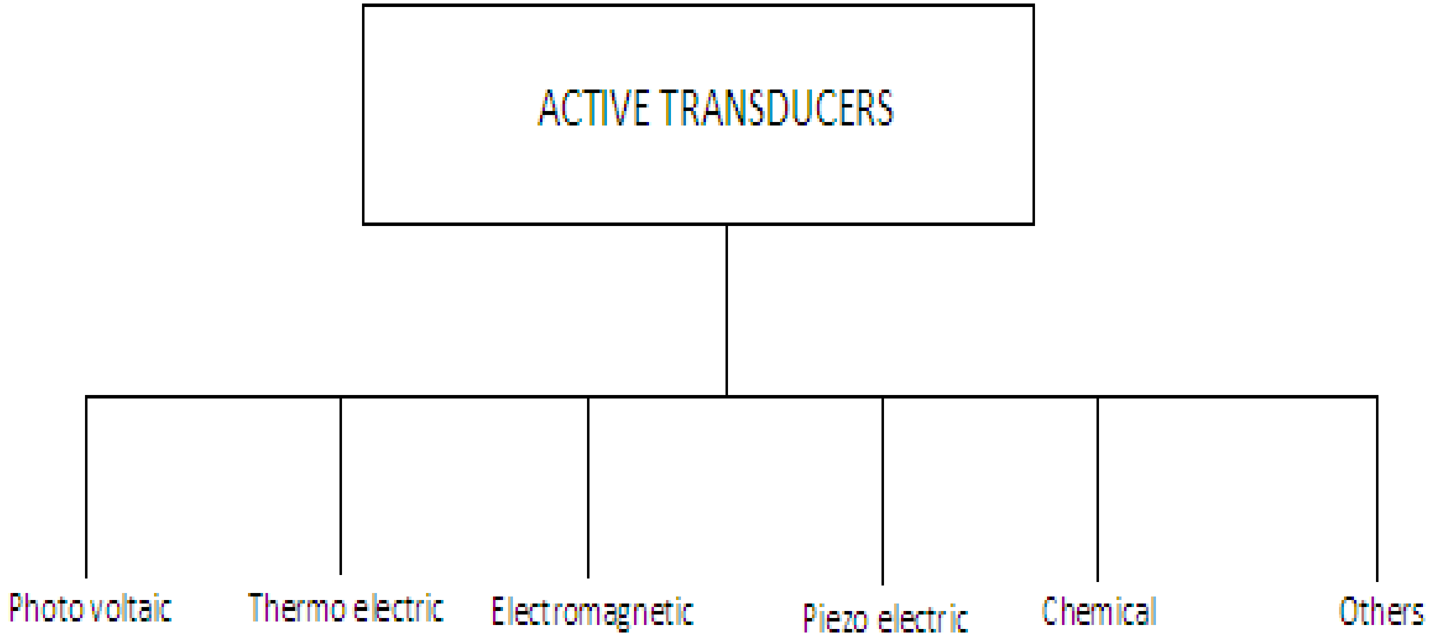
Active transducers :

These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used.

CLASSIFICATION OF ACTIVE TRANSDUCERS

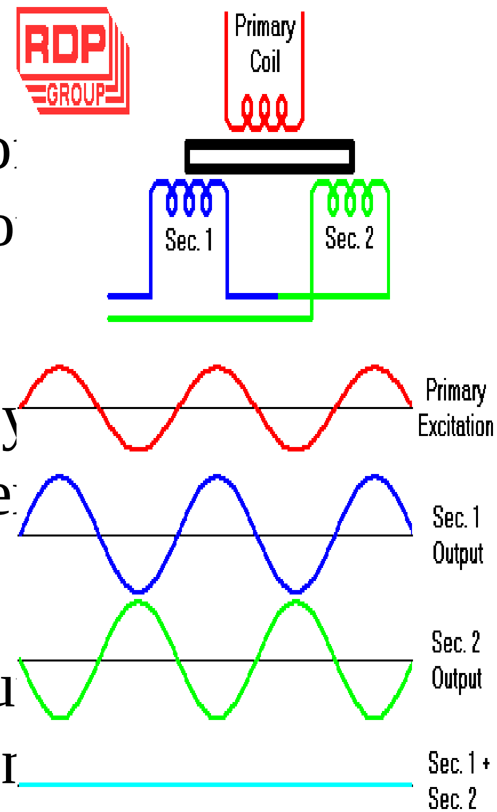


Passive Transducers :

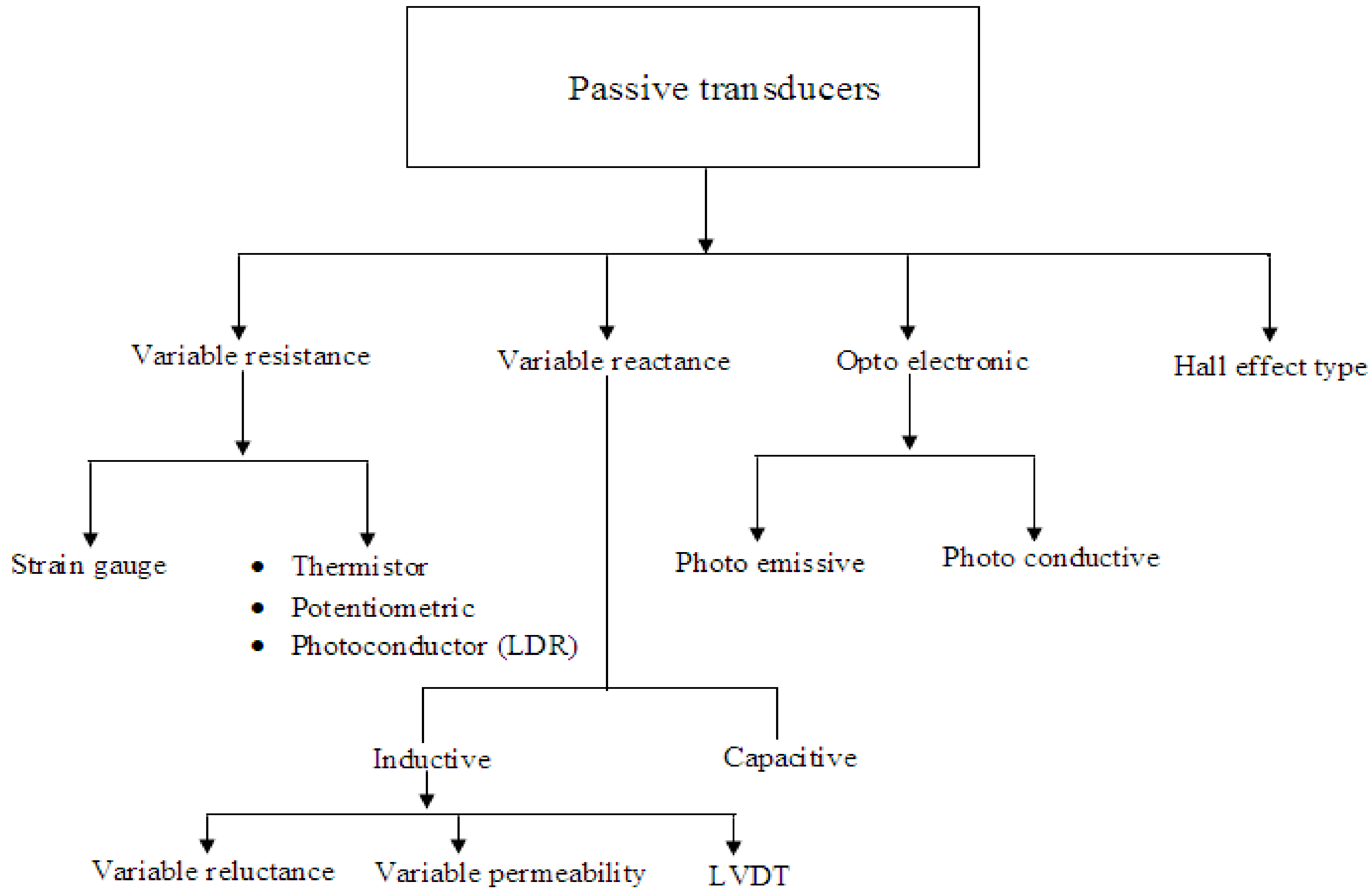
I. These transducers need external source o power for their operation. So they are no self generating type transducers.

II. A DC power supply or an audio frequenc generator is used as an external powe source.

III. These transducers produce the outpu signal in the form of variation i resistance, capacitance, inductance o some other electrical parameter in response to the quantity to be measured.



CLASSIFICATION OF PASSIVE TRANSDUCERS



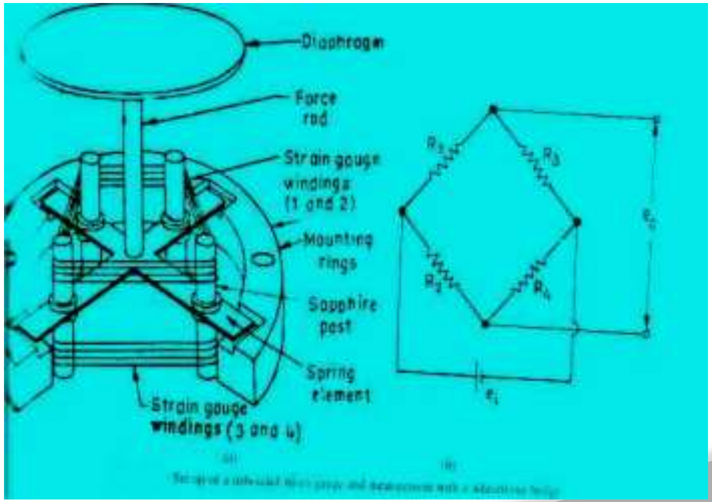
PRIMARY AND SECONDARY TRANSDUCERS

- Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured.

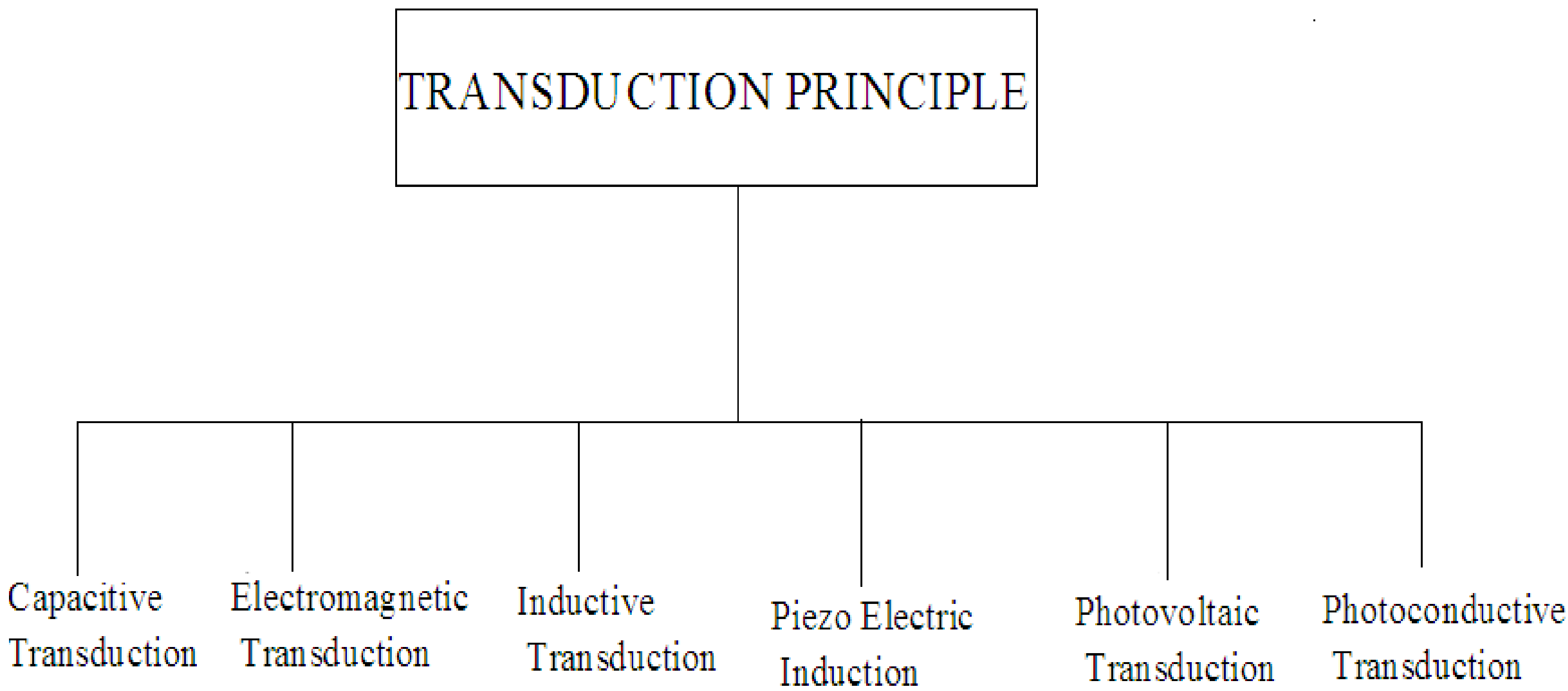
- The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducers.

•Ref fig in which the diaphragm act as primary transducer. It convert pressure (the quantity to be measured) into displacement(the mechanical signal).

•The displacement is then converted into change in resistance using strain gauge. Hence strain gauge acts as the secondary transducer.



CLASSIFICATION OF TRANSDUCERS ACCORDING TO TRANSDUCTION PRINCIPLE



CAPACITIVE TRANSDUCER:

- In capacitive transduction transducers the measurand is converted to a change in the capacitance.
- A typical capacitor is comprised of two parallel plates of conducting material separated by an electrical insulating material called a dielectric. The plates and the dielectric may be either flattened or rolled.
- The purpose of the dielectric is to help the two parallel plates maintain their stored electrical charges.
- The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by

$C = \varepsilon_0 \varepsilon_r A / d$

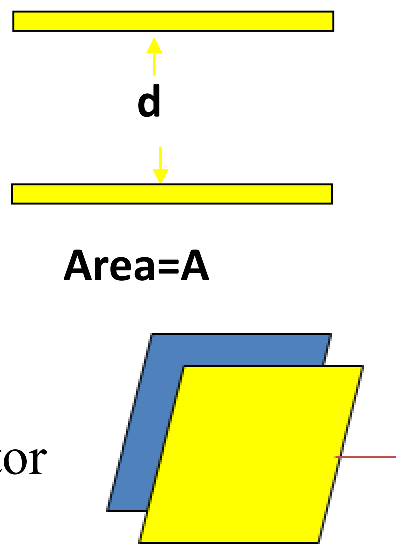
d is the separation distance of plates (m)

C is the capacitance (F, Farad)

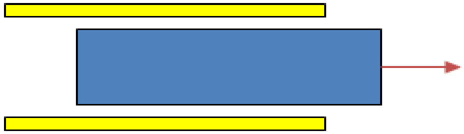
ε_0 : absolute permittivity of vacuum

ε_r : relative permittivity

A is the effective (overlapping) area of capacitor plates (m2)

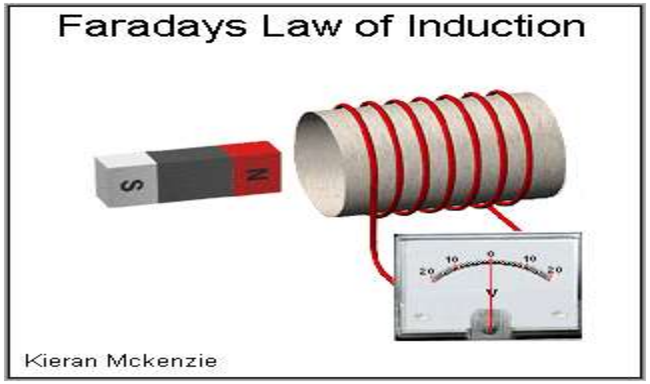


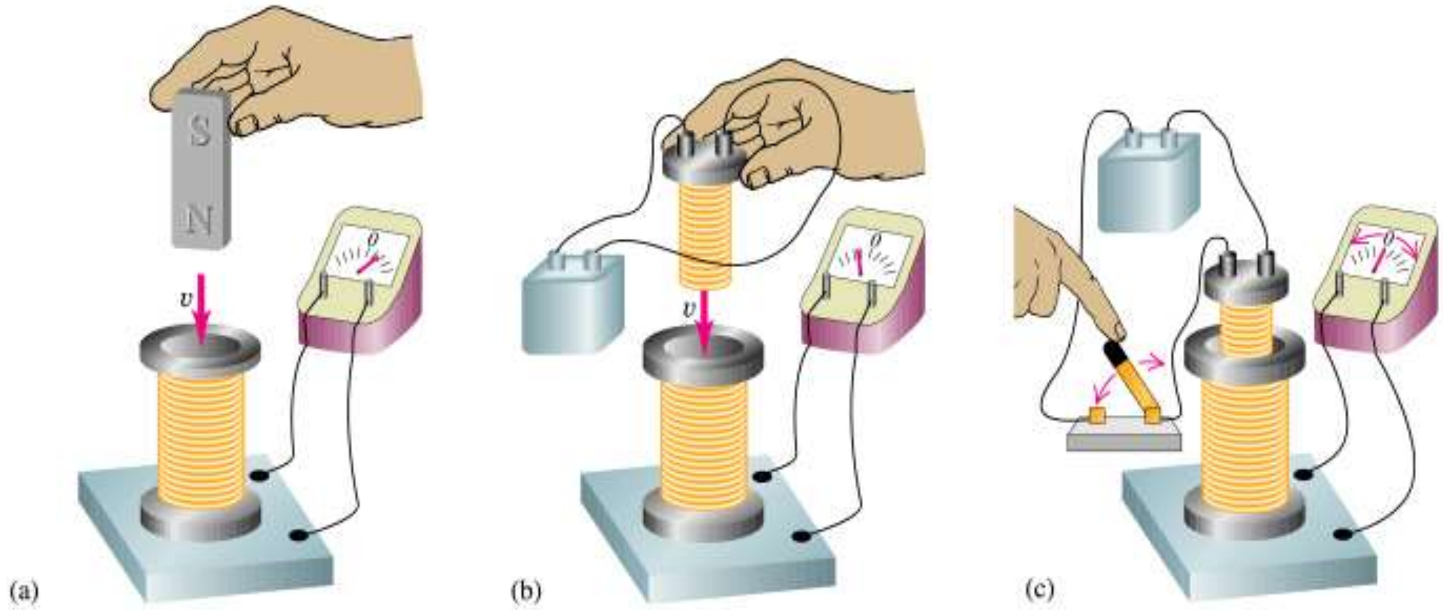
Either A, d or ε can be varied.



ELECTROMAGNETIC TRANSDUCTION:

- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux





Current induced in a coil.

STRAIN GAUGE

The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.

This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

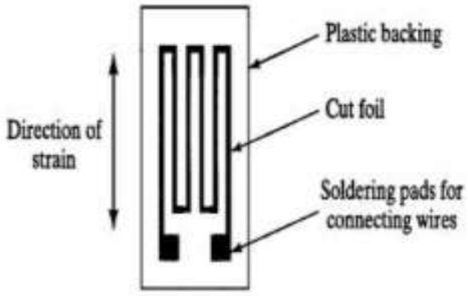
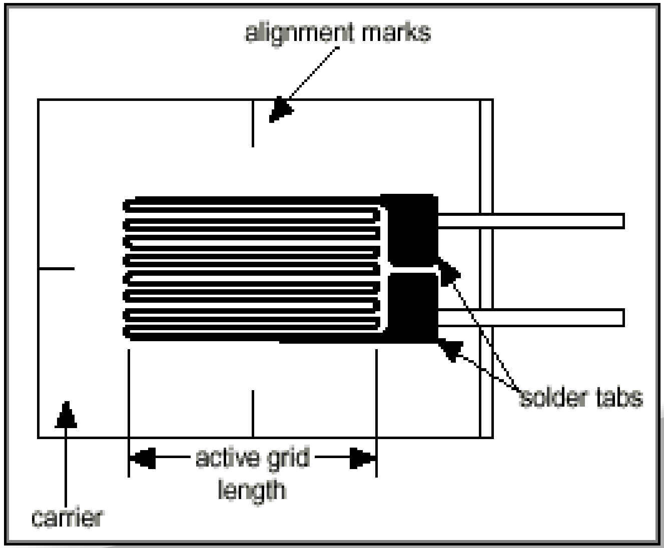


FIGURE 8.2

Foil strain gage.



TYPES OF STRAIN GAUGE

The type of strain gauge are as

1. Wire gauge
   a) Unbonded
   b) Bonded
   c) Foil type
2. Semiconductor gauge

UNBONDED STRAIN GAUGE

- An unbonded meter strain gauge is shown in fig

- This gauge consist of a wire stretched between two point in an insulating medium such as air. The wires may be made of various copper, nickel, crome nickle or nickle iron alloys.

- In fig the element is connected via a rod to diaphragm which is used for sensing the pressure. The wire are tensioned to avoid buckling when they experience the compressive force.

- The unbounded meter wire gauges used almost exclusively in transducer application employ preloaded resistance wire connected in Wheatstone bridge as shown in fig.

- At initial preload the strain and resistance of the four arms are nominally equal with the result the output voltage of the bridge is equal to zero.

- Application of pressure produces a small displacement , the displacement increases a tension in two wire and decreases it in the other two thereby increase the resistance of two wire which are in tension and decreasing the resistance of the remaining two wire .
- This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure .

BONDED STRAIN GAUGE

- The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.
- A resistance wire strain gauge consist of a grid of fine resistance wire. The grid is cemented to carrier which may be a thin sheet of paper bakelite or teflon.
- The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical demage.
- The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.

BONDED METAL FOIL STRAIN GAUGE

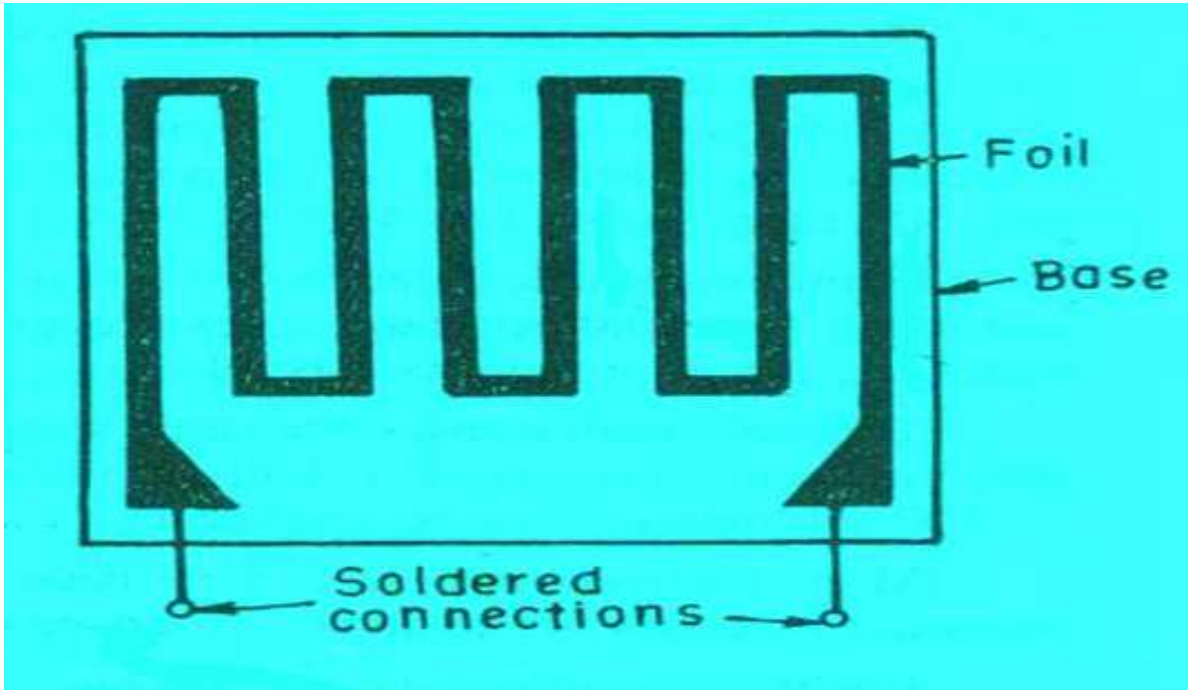
It consist of following parts:

1.Base (carrier) Materials: several types of base material are used to support the wires. Impregnated paper is used for room temp. applications.

2.Adhesive: The adhesive acts as bonding materials. Like other bonding operation, successful starain gauge bonding depends upon careful surface preparation and use of the correct bonding agent.

In order that the strain be faithfully transferred on to the strain gauge, the bond has to be formed between the surface to be strained and the plastic backing material on which the gauge is mounted

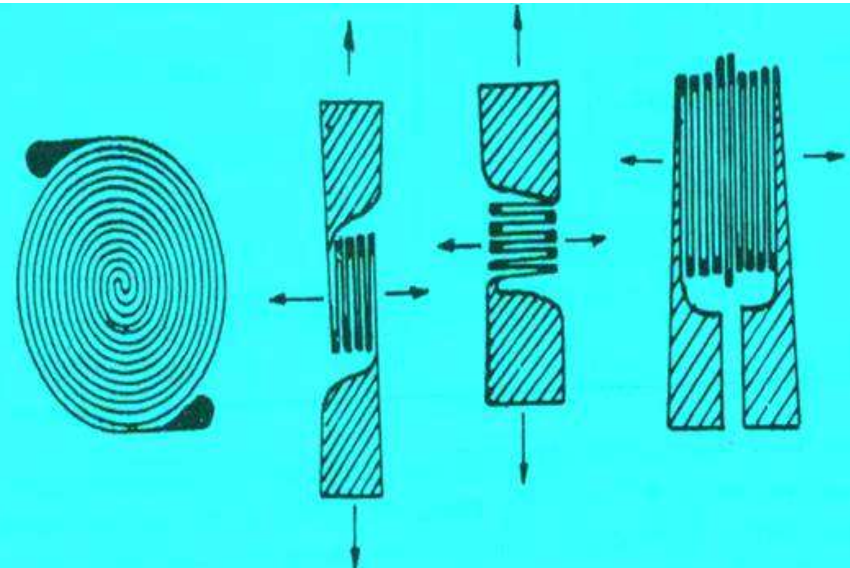
BONDED METAL FOIL STRAIN GAUGE



Bonded metal foil gauge.

- This class of strain gauge is only an extension of the bonded metal wire strain gauges.
- The bonded metal wire starin gauge have been completely superseded by bonded metal foil strain gauges.
- Metal foil strain gauge use identical material to wire strain gauge and are used for most general purpose stress analysis application and for many transducers.

METAL FOIL STRAIN GAUGE



Metal foil strain gauges.

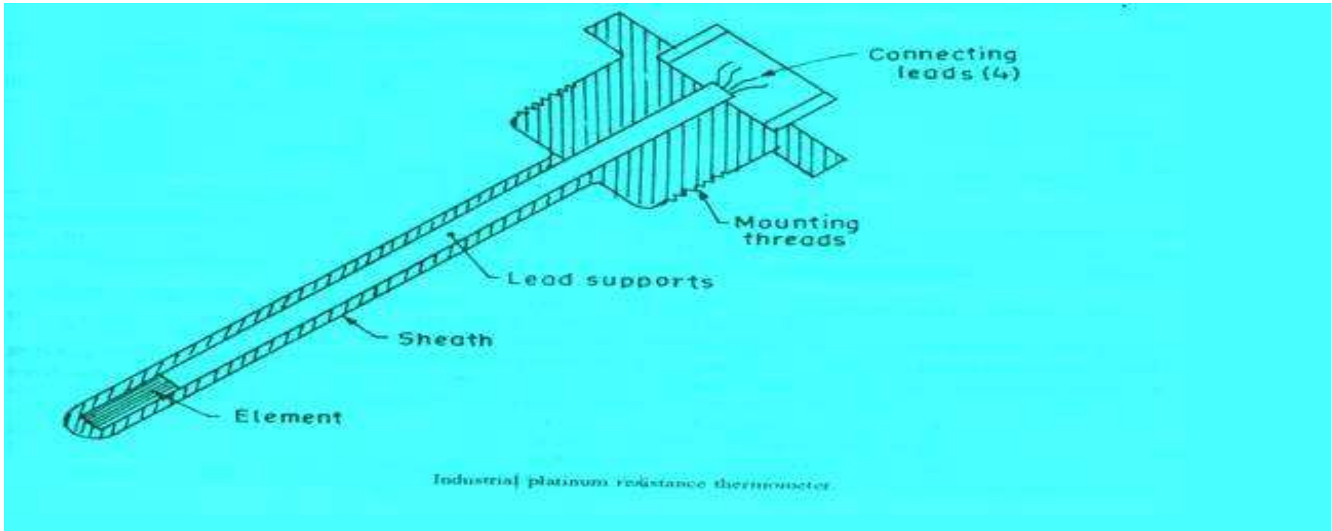
RESISTANCE THERMOMETER

- Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.

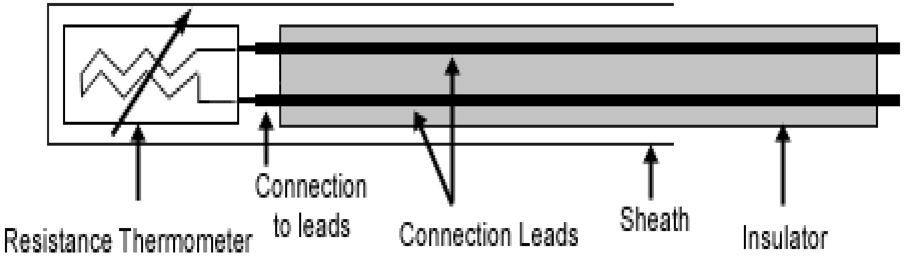
- Fig shows the simplest type of open wire construction of platinum résistance thermometer. The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.

- This assembly is then placed at the tip of probe

- This wire is in direct contact with the gas or liquid whose temperature is to be measured.



Industrial platinum resistance thermometer



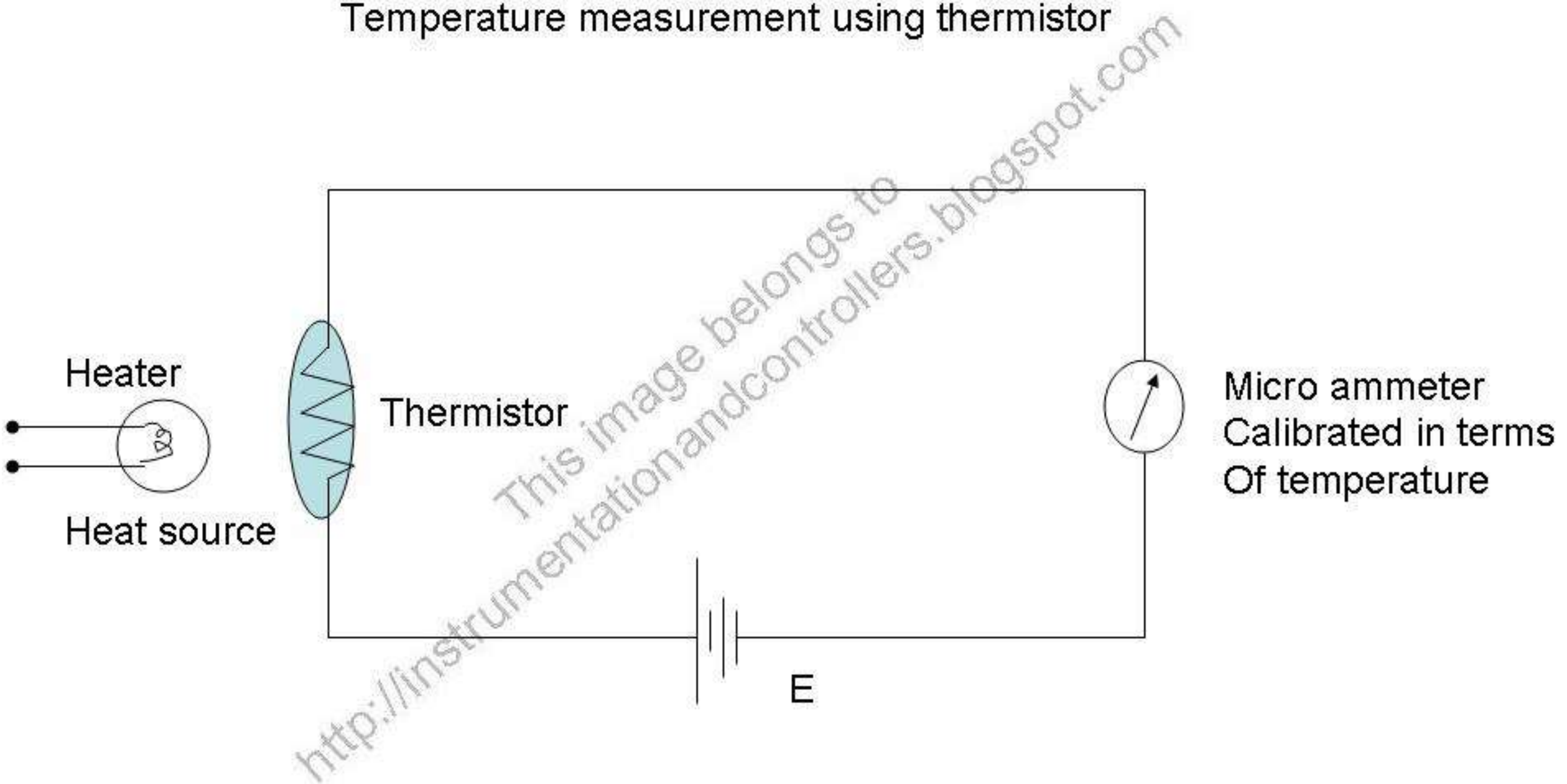
THERMISTOR

- Thermistor is a contraction of a term “thermal resistor”.

- Thermistor are temperature dependent resistors. They are made of semiconductor material which have negative temperature coefficient of resistivity i.e. their resistance decreases with increase of temperature.

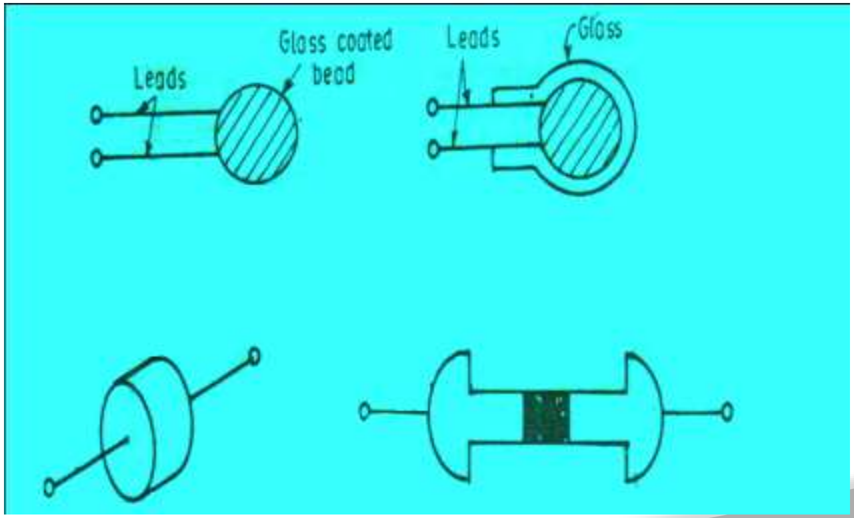
- Thermistor are widely used in application which involve measurement in the range of 0-60^{o} Thermistor are composed of sintered mixture of metallic oxides such as magnese, nickle, cobalt, copper, iron and uranium

Temperature measurement using thermistor



•The thermistor may be in the form of beads, rods and discs.

•The thermistor provide a large change in resistance for small change in temperature. In some cases the resistance of themistor at room temperature may decreases as much as 6% for each 1ºC rise in temperature.

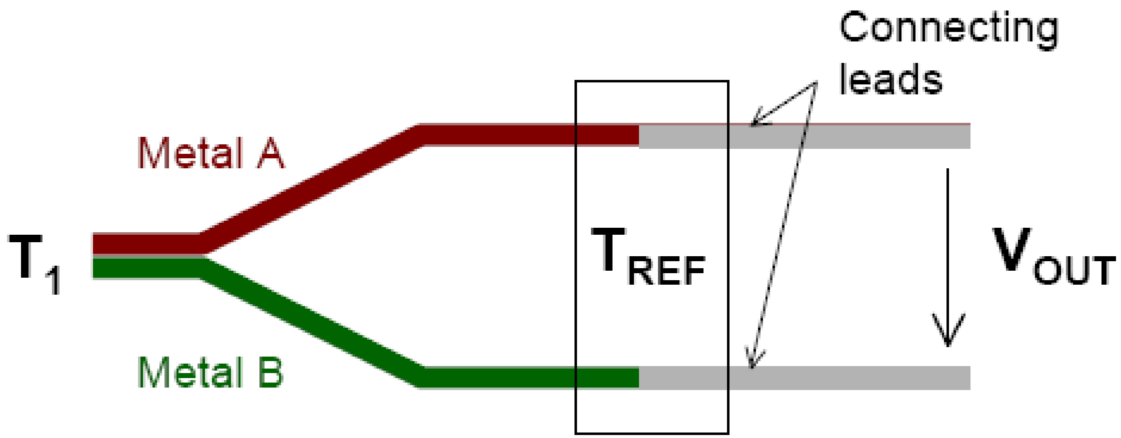


Thermocouples

<u>See beck Effect</u>

When a pair of dissimilar metals are joined at one end, and there is a temperature difference between the joined ends and the open ends, thermal emf is generated, which can be measured in the open ends.

This forms the basis of thermocouples.

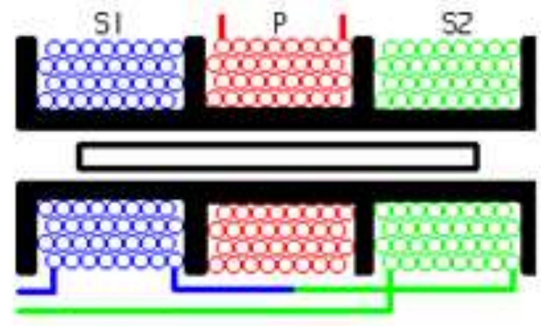


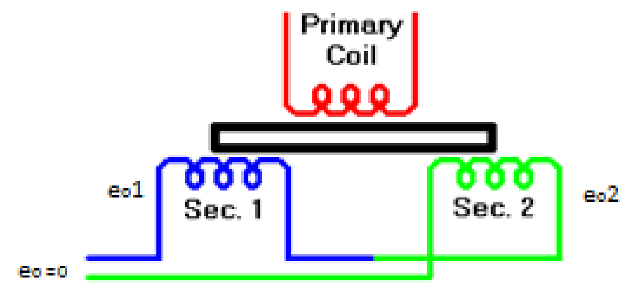
Typical Specifications

	Handheld/Economy	Industrial Grade
Measurable velocities	0.2-20 m/s	0.2-90 m/s
Operating temp ranges	0-50 °C	-40-200 °C
Velocity Accuracy	± 3% reading	± 1% reading
Time constant	200 ms	100 ms
Interfacing options	Handheld reader, RS232	RS232, RS485, voltage, 4-20 mA, Modbus, Profibus, etc.

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER(LVDT)

- AN LVDT transducer comprises a coil former on to which three coils are wound.
- The primary coil is excited with an AC current, the secondary coils are wound such that when a ferrite core is in the central linear position, an equal voltage is induced in to each coil.
- The secondary are connected in opposite so that in the cent position the outputs of secondary cancels each other out.



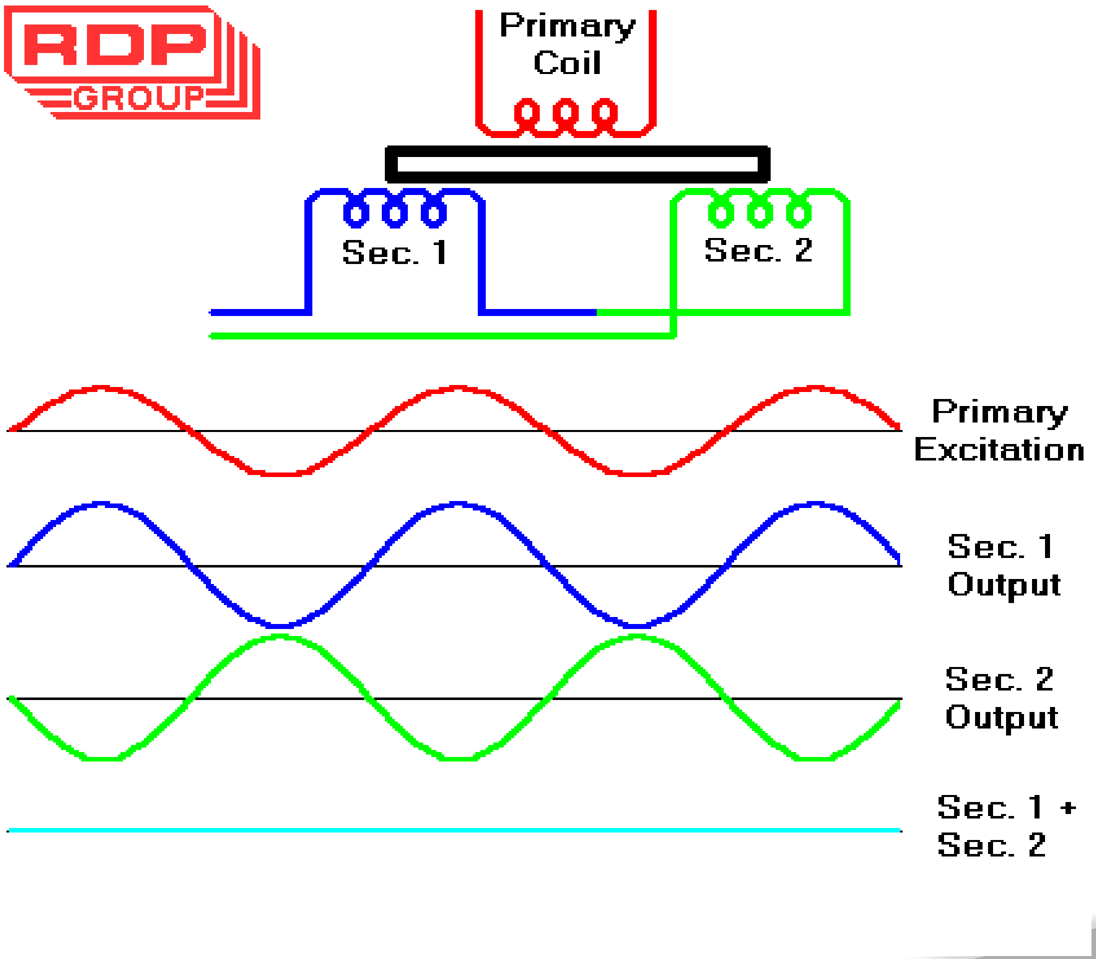


equal coupling with both secondaries therefore eo2 equal eo1

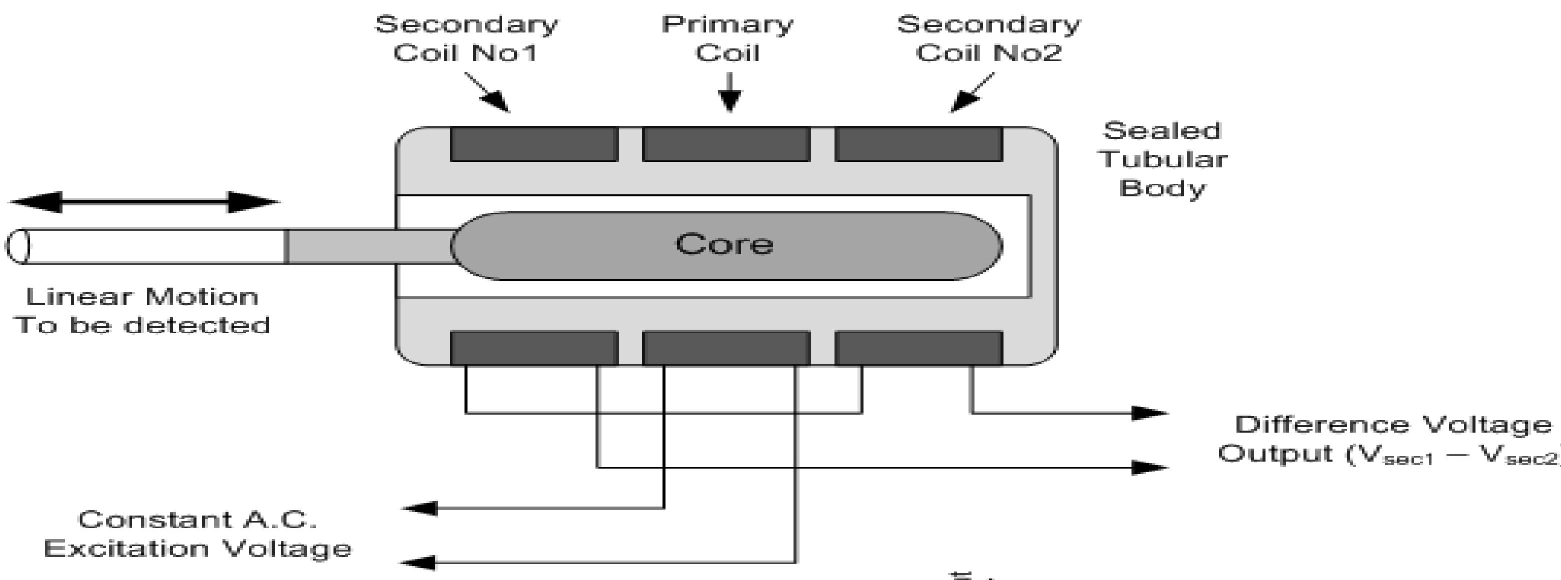
•The excitation is applied to the primary winding and the armature assists the induction of current in to secondary coils.

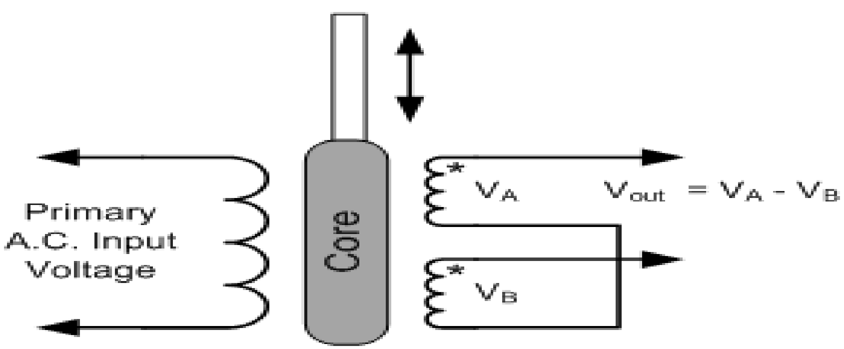
•When the core is exactly at the center of the coil then the flux linked to both the secondary winding will be equal. Due to equal flux linkage the secondary induced voltages (eo1 & eo2) are equal but they have opposite polarities. Output voltage eo is therefore zero. This position is called “null position”

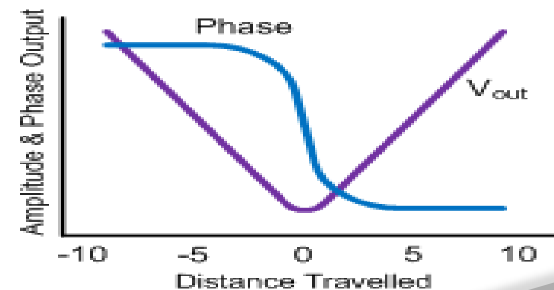
LVDT

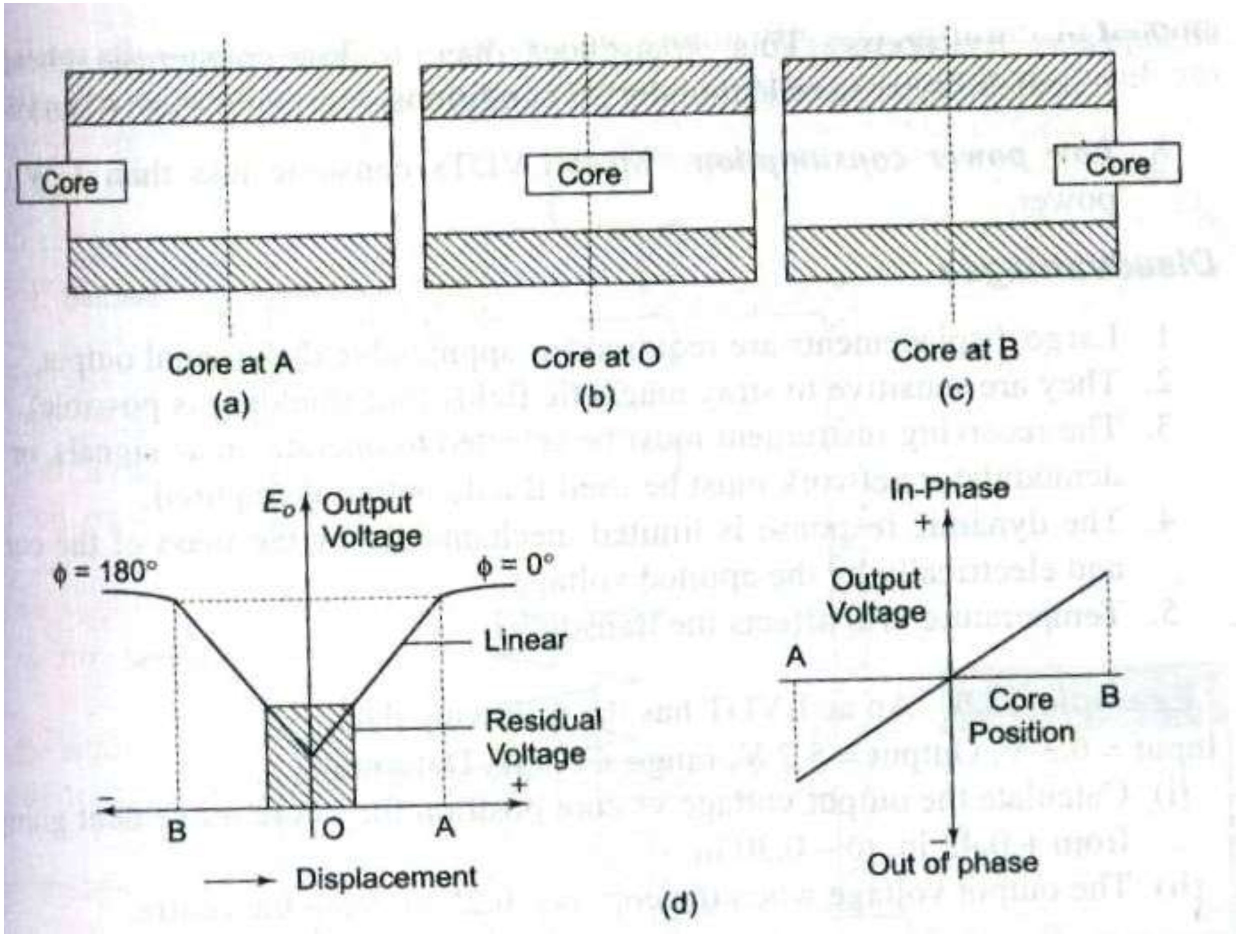

RDP GROUP
Primary Coil
Sec. 1
Sec. 2
Primary Excitation
Sec. 1 Output
Sec. 2 Output
Sec. 1 + Sec. 2

Three Coil mutual inductance device (LVDT)





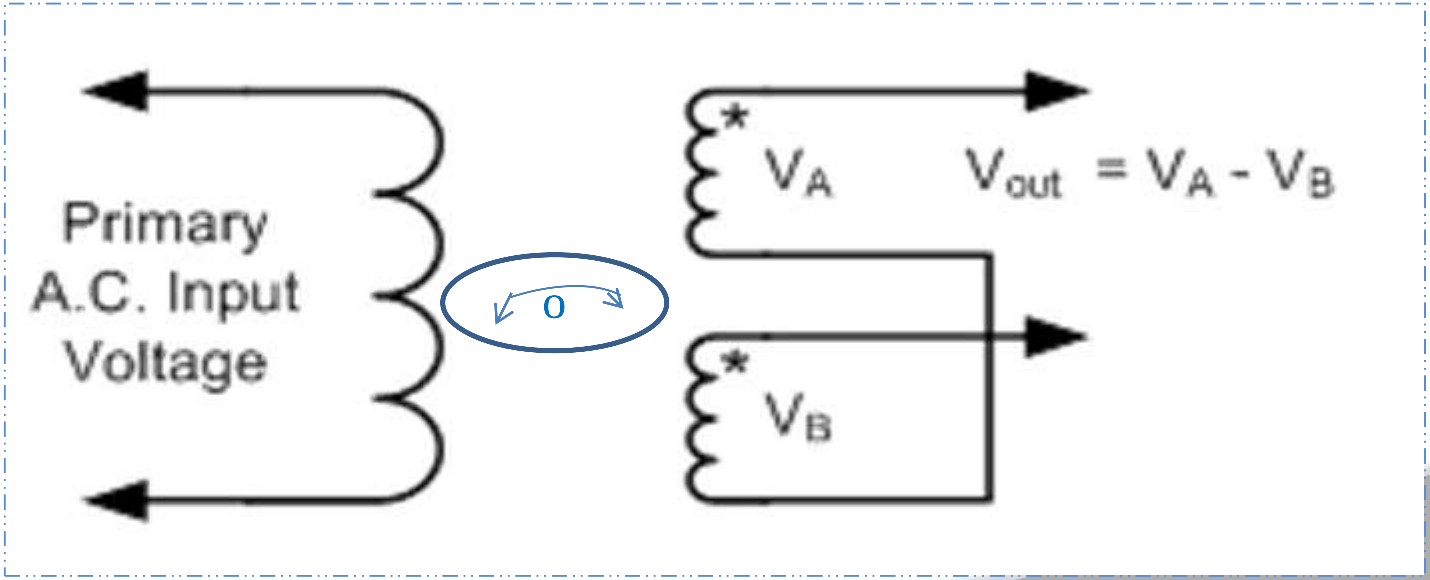



Core
Core
Core
Core at A
(a)
Core at O
(b)
Core at B
(c)
E_o Output Voltage
ϕ = 180°
ϕ = 0°
Linear
Residual Voltage
B
O
A
Displacement
In-Phase
Output Voltage
A
B
Core Position
Out of phase
(d)

Rotary Variable Differential Transformer

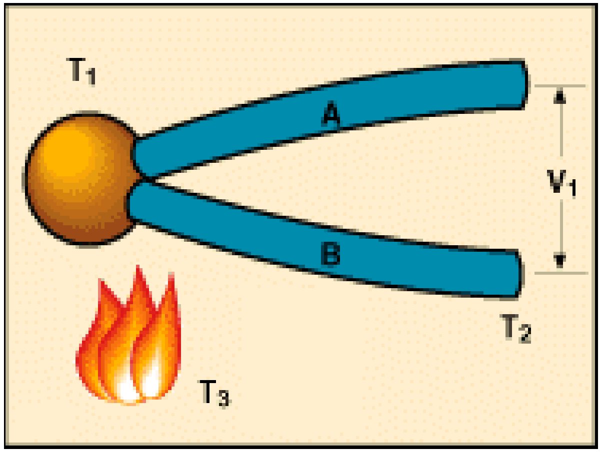
A RVDT is a type of electrical transformer used for measuring Angular Displacement .

The RVDT construction is similar in construction to LVDT, except that a cam-shaped core replaces the core in the LVDT as shown below.



What are thermocouples?

Thermocouples operate under the principle that a circuit made by connecting two dissimilar metals produces a measurable voltage (emf- electromotive force) when a temperature gradient is imposed between one end and the other.



They are inexpensive, small, rugged and accurate when used with an understanding of their peculiarities.

Thermocouples Principle of Operation

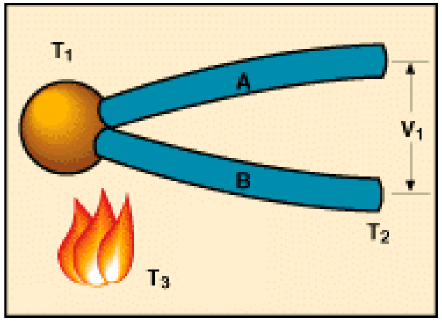
In, 1821 T. J. Seebeck observed the existence of an electromotive force (EMF) at the junction formed between two dissimilar metals (Seebeck effect).

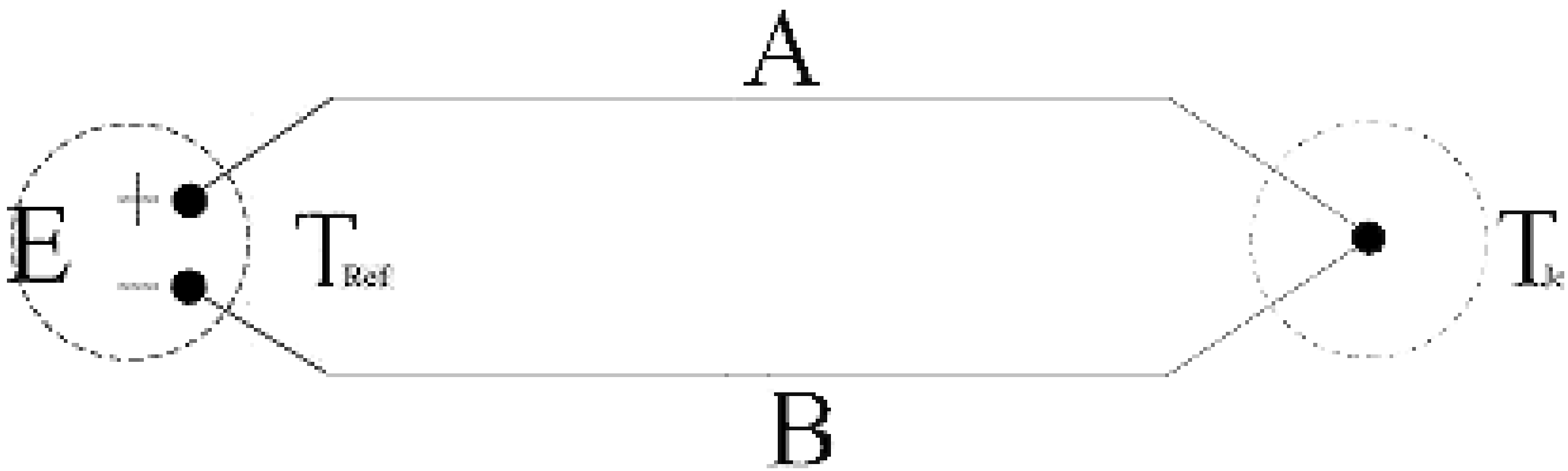
Seebeck effect is actually the combined result of two other phenomena, Thomson and Peltier effects.

Thomson observed the existence of an EMF due to the contact of two dissimilar metals at the junction temperature.

Peltier discovered that temperature gradients along conductors in a circuit generate an EMF.

The Thomson effect is normally much smaller than the Peltier effect.




A
E
+
−
T Ref
T
B

How thermocouples work

It is generally reasonable to assume that the emf is generated in the wires, not in the junction. The signal is generated when dT/dx is not zero.

When the materials are homogeneous, ε, the thermoelectric power, is a function of temperature only.

Two wires begin and end at the same two temperatures.

$$E = \int_0^L \varepsilon_A \frac{dT}{dx}dx + \int_L^0 \varepsilon_B \frac{dT}{dx}dx \qquad \text{Equation 1}$$

If the wires are both homogeneous, then

$$E = \int_{T_{Ref}}^{T_{Jct}} \varepsilon_A\, dT + \int_{T_{Jct}}^{T_{Ref}} \varepsilon_B dT \qquad \text{Equation 2}$$

If both wires begin at T_{Ref} and end at T_{Jct}, then

$$E = \int_{T_{Ref}}^{T_{Jct}} (\varepsilon_A - \varepsilon_B) dT \qquad \text{Equation 3}$$

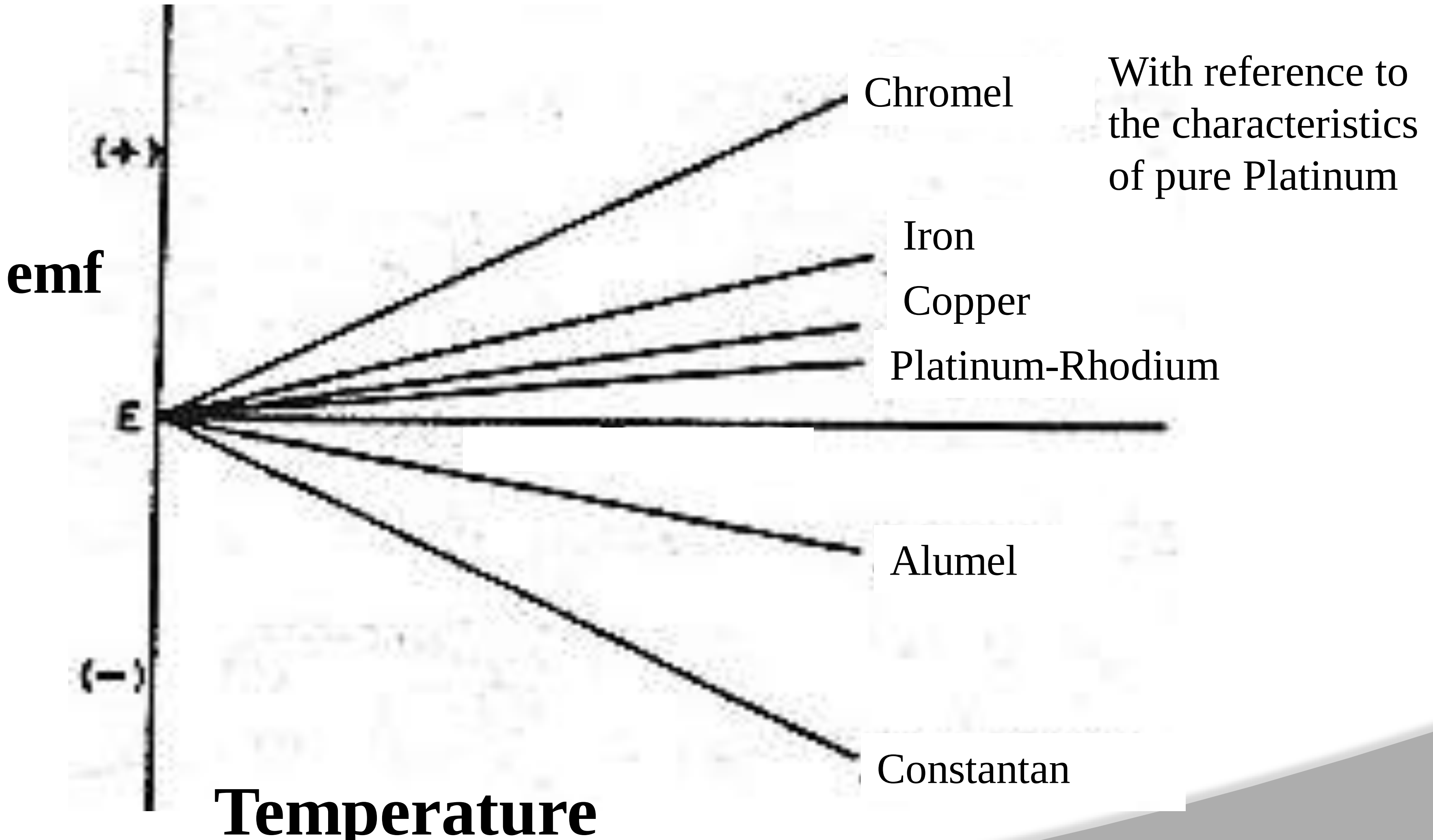
For small temperature differences, we can use the average calibrations:

$$E = (\varepsilon_A - \varepsilon_B)(T_{Jct} - T_{Ref}) = \varepsilon_{AB}(T_{Jct} - T_{Ref}) \qquad \text{Equation 4}$$

Generally, a second order Eqn. is used.

$$E = \alpha(T - T_o) + \beta(T - T_o)^2$$

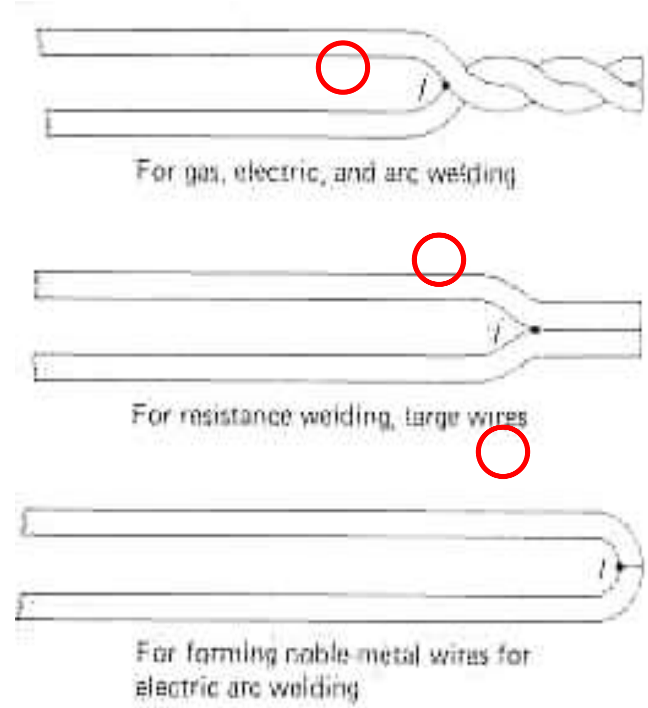
Material EMF vs Temperature

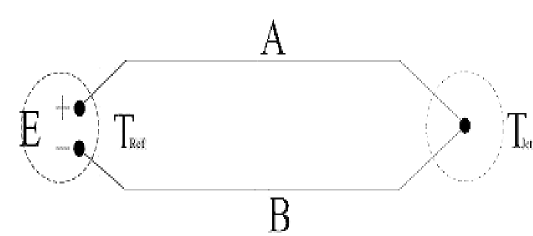


Thermocouple Effect

Any time a pair of dissimilar wires is joined to make a circuit and a thermal gradient is imposed, an emf voltage will be generated.

- Twisted, soldered or welded junctions are acceptable. Welding is most common.
- Keep weld bead or solder bead diameter within 10-15% of wire diameter
- Welding is generally quicker than soldering but both are equally acceptable
- Voltage or EMF produced depends on:
  - Types of materials used
  - Temperature difference between the measuring junction and the reference junction





The piezoelectric effect

- Piezoelectric effect is the generation of electric charge in crystalline materials upon application of mechanical stress.
- The opposite effect is equally useful: application of charge across the crystal causes mechanical deformation in the material.
- The piezoelectric effect occurs naturally in materials such as quartz (SiO_2 - a silicon oxide)
- Has been used for many decades in so called crystal oscillators.

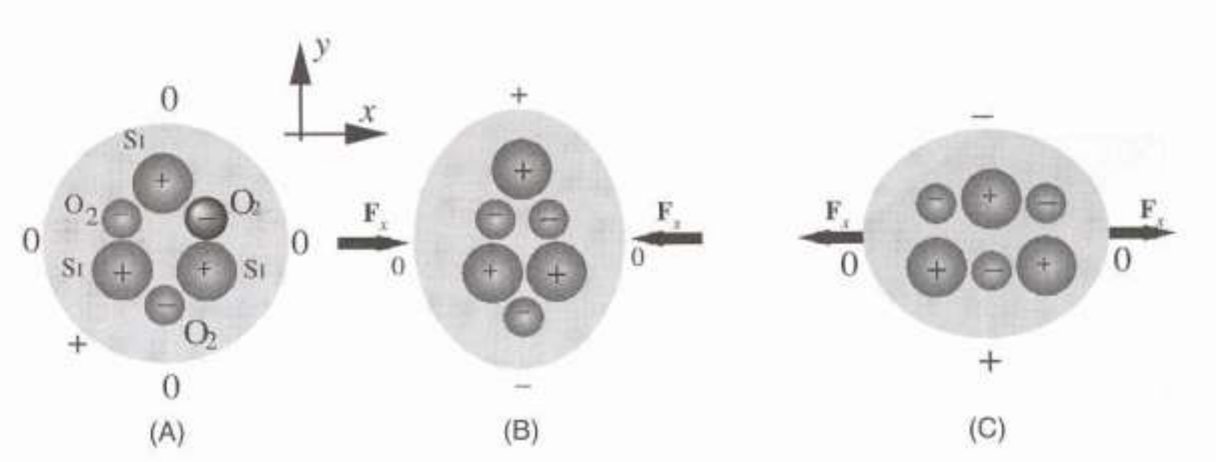
The piezoelectric effect

- It is also a property of some ceramics and polymers
- We have already met the piezoresistive materials of chapter 5 (PZT is the best known) and the polymer piezoresistive materials PVF and PVDF.
- The piezoelectric effect has been known since 1880
- First used in 1917 to detect and generate sound waves in water for the purpose of detecting submarines (sonar).
- The piezoelectric effect can be explained in a simple model by deformation of crystals:

The piezoelectric effect

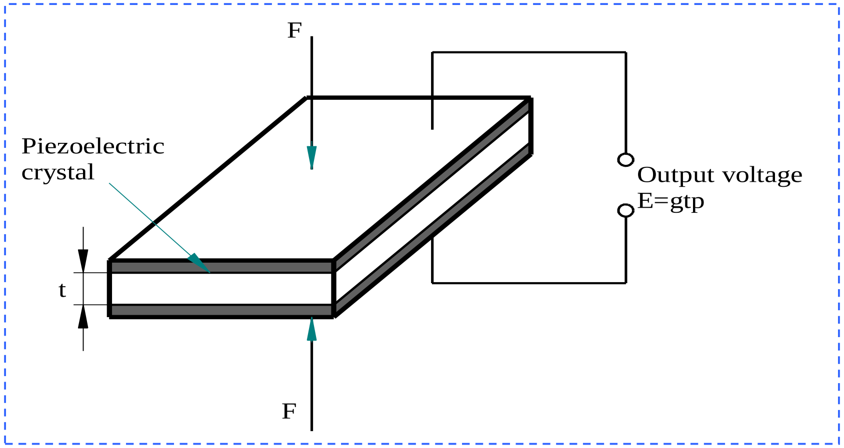
Deformation in one direction (**B**) displaces the molecular structure so that a net charge occurs as shown (in Quartz crystal - SiO_2)

Deformation in a perpendicular axis (**B**) forms an opposite polarity charge



Piezo-Electric Transducers

Certain materials can produce an electrical potential when subjected to mechanical strain or conversely, can change dimensions when subjected to voltage. This effect is called *'Piezoelectric effect'.*



The fig shows a piezoelectric crystal placed between two plate electrodes and when a force 'F' is applied to the plates, a stress will be produced in the crystal and a corresponding deformation. The induced charge $Q=d \times F$ where 'd' is the piezoelectric constant.

The output voltage $E=g \times t \times p$ where 't' is crystal thickness, 'p' is the impressed pressure & 'g' is called voltage sensitivity given by $g=(d/e)$, e being the strain.

Piezo-Electric Materials

The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartrate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape.

Quartz is most suitable and is used in electronic oscillators. Its output is low but stable.

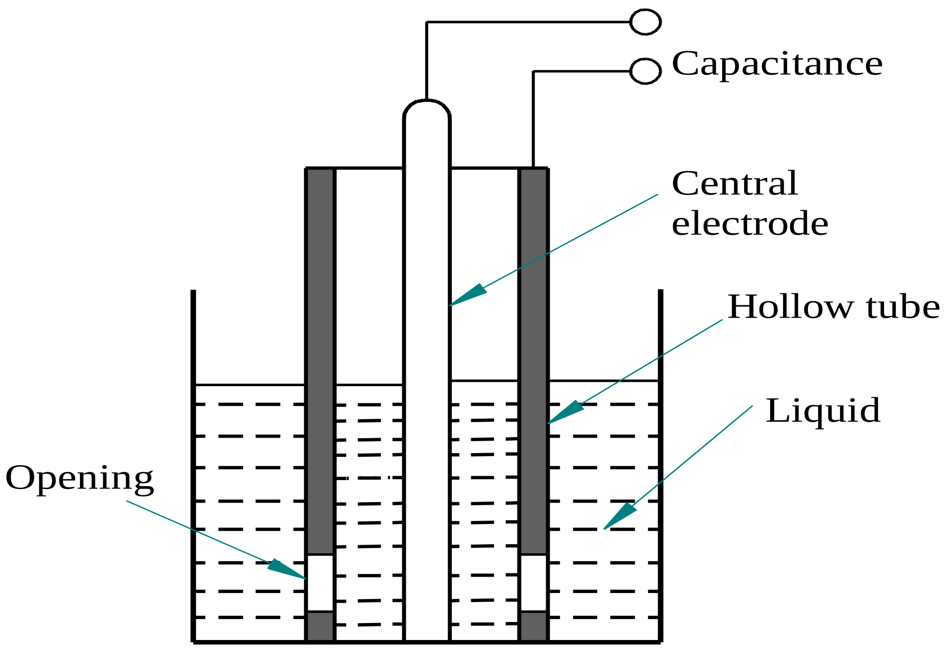
Rochelle salt provides highest output, but requires protection from moisture in air & cannot be used above 45^{o}C.

Barium titanate is polycrystalline, thus it can be formed into a variety of sizes & shapes.

Piezoelectric transducers are used to measure surface roughness, strain, force & torque, Pressure, motion & noise.

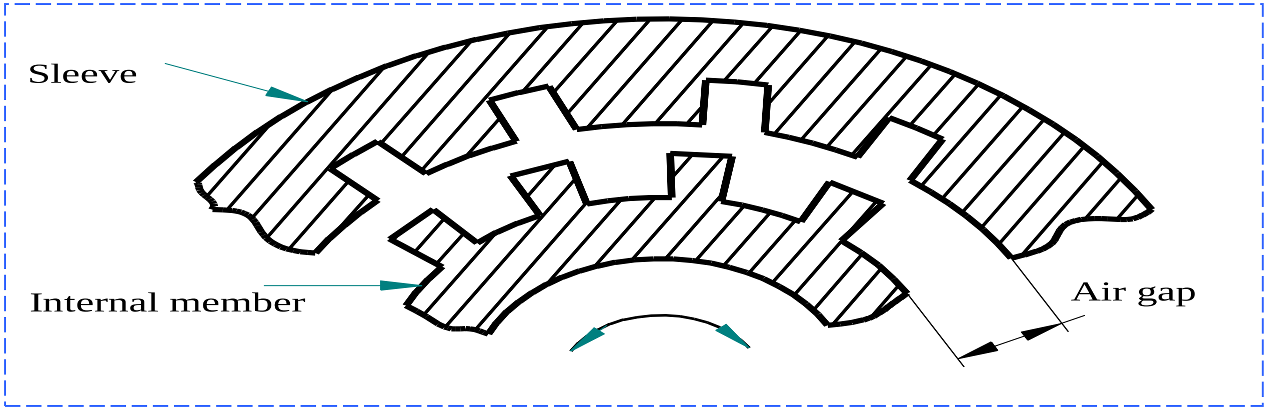
Capacitive Transducer

Capacitance Pickup to measure liquid level (Changing dielectric constant)



The above fig. shows a device used for the measurement of liquid level in a container. The capacitance between the central electrode and the surrounding hollow tube varies with changing dielectric constant brought about by changing liquid level. Thus the capacitance between the electrodes is a direct indication of the liquid level. Variation in dielectric constant can also be utilized for measurements of thickness, density, etc.

Capacitive Transducer
(Torque meter)

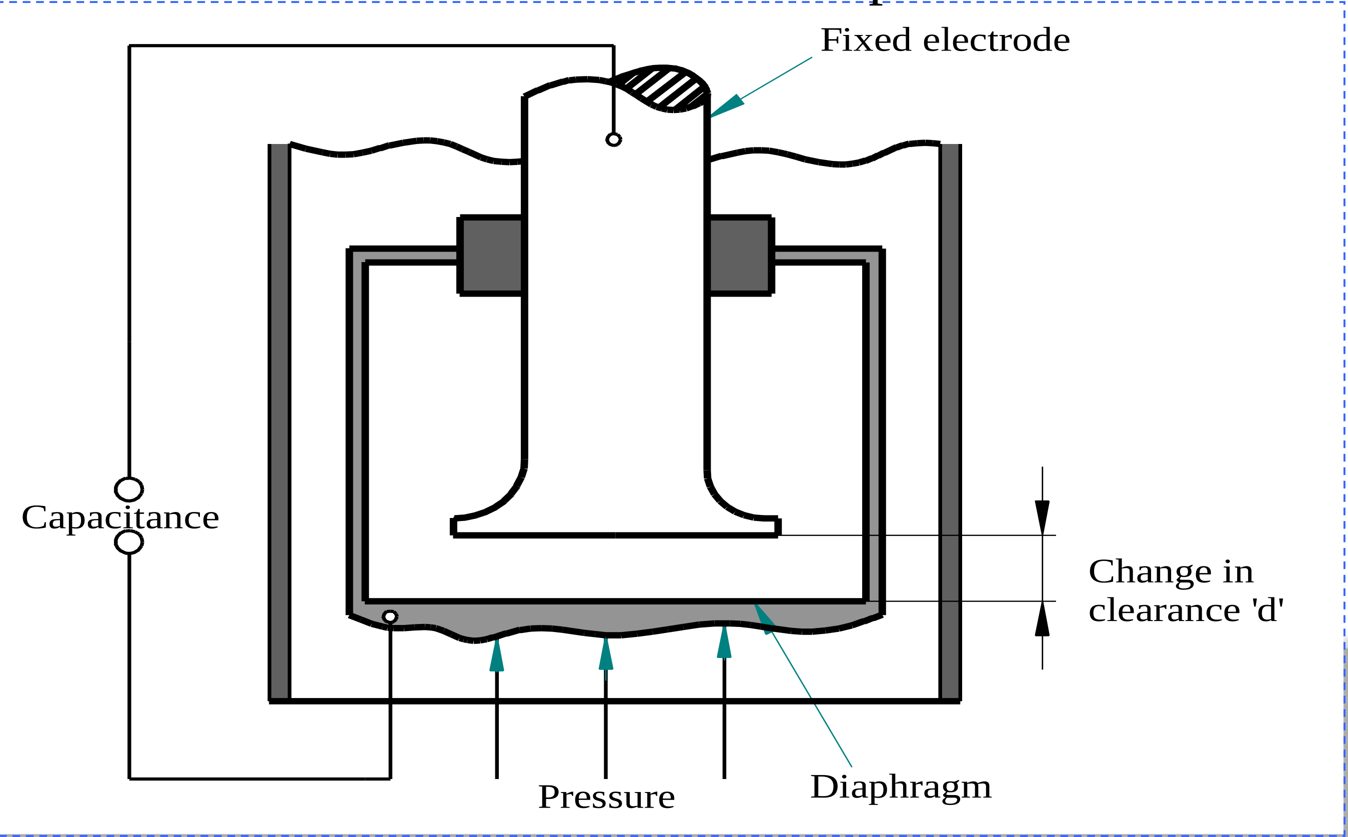


Capacitance changes depending on the change in effective area. This principle is used in the secondary transducing element of a *Torque meter.* This device uses a sleeve with serrations cut axially and a matching internal member with similar serrations as shown in the above fig.

Torque carried by an elastic member causes a shift in the relative positions of the serrations, thereby changing the effective area. The resulting capacitance change may be calibrated to read the torque directly.

Capacitive Transducer
(Capacitive Type Pressure Transducer)

The capacitance varies inversely as the distance between the plates. The fig shows a capacitive type pressure transducer where the pressure applied to the diaphragms changes the distance between the diaphragm & the fixed electrode which can be taken as a measure of pressure.



Advantages of Capacitive Transducers

(1) Requires extremely small forces to operate and are highly sensitive
(2) They have good frequency response and hence useful for dynamic measurements.
(3) High resolution can be obtained.
(4) They have high input impedance & hence loading effects are minimum.
(5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

(1) Metallic parts must be properly insulated and the frames must be earthed.
(2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.
(3) They are sensitive to temperature affecting their performance.
(4) The instrumentation circuitry used with these transducers are complex.
(5) Capacitance of these transducers may change with presence of dust particles & moisture.

Magnetostrictive Transducers

Characteristics:

□Magnetostrictive materials transduce or convert magnetic energy Character istics: to mechanical energy and vice versa.

□If a magnetostrictive material is magnetized, it strains. Conversely, if an external force produce a strain in a magnetostrictive material the an external force produce a strain in a magnetostrictive material, the magnetic state of the material will change.

□Magnetostriction is an inherent material is an inherent material property that does not property that does not degrade with time.

□The pp p rinci ple of o peration of these transducers de pends on the chan ge of permeability of ferromagnetic materials, like Ni, when they are subjected to strain

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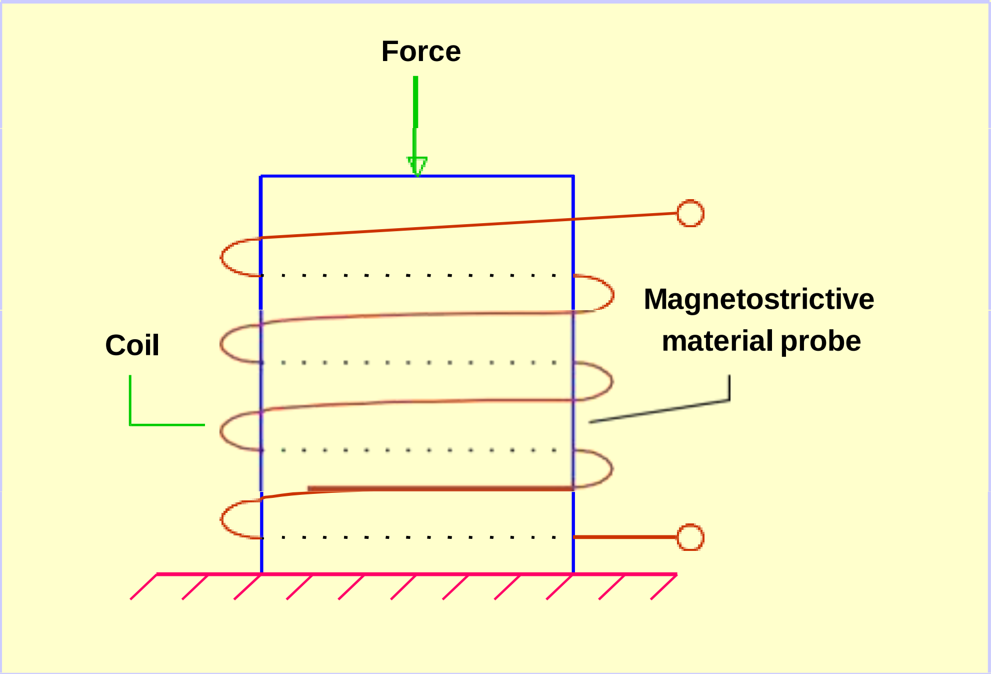
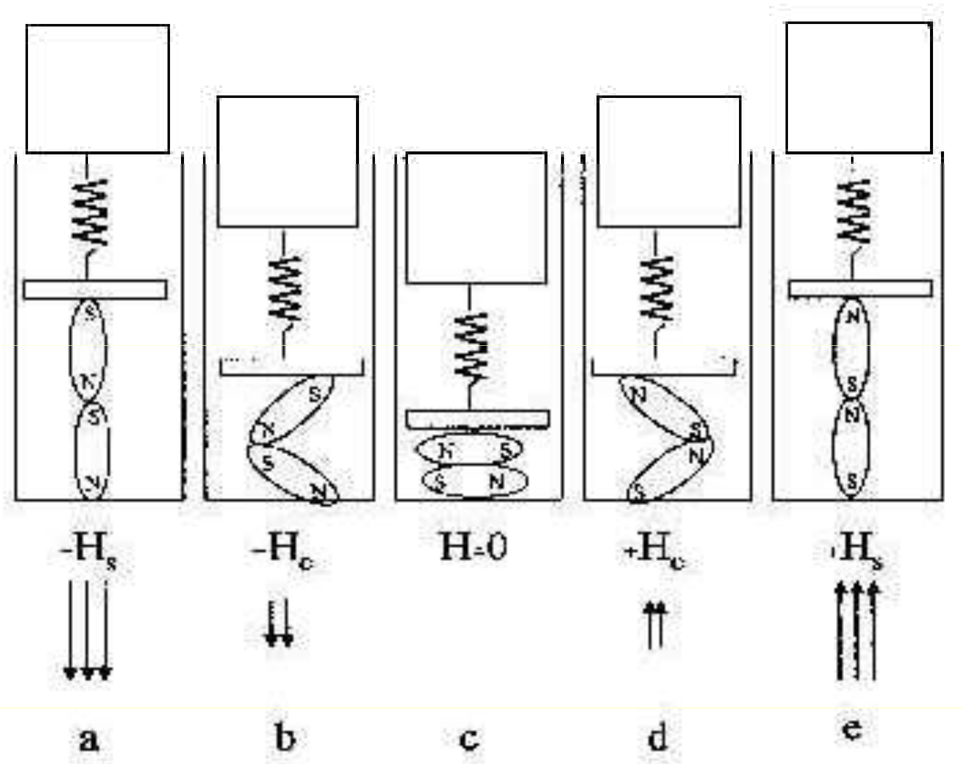
- ✓ Magnetostriction is an inherent material property that does not degrade with time.
- ✓ The principle of operation of these transducers depends on the change of permeability of ferromagnetic materials, like Ni, when they are subjected to



The schematic representation of a magnetostrictive transducer

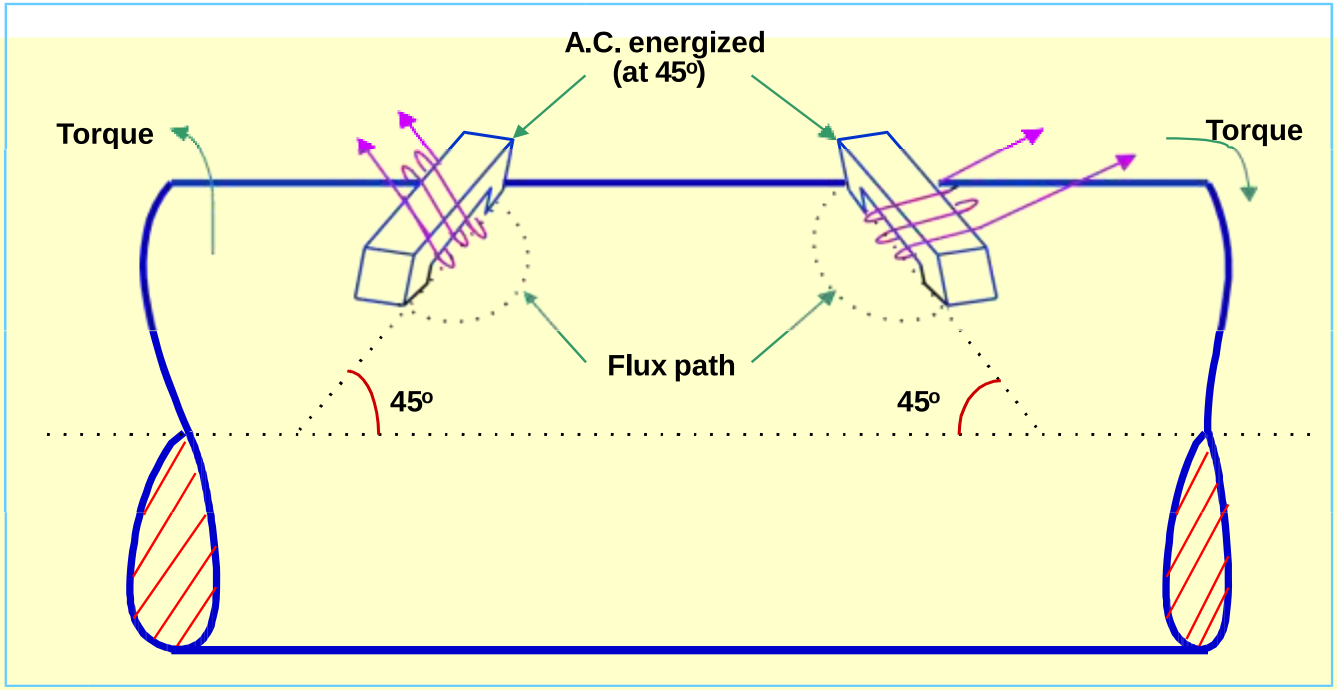
An actual magnetostrictive transducer

Magnetostrictive Transducers



A simplistic representation of the strain and magnetic induction observed in magnetostrictive materials

Measurement of Shaft Torque: A Popular Application



✓An a.c. bridge circuit is employed, with two coils forming two arms.

✓The voltage output of the a.c. bridge gives a measure of the torque applied.

Measurment of Physical Parameters

HUMIDITY MEASUREMENT

Humidity is the amount of water vapour in the air and Humidity Measurement is a measure of relative amount of water vapour present in the air or a gas.

The humidity can be expressed in different ways:

- Absolute Humidity
- Relative Humidity
- Dew Point

HUMIDITY MEASUREMENT

Devices that indirectly measure humidity by sensing changes in physical or electrical properties in materials due to their moisture content are called hygrometers.

The three major instruments used for measuring humidity in industry are:

The Electrical Hygrometer

The Psychrometer

The Dew Point Meter

RESISTANCE HYGROMETER

This is an electrical hygrometer.
It is an active transducer.
These instruments are suitable for measuring moisture levels between 15% and 95%.
It has typical measurement uncertainty of 3%.
Atmospheric contaminates and operation in saturation conditions both cause characteristics drift.

PRINCIPLE OF RESISTANCE HYGROMETER

Some Hygroscopic Salts exhibit a change in resistivity with humidity. Resistive hygrometer humidity sensors use the change in resistance of a hygroscopic material between two electrodes on an insulating substrate.

The hygroscopic salt is deposited between two electrodes. The resistance of the element changes when it is exposed to variations in humidity.

RESISTANCE HYGROMETER

The Resistance Hygrometer should not be exposed to conditions of 100% humidity as the resulting condensation may damage the device.

These are accurate to within ± 2.5 % or ± 1.5 % in some cases.

Response times are typically of the order of a few seconds.

APPLICATIONS

Humidity sensors can be used not only to measure the humidity in an atmosphere but also to automatically control:

-> Humidifiers
-> Dehumidifiers
-> Air conditioners for adjustment.

VELOCITY MEASUREMENT

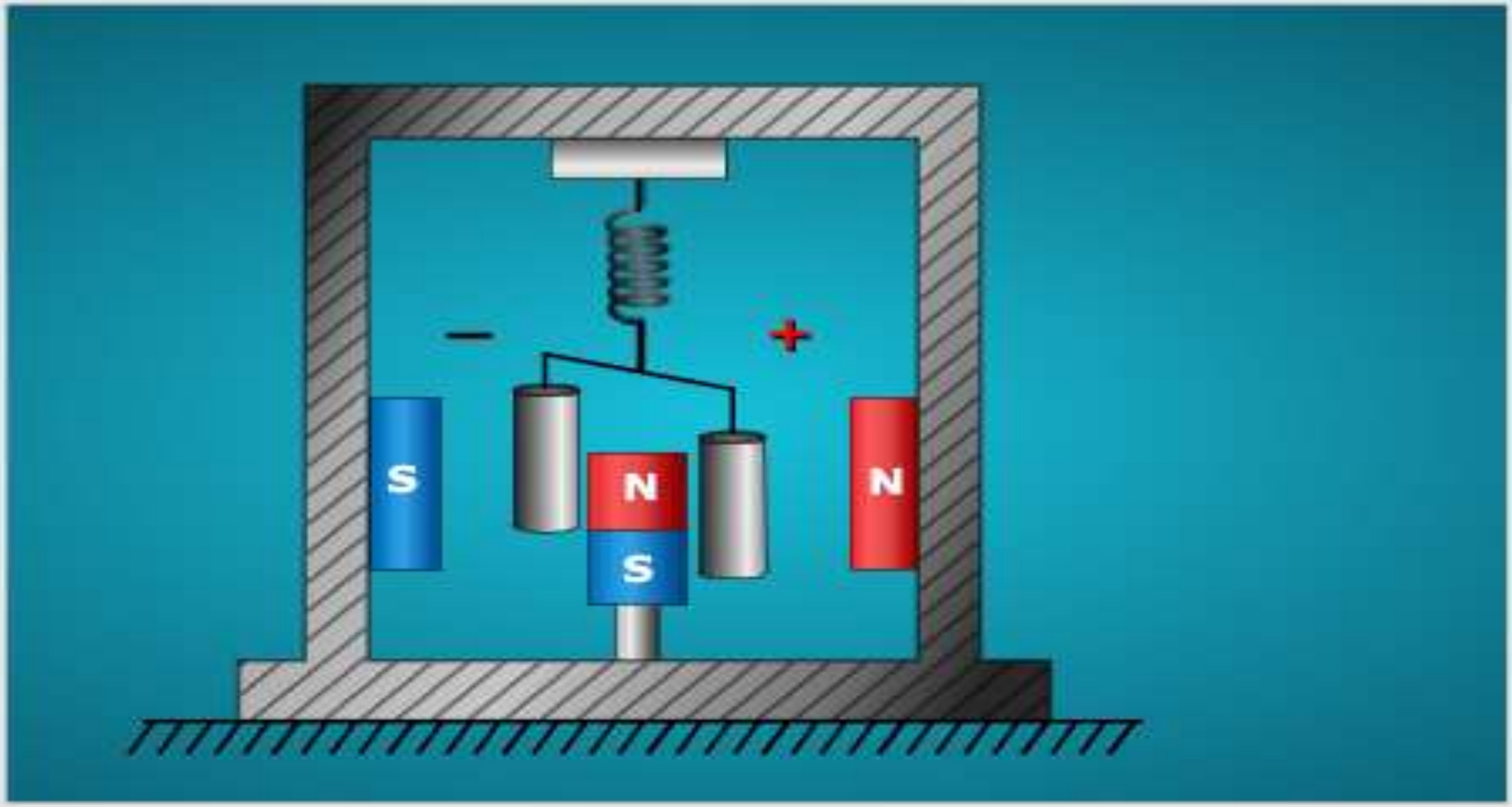
- Velocity is the rate of change of distance in a specific direction
- Velocity is a vector quantity having both magnitude and direction
- The average velocity of an object having a displacement (Δx) during a time interval (Δt) is given by

$$\bar{\upsilon} = \frac{\Delta x}{\Delta t}$$

- Velocity transducers are used to measure linear velocity and angular velocity
- To measure linear velocity, it must be converted into angular velocity, and then measured

Linear Velocity Transducers

- The linear velocity transducers use the principle of electromagnetic induction and converts mechanical vibrations into alternating voltages. So, they are referred to as electromagnetic transducers
- Electromagnetic transducers are of two types:



Moving Coil Type Velocity Transducer

- The moving coil type velocity transducer operates based on the action of moving coil in a magnetic field
- The construction of such transducer is given in image
- A coil is hung up between the pole pieces of the permanent magnet and the spring assembly acts as the support of the suspended coil
- The moving coil in the magnetic field produces voltage. The output is directly proportional to the velocity of the moving coil
- This system is also referred to as electrodynamic pick-up system and it is used for measuring linear, sinusoidal or random velocities

- The voltage induced in the coil at any instant of time is given by

$$e_0 = B.l.v$$

where e_0 – Output voltage,

B – Flux density

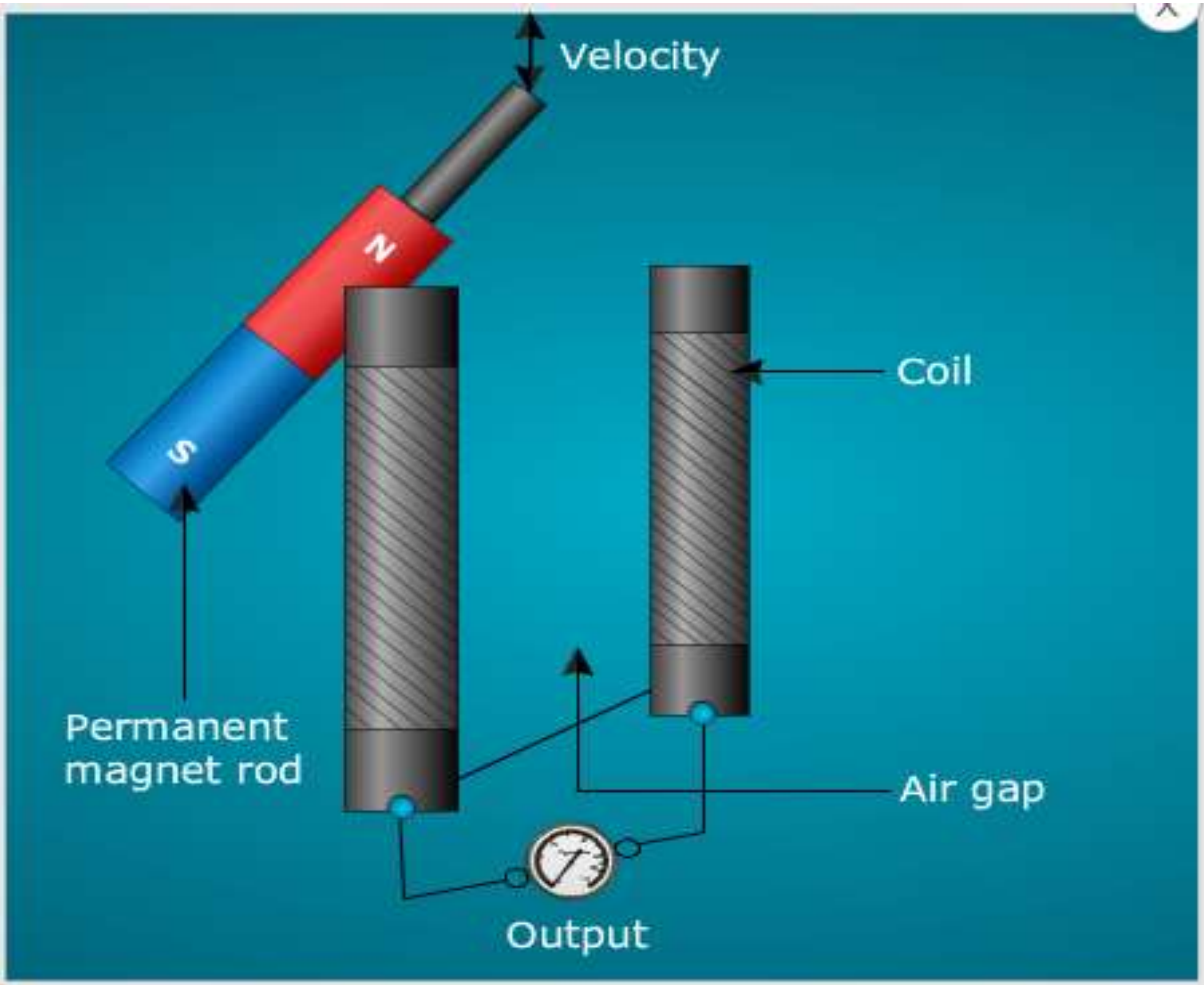
l – Length of coil

v – Relative velocity of the coil with respect to the permanent magnet which is fixed

Advantages

- The system forms closed magnetic circuit with constant air gap
- The entire unit is placed inside antimagnetic material case, hence the effects of stray magnetic fields are reduced
- Damping is achieved by an electrical means. Under varying temperature conditions, the system provides high stability

MOVING MAGNET TYPE VELOCITY TRANSDUCERS



Moving Magnet Type Velocity Transducers

- A constant polarized field is obtained with the help of permanent magnet
- Image shows the construction of transducer
- Permanent magnet rod, whose velocity is to be measured is surrounded by a coil
- Voltage gets induced in the coil due to the motion of rod and the amplitude of induced voltage is proportional to the velocity of the rod
- Direction of motion of the rod is determined by the polarity of the output voltage

Advantages

- There are no mechanical surfaces or contact, hence the maintenance required is negligible
- The output voltage is linearly proportional to the velocity
- Robust and less expensive

Limitations

- The stray magnetic field affects the performance of these transducers
- Limited frequency response

TEMPARATURE MEASUREMENT

Thermocouples

overview, reference junction, proper connections, types, special limits of error wire, time constants, sheathing, potential problems, DAQ setup

RTDs

overview, bridges, calibration, accuracy, response time, potentail problems

Thermistors

Infrared Thermometry

fundamentals, emissivity determination, field of view

Other

Non-electronic measurement, thin-film heat flux gauge

Temperature Controllers

How to Choose

Standards, cost, accuracy, stability, sensitivity, size, contact/non-contact, temperature range, fluid type

THERMOCOUPLES

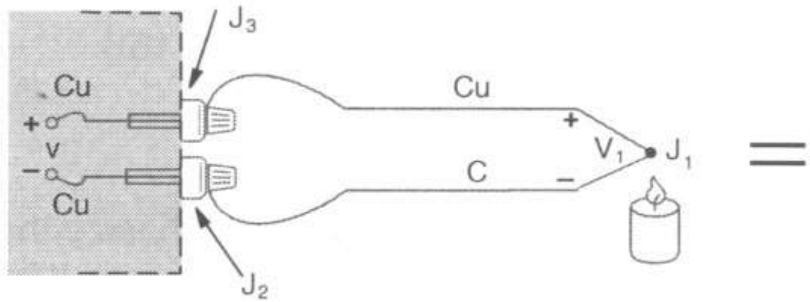
Seebeck effect

If two wires of dissimilar metals are joined at both ends and one end is heated, current will flow.
If the circuit is broken, there will be an open circuit voltage across the wires.
Voltage is a function of temperature and metal types.
For small DT's, the relationship with temperature is linear

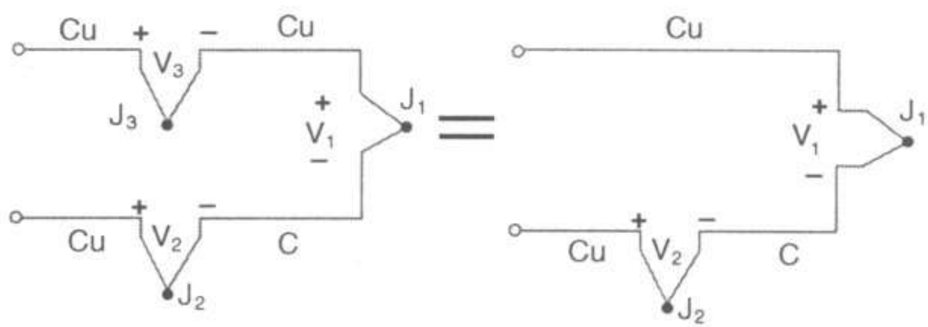
For larger ΔT's, non-linearities may occur.

MEASURING THE THERMOCOUPLE VOLTAGE

If you attach the thermocouple directly to a voltmeter, you will have problems.



EQUIVALENT CIRCUITS



You have ju … ltage will be proportional … T_1 and T_2). Note that this is 'Type T' thermocouple.

LIQUID LEVEL MEASUREMENT

- Generally, there are two methods used in industries for measuring liquid level.

  These are

  1. Direct Method
  2. Indirect Method

- Direct method use the varying level of the liquid as a mean of obtaining the measurement and the indirect method use a variable that changes with the liquid level to accurate the measuring mechanism.

1. DIRECT METHOD

This is the simplest method of measuring liquid level. In this method, the level of the liquid is measured directly by means of the following level indicators

i.Sight Glass / Gauge Glass

ii.Float Type / Float - Operated Level Gauges

iii.Torque Tube Displacer / Float Displacement Type Level Gauges

2. INDIRECT METHODS

Following are the indirect methods of liquid level measurement generally used in industries.

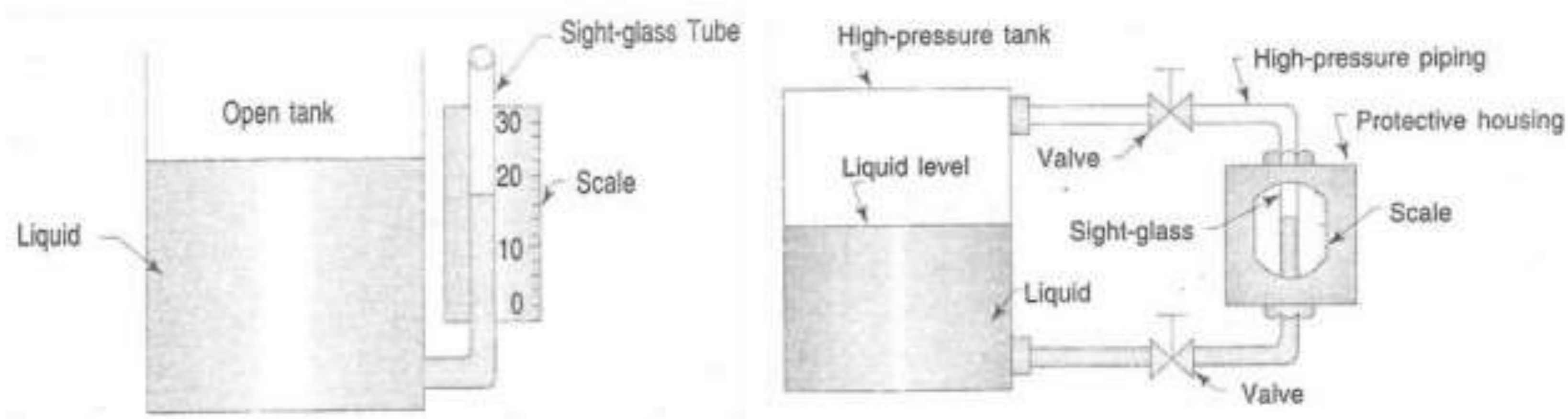
i.Hydrostatic pressure type

ii.Electrical methods

iii.Ultrasonic level sensor

SIGHT GLASS / GAUGE GLASS

•Sight glass is used for the continuous indication of liquid level within a tank or vessel. A sight glass instrument consists of a graduated tube of toughened glass which is connected to the interior of the tank at the bottom in which the water level is required.



- Fig.1 shows a simple sight glass for an open tank in which the liquid level in the sight glass matches the level of liquid in the tank. As the level of liquid in the tank rises and falls, the level in the sight glass also rises and falls accordingly. Thus, by measuring the level in the sight glass, the level of liquid in the tank is measured. In sight glass, it is not necessary to use the same liquid as in the tank. Any other desired liquid also can be used.

- Fig.2 shows a high pressure sight glass in which measurement is made by reading the position of the liquid level on the calibrated scale. This type of sight glass in high pressure tanks is used with appropriate safety precautions. The glass tube must have a small inside diameter and a thick wall.

Advantages

- Direct reading is possible
- Special designs are available for use up to 316°C and 10000 psi.
- Glassless designs are available in numerous materials for corrosion resistance.

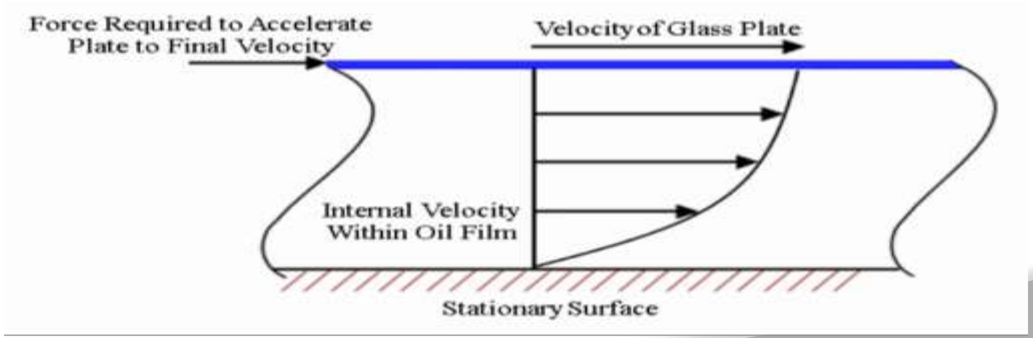
Disadvantages

- Overlapping gauges are needed for long level spans Accuracy and readability depend on the cleanliness of glass and fluid
- It is read only where the tank is located, which is not always convenient.

FLOW MEASUREMENT

DEFINITION OF FLOW & FLUID TYPES

- **Flow** is the motion characteristics of constrained fluids (liquids or gases). It deals with two things: how much (total) and how fast (rate)
- **Viscosity:** Dynamic or absolute viscosity (η) is measure of the resistance to a fluid to deformation under shear stress, or an internal property of a fluid that offers resistance to flow.
- Fluids may generally be divided into two types: **Newtonian** and **Non-Newtonian** fluids.
- When held at a constant temperature, the viscosity of a Newtonian fluid will not change regardless of the size of the shear force.
- When held at a constant temperature, the viscosity of a



REYNOLDS NUMBER

- The Reynolds number is the ratio of inertial forces to viscous forces of fluid flow within a pipe and is used to determine whether a flow will be laminar or turbulent.
- $$RD = \frac{V.D}{\rho_{\mu}}$$

RD = Reynolds number

V = average velocity

D = inside pipe diameter

ρ = density of flowing fluid

μ = absolute viscosity

UNITS OF FLOW

- The units used to describe the flow measured can be of several types depending on how the specific process needs the information.
- Solids: Normally expressed in weight rate like Tonnes/hour, Kg/minute etc.
- Liquids: Expressed both in weight rate and in volume rate.

Examples: Tonnes/hour, Kg/minute, litres/hour, litres/minute, m^3/hour etc.

- Gases: Expressed in volume rate at NTP or STP like Std m^3/hour, Nm^3/hour etc.
- Steam: Expressed in weight rate like Tonnes/hour, Kg/minutes etc. Steam density at different temperatures and pressures vary.
- Hence the measurement is converted into weight rate of water which is used to produce steam at the point of measurement.

TYPES OF FLOW

- **Laminar Flow** occurs at low Reynolds numbers, typically Re < 2000, where viscous forces are dominant. Laminar flow is characterized by layers of flow traveling at different speeds with virtually no mixing between layers. The velocity of the flow is highest in the center of the pipe and lowest at the walls of the pipe.

- **Turbulent Flow** occurs at high Reynolds numbers, typically Re > 4000, where inertial forces are dominant. Turbulent flow is characterized by irregular movement of the fluid in the pipe. There are no definite layers and the velocity of the fluid is nearly uniform through the cross section of the pipe. The flow is turbulent.

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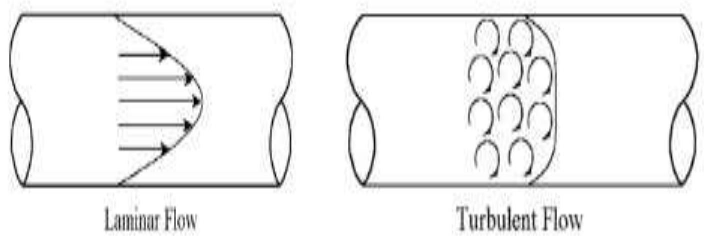
- **Transitional Flow** typically occurs at Reynolds numbers between 2000 and 4000. Flow in this region may be laminar, it may be turbulent or it may exhibit characteristics of both.



Bernoulli's Equation

- Bernoulli's principle says that a rise (fall) in pressure in a flowing fluid must always be accompanied by a decrease (increase) in the speed, and conversely, i.e. an increase (decrease) in the speed of the fluid results in a decrease (increase)

$$p + \frac{1}{2}\rho V^2 + \rho g h = constant$$

$$\frac{\partial}{\partial s}\left(\frac{v^2}{2} + \frac{p}{\rho} + g.h\right) = 0$$

$$\frac{v^2}{2} + \frac{p}{\rho} + g.h = constant$$

$$\frac{v^2}{2g} + \frac{p}{\gamma} + h = constant, where\ \gamma = \rho.g$$

$$\frac{\rho v^2}{2} + p = constant$$

$$\frac{\rho {v_1}^2}{2} + p_1 = \frac{\rho {v_2}^2}{2} + p_2 = constant$$

BASIC REQUIREMENTS FOR FLOW MEASUREMENT

- Ability to calibrate
- Ability to integrate flow fluctuations
- Easy integration with piping system
- High accuracy
- High turn-down ratio
- Low cost
- Low sensitivity to dirt particles
- Low pressure loss
- No moving parts
- Resistant to corrosion and erosion

FACTOR AFFECTING FLOW METER PERFORMANCE

- Process Media – Gas/Liquid
- Temperature
- Velocity
- Viscosity
- Pressure
- Density

Introduction

Pressure is define as force divided by area. (exerts on solid, gas, liquid)

$$P = F/A$$

F = force in newton/ lb

A = area in m^2/ in^2

The unit of pressure is in Pa, psi, atm, bar, torr

1 psi = 6895 pa

1 bar = 105 Pa

1 atm = 101325 Pa

1 torr = 133.3 Pa

Static and Dynamic Pressure

Static pressure is the pressure of fluid or gases that are stationary or not in motion.

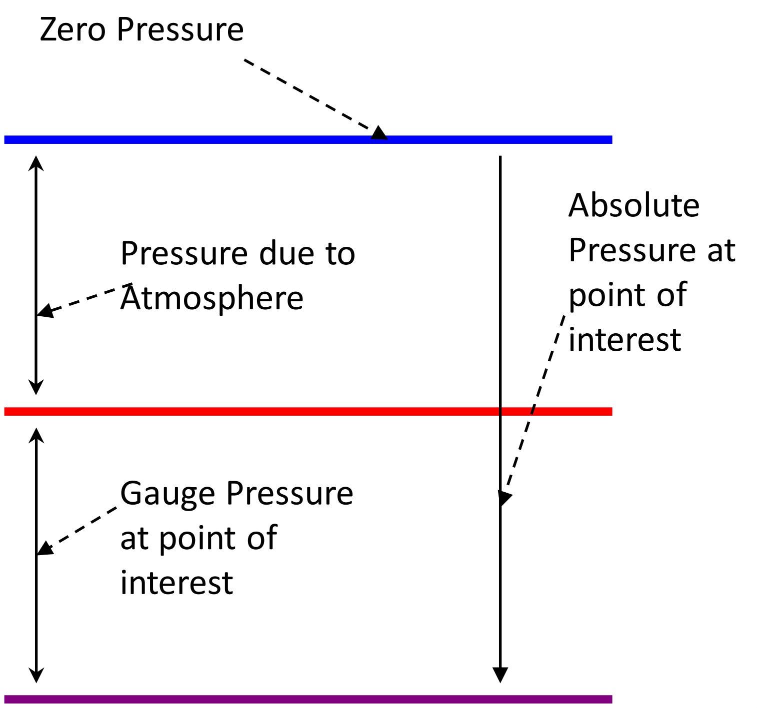
Dynamic pressure is the pressure exerted by a fluid or gas when it impacts on a surface or an object due to its motion or flow.

Pressure Measurement

Absolute pressure is the pressure measured wrt a vacuum (unit = psia)

Gauge pressure is the pressure measured wrt atmospheric pressure (unit = psig)

Atmospheric pressure is the pressure on the earth's surface due to the weight of gases in the earth's atmosphere (14.7psi)



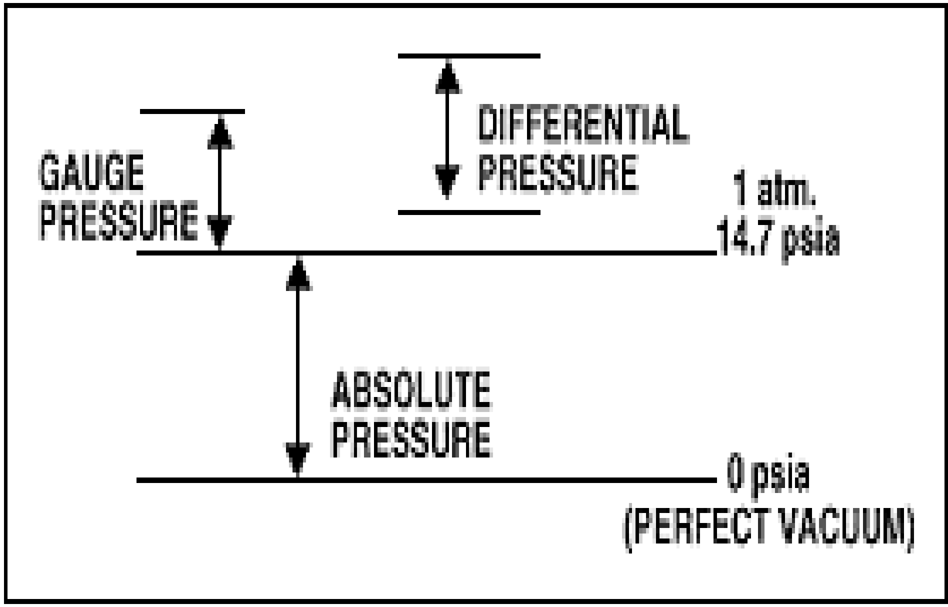
Types of Pressure measurements

Absolute pressure is measured relative to a perfect vacuum (psia)

Gauge pressure is measured relative to ambient pressure (psig)

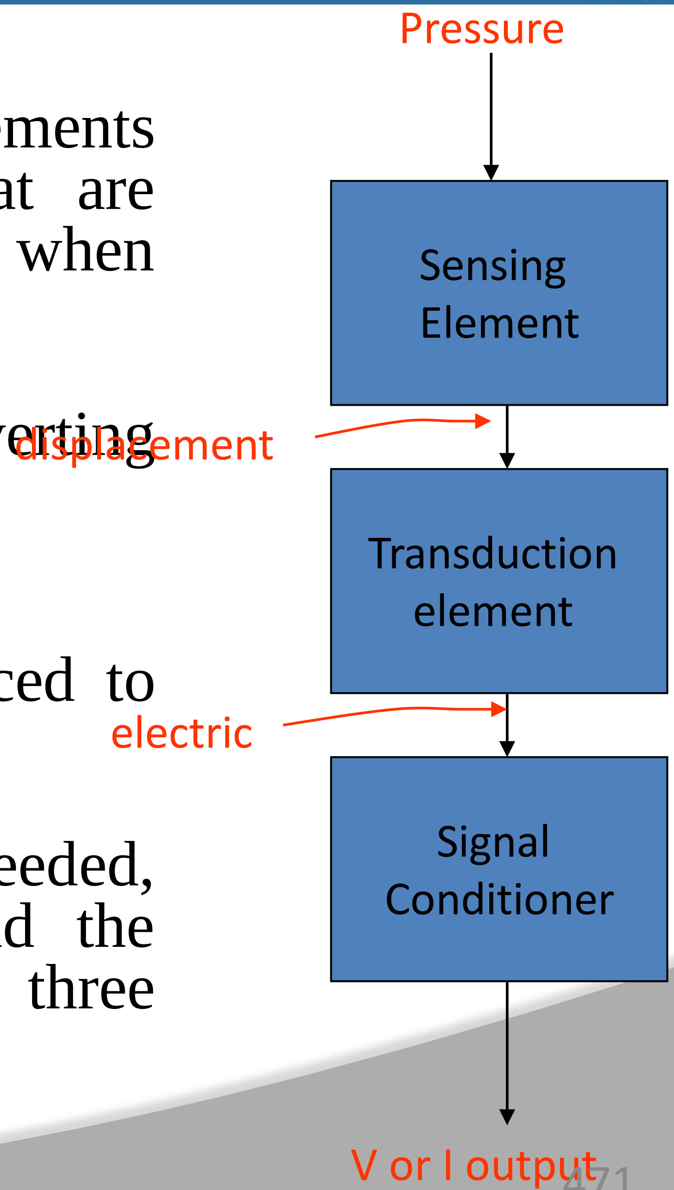
Differential pressure is the difference in pressure between two points of measurement. (psid).

Note that the same sensor may be used for all three types; only the reference is different.



PRESSURE SENSING

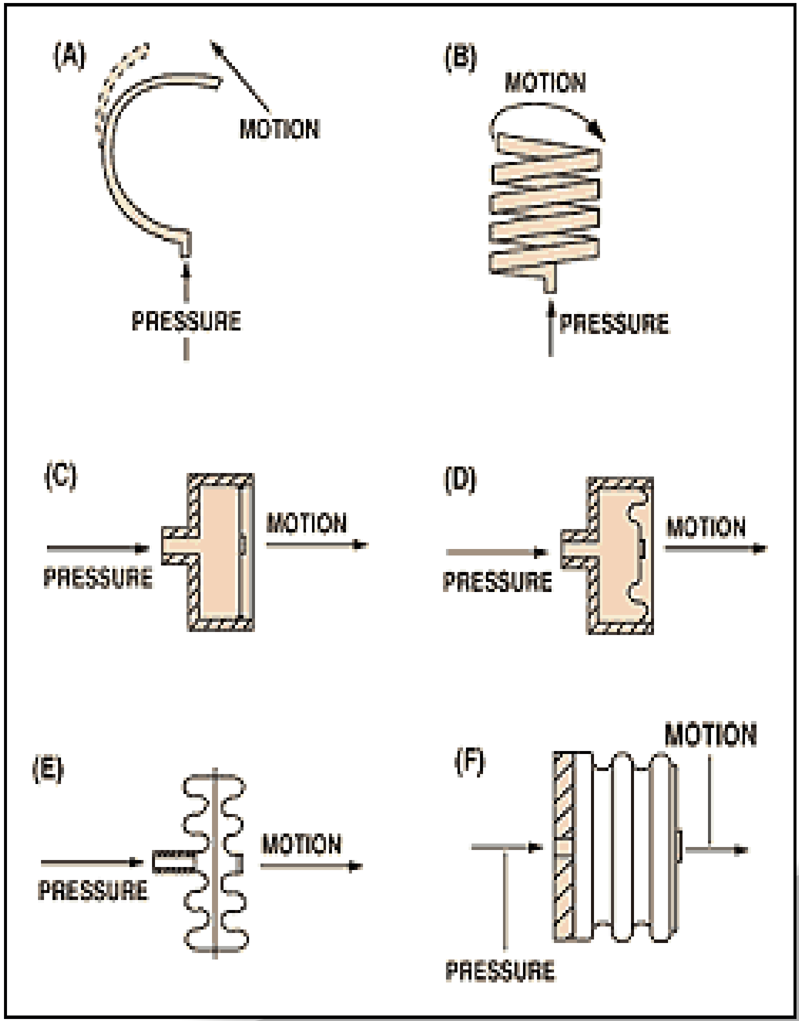
- Pressure is sensed by mechanical elements such as plates, shells, and tubes that are designed and constructed to deflect when pressure is applied.
- This is the basic mechanism converting pressure to physical movement.
- Next, this movement must be transduced to obtain an electrical or other output.
- Finally, signal conditioning may be needed, depending on the type of sensor and the application. Figure 8 illustrates the three functional blocks.



SENSING ELEMENTS

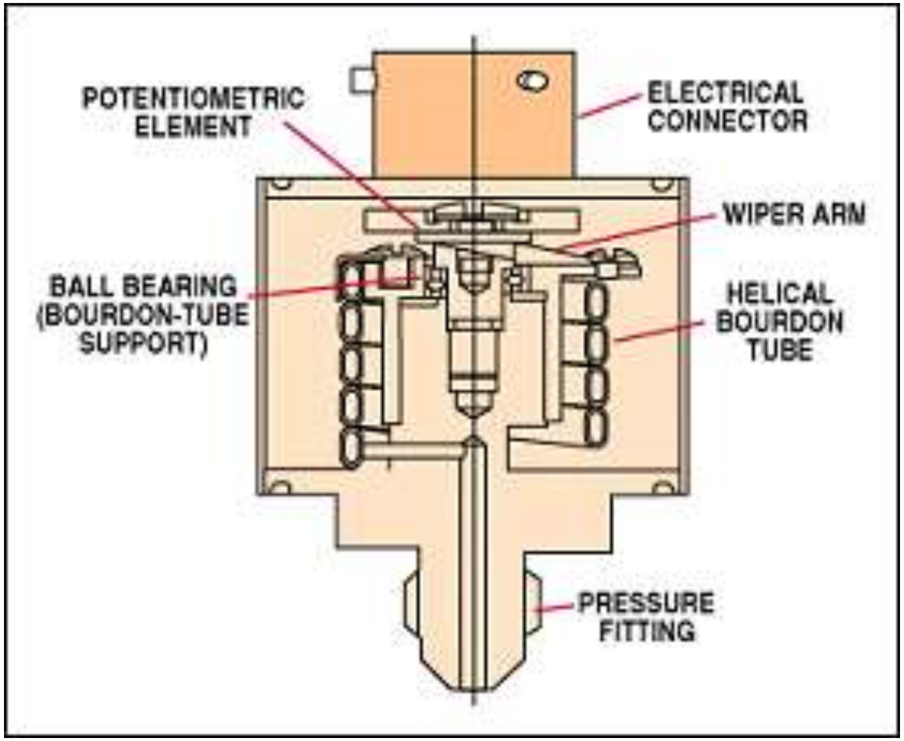
The main types of sensing elements are Bourdon tubes, diaphragms, capsules, and bellows

All except diaphragms provide a fairly large displacement that is useful in mechanical gauges and for electrical sensors that require a significant movement



POTENTIOMETRIC PRESSURE SENSORS

- Potentiometric pressure sensors use a Bourdon tube, capsule, or bellows to drive a wiper arm on a resistive element.
- For reliable operation the wiper must bear on the element with some force, which leads to repeatability and hysteresis errors.
- These devices are very low cost, however, and are used in low-performance applications such as dashboard oil pressure gauges

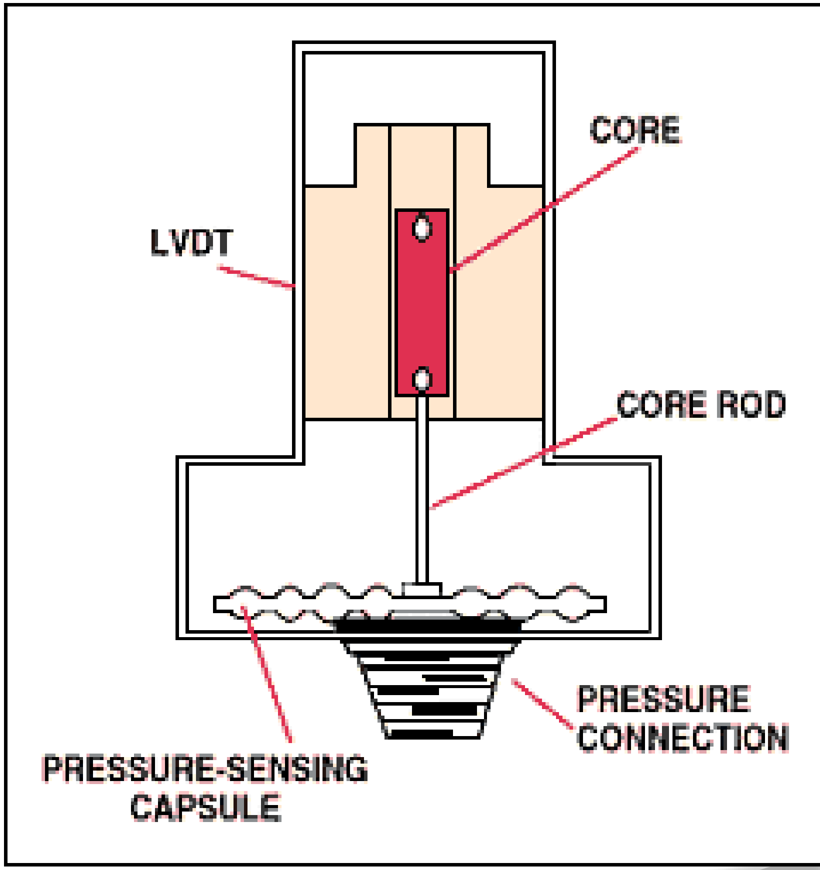


Inductive Pressure Sensors

- Several configurations based on varying inductance or inductive coupling are used in pressure sensors. They all require AC excitation of the coil(s) and, if a DC output is desired, subsequent demodulation and filtering.

- The LVDT types have a fairly low frequency response due to the necessity of driving the moving core of the differential transformer

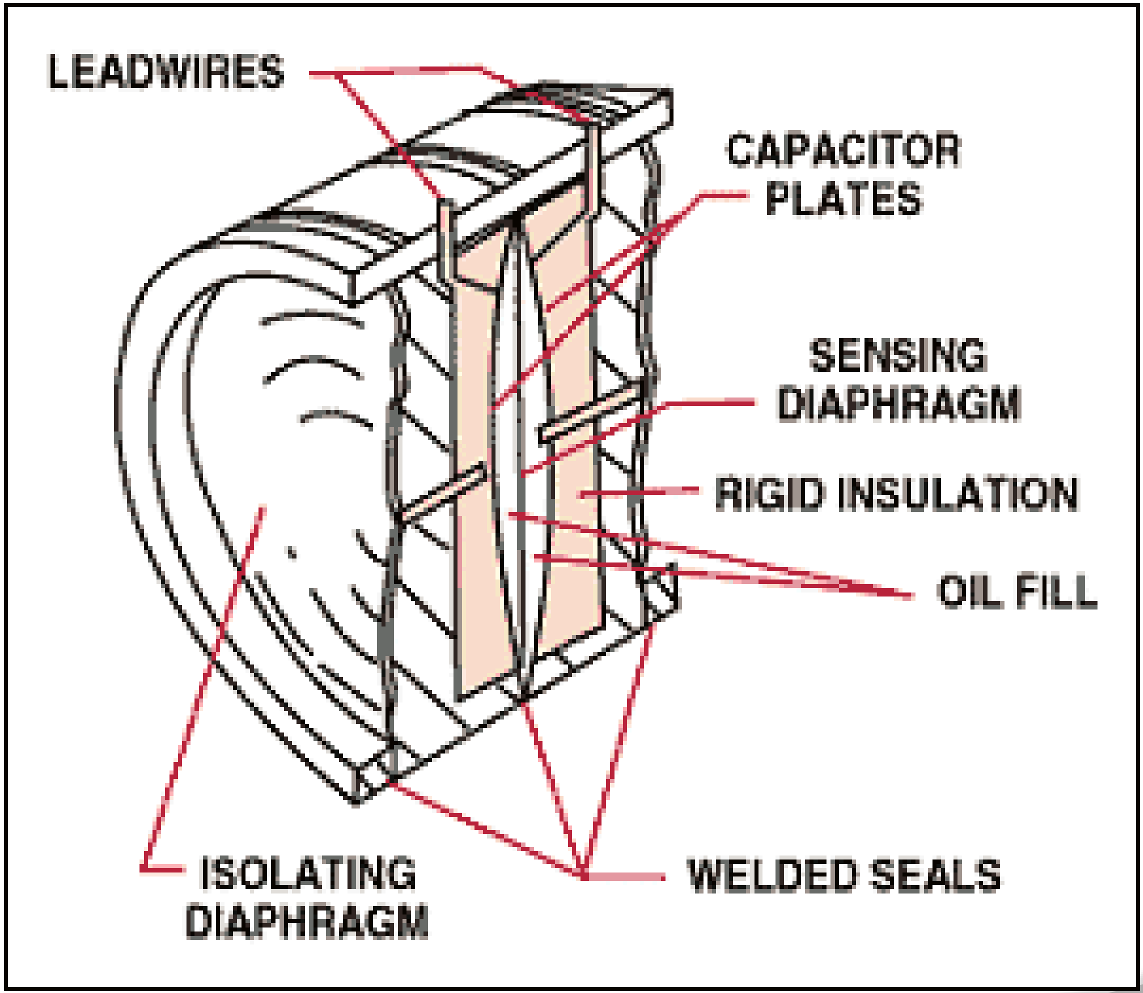
- The LVDT uses the moving core to vary the inductive coupling between the transformer primary and secondary.



CAPACITIVE PRESSURE SENSORS

- Capacitive pressure sensors typically use a thin diaphragm as one plate of a capacitor.
- Applied pressure causes the diaphragm to deflect and the capacitance to change.
- This change may or may not be linear and is typically on the order of several picofarads out of a total capacitance of 50-100 pF.
- The change in capacitance may be used to control the frequency of an oscillator or to vary the coupling of an AC signal through a network.
- The electronics for signal conditioning should be located close to the sensing element to prevent errors due to stray capacitance.

CAPACITIVE PRESSURE SENSORS

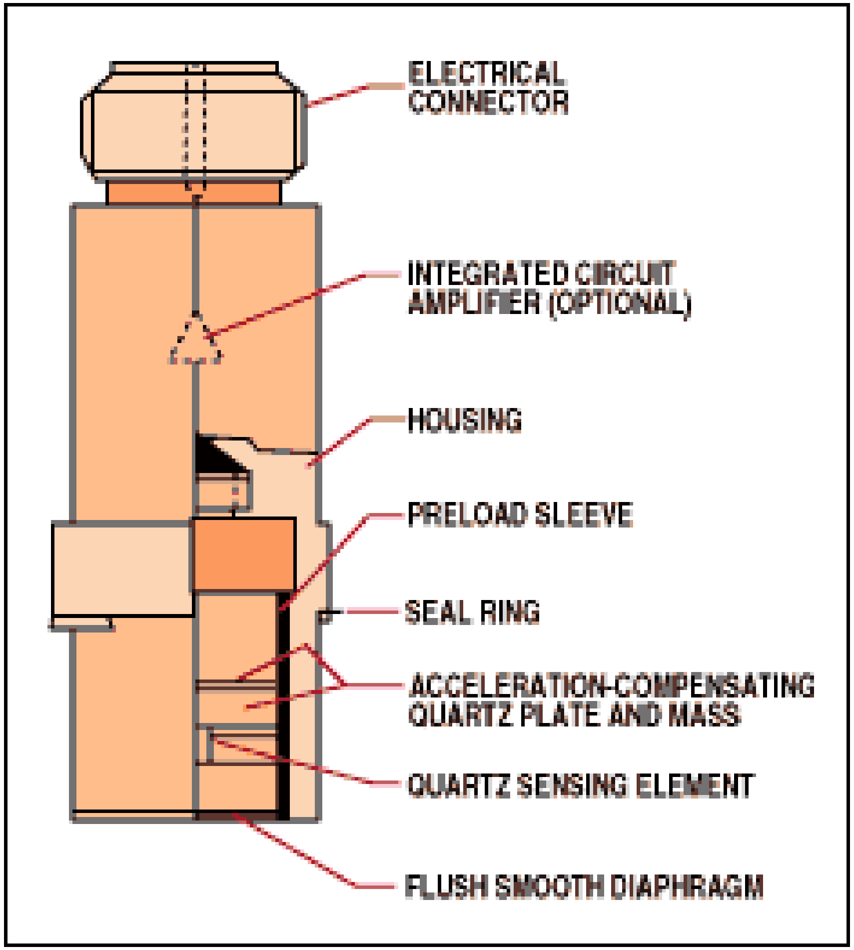


Capacitive Pressure Sensors

PIEZOELECTRIC PRESSURE SENSORS

Piezoelectric elements are bi-directional transducers capable of converting stress into an electric potential and vice versa.
One important factor to remember is that this is a dynamic effect, providing an output only when the input is changing.
This means that these sensors can be used only for varying pressures.
The piezoelectric element has a high-impedance output and care must be taken to avoid loading the output by the interface electronics. Some piezoelectric pressure sensors include an internal amplifier to provide an easy electrical interface.

Piezoelectric Pressure Sensors.



Piezoelectric sensors convert stress into an electric potential and vice versa. Sensors based on this technology are used to measure varying pressures.

Strain Gauge Pressure Sensors

Strain gauge sensors originally used a metal diaphragm with strain gauges bonded to it.

the signal due to deformation of the material is small, on the order of 0.1% of the base resistance

Semiconductor strain gauges are widely used, both bonded and integrated into a silicon diaphragm, because the response to applied stress is an order of magnitude larger than for a metallic strain gauge.

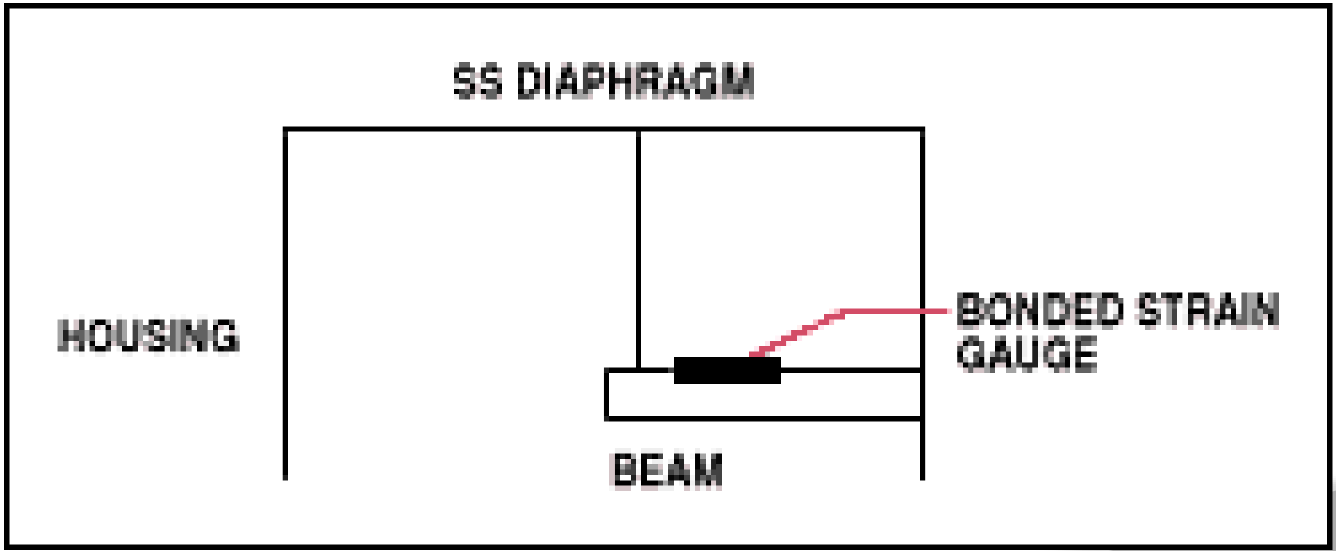
Strain Gauge Pressure Sensors

When the crystal lattice structure of silicon is deformed by applied stress, the resistance changes. This is called the piezoresistive effect. Following are some of the types of strain gauges used in pressure sensors.

Deposited strain gauge. Metallic strain gauges can be formed on a diaphragm by means of thin film deposition. This construction minimizes the effects of repeatability and hysteresis that bonded strain gauges exhibit. These sensors exhibit the relatively low output of metallic strain gauges.

Strain Gauge Pressure Sensors

Bonded semiconductor strain gauge. A silicon bar may be bonded to a diaphragm to form a sensor with relatively high output. Making the diaphragm from a chemically inert material allows this sensor to interface with a wide variety of media



Displacement measurement

There are a wide variety of devices used to measure displacement

- Potentiometer
- Linear and Rotary Variable Differential Transformers
- Capacitive Displacement Sensors
- Linear Velocity Transducers
- Angular Displacement and Velocity Devices