ELECTRONICS MEASUREMENT & INSTRUMENTATION

3rd semester
Electronics & Telecommunication Engineering

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UNIT-1: QUALITIES OF MEASUREMENT

- Measurement is the act or the result of a quantitative comparison between a predetermined standard and an unknown magnitude.

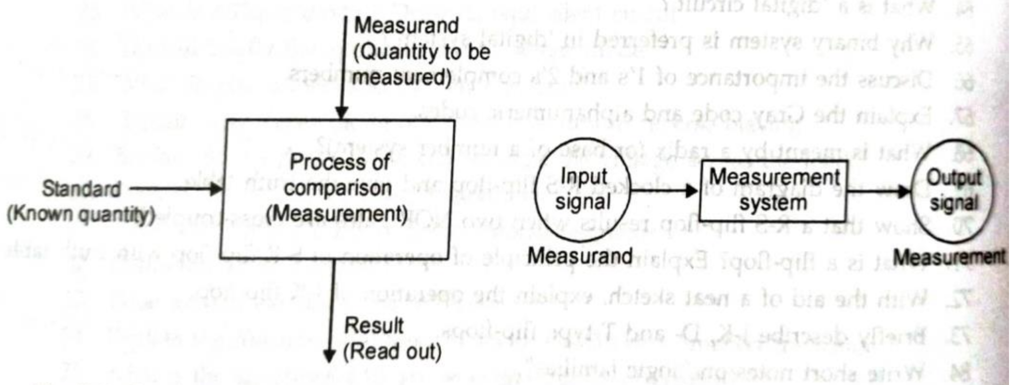


Fig. 3.1. Fundamental measuring process. **Fig. 3.2.** Measurand and measurement.

- Measurements are always performed with the help of using some instruments or some tools

Example: Rulers, thermometer, stopwatch etc.

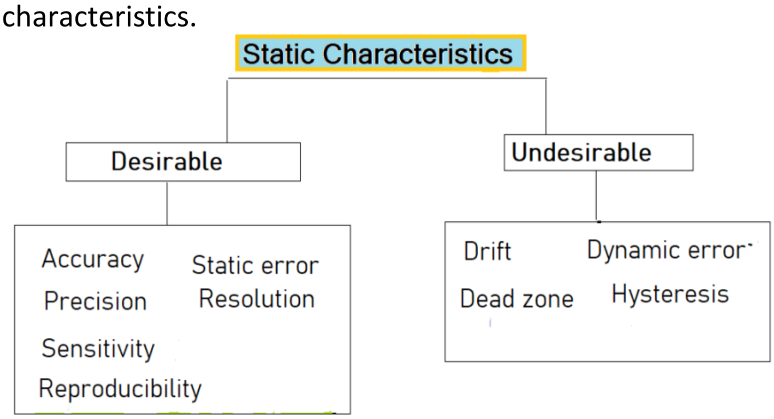
- Measuring instruments are the device which indicates the measured quantity into a broadly displayed information. Or (Device which is used for measuring the unknown quantity)
- A measuring instrument can directly show the measured value or it can show the equivalent value to known measure value of the same quantity.
- Instrumentation is the process/ technology of using instruments to measure and control the physical and chemical properties of any material.
- The performance of an instrument is described by means of quantitative qualities termed as Characteristics. There are two basic performance characteristics of measuring instruments. Static Characteristics and Dynamic Characteristics.

1.1Discuss the Static Characteristics

1.2 Accuracy, sensitivity, reproducibility & static error of instruments

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:

It is the degree of closeness of readings from an instrument to the true value. Always accuracy is measured relative to the true value or actual value.

The measured quantity may be different from the true value due to the effects of temperature, humidity, etc.

The algebraic difference between the indicated value of an instrument, Ai and the true value, At is known as accuracy. Mathematically, it can be represented as −

$Accuracy = A_i - A_t$

Precision:

It is the degree of closeness of reading with the previous reading. An instrument is said to be precise when there is negligible difference between successive readings.

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:

It refers to the least change in measured value to which instrument or device responds. The ratio of change in the output of an instrument to a change in the value of the quantity to be measured is known as sensitivity.

The usage of this term is generally limited to linear devices, where the plot of output to input magnitude is straight.

Reproducibility:

Reproducibility is the deviation of the results obtained when the same sample is measured continuously for multiple times with changed measuring conditions.

In order to evaluate reproducibility, at least one of the parameters below should be varied: 1) measuring time; 2) resample; 3) different operator; 4) different instrument; 5) different place.

Static Error:

The difference between the true value of the measuring quantity to the value shown by the measuring instrument under not varying process conditions.

Static error = True value of a measured variable – Instrument reading.

+ Ve Static error means Instrument reads high,

– Ve Static error means Instrument reading low

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.

Drift:

It is a slow variation in the output signal of a transducer or measuring system which is not due to any change in the input quantity. It is primarily due to changes in operating conditions of the components inside the measuring system.

Dead Zone:

It is the largest change of input quantity for which there is no output of the instrument.

The dead zone occurs more often due to static friction in indicating an instrument.

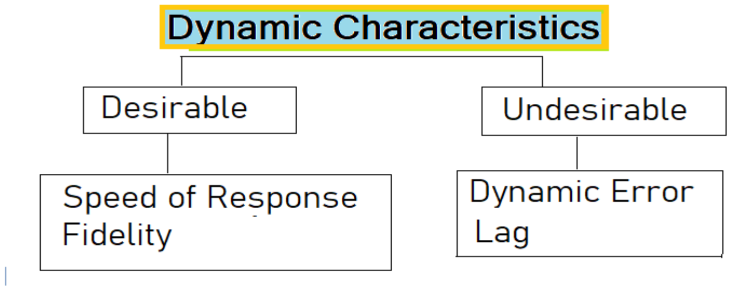
Hysteresis:

Hysteresis is a phenomenon which depicts different output effects when loading and unloading whether it is a mechanical system or any electrical system or any other system. Hysteresis is the difference in the readings of an instrument, which fixed value of the input signal, which depends on whether that input value is approached from increasing or decreasing values of input.

1.3 Dynamic characteristics & speed of instruments.

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.



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.

Fidelity:

The degree to which an instrument indicates changes in the measured quantity without any dynamic error is known as Fidelity
(It is the ability of the system to reproduce the output in the same form as the input).

Dynamic Error:

The difference between the true value of the measured quantity to the value shown by the measuring instrument under varying conditions.

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.

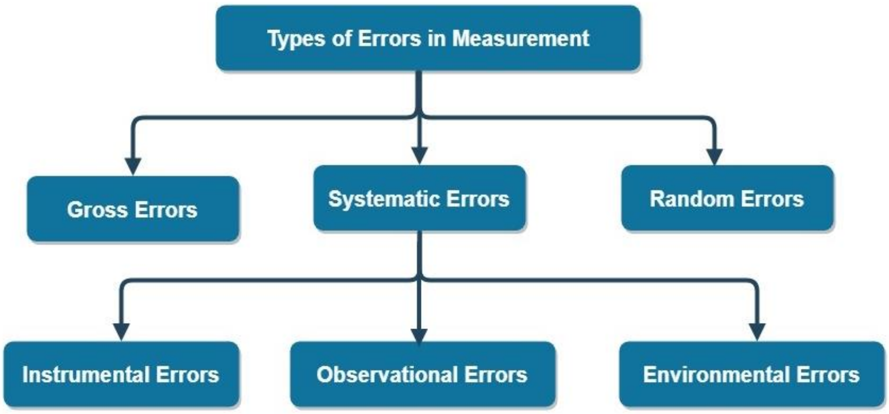
1-4 Errors of an instrument & explain various types

The errors, which occur during measurement are known as measurement errors. It is nothing but the difference between the true or actual value and the measured value.

Types of Measurement Errors

The errors in measurement may happen from the various sources which are generally categorized into the following types.

- Gross Errors
- Systematic Errors
- Random Errors



Gross Errors:

The errors occur due to human mistakes in reading instruments, recording and calculating results of measurement are known as gross errors. Although it is probably impossible to eliminate the gross error completely, yet one should try to anticipated and correct them. Sometimes, the gross errors may also occur due to improper selection of the instrument. The gross errors can minimize by following these two steps.

- Choose the best suitable instrument, based on the range of values to be measured.
- Note down the readings carefully

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

The systematic errors can be classified into the following three types.

- 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.

Random Errors

These errors occur due to a group of small factors which fluctuate from one measurement to another. The situations or disturbances which cause these errors are unknown, hence they are termed as Random errors. Sources of these errors are not obvious and not easily figured. 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.

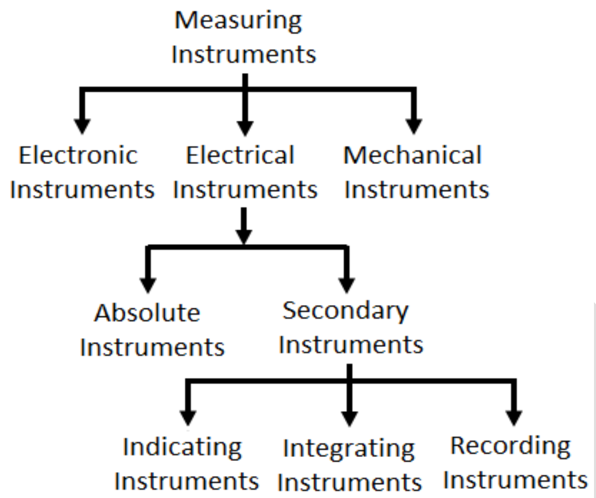
Following are the parameters that are used in statistical analysis.

- **Mean**: Average of all the readings. It is the most probable value.
- **Dispersion**: Property by the virtue of which values are scattered or dispersed around the central value. For two sets of data, if one set has less dispersion than other, that set can be regarded for measurement of random errors.
- **Range**: It is the difference between the greatest and least value of data. It is the measure of Dispersion.
- **Deviation**: Deflection of the observed reading from the mean value is known as Deviation. The algebraic sum of all deviations is zero.
- **Standard Deviation**: When squares of individual deviations are added up, the sum is divided by the total number of the readings, square root of the resultant value is known as Standard Deviation.
- **Variance**: Square of the standard deviation is known as Variance.

UNIT-2: INDICATING INSTRUMENTS

Indicating instruments are those instruments that indicate the magnitude of a quantity being measured. They generally make use of a dial and a pointer for this purpose. Ordinary voltmeters, ammeters, and wattmeters belong to this category.

2.1 Introduction to Indicator & Display devices & its types



Electronic instruments:

These instruments have very fast response. For example, a cathode ray oscilloscope (CRO) is capable to follow dynamic and transient changes of the order of few nano seconds (10^{-9} sec).

Electrical instruments:

Electrical methods of indicating, the output of detectors are more rapid than mechanical methods. The electrical system normally depends upon a mechanical meter movement as indicating device.

Mechanical instruments:

They are very reliable for static and stable conditions. The disadvantage is they are unable to respond rapidly to measurement of dynamic and transient conditions.

Absolute Instrument:

Absolute Instrument are those instruments which indicate the quantity to be measured in terms of the constants of the instruments and their deflection only.

Secondary Instruments:

Secondary Instruments are those in which the value of the electrical quantity to be measured can be determined from the deflection of instrument only when they have been pre-calibrated by comparison with an absolute instrument.

Secondary Instruments may also be classified as follows:

Indicating Instrument:

The instrument which indicates the magnitude of the measured quantity is known as the indicating instrument**.** The voltmeter, ammeter, power factor meter are the examples of the indicating instrument.

Integrating Instrument:

Integrating instruments are those which measure the total quantity of electricity delivered in a particular time. The energy meter, watt-hour meter and the energy meter are the examples of integrating instrument.

Recording Instrument:

The instrument records the circuit condition at a particular interval of time is known as the recording instrument**.**

According to the Principle of operation instruments are classified as

Moving coil
Moving Iron
Electrodynamic
Hot-wire
Induction
Thermoelectric
Rectifier type

Torque in indicating Instrument

Torque is defined as the measure of the force that can cause an object to rotate about an axis.

For satisfactory operation of an indicating instrument three forces/ Torque are essentially required, these are as follows.

- Deflecting Force
- Controlling Force
- Damping Force.

Deflecting force or Deflecting Torque:

- The torque needed to move the pointer over a calibrated scale is known as deflecting torque
- To obtain this force in an instrument, different effects of electric current use such as magnetic effect, heating effect, chemical effect etc.
- The deflecting torque in the analog measurement device is proportional to the current through the coil.

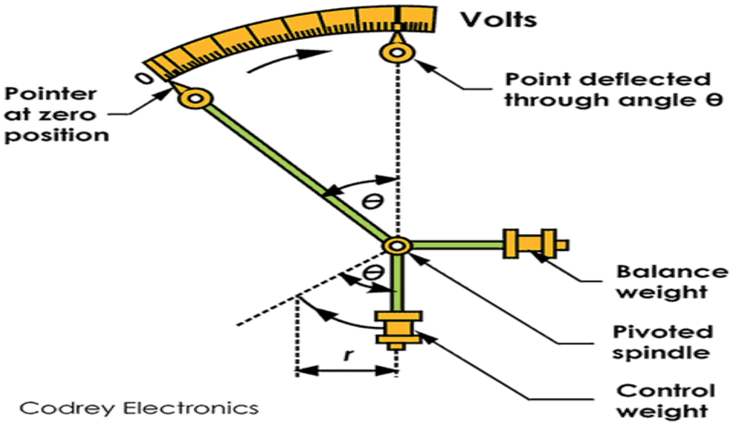
Controlling force or Controlling Torque:

- The torque which controls the movements of the pointer is called the control torque.
- The controlling torque (T_c) opposes the deflecting torque and increases with the deflection of the moving system. The pointer comes to rest at a position where the two opposing torques are equal i.e. $T_d = T_c$.
- The controlling torque can be produced in two ways. They are,

- Spring control
- Gravity control

Gravity control:

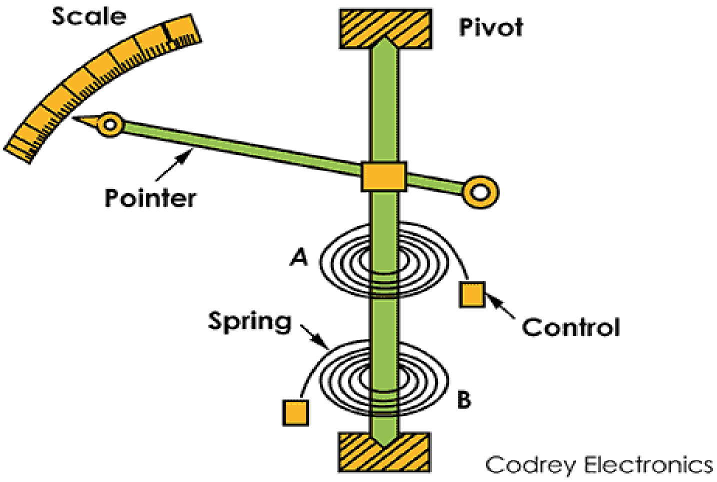
- In Gravity control method, small adjustable weights are attached to the opposite extension of the pointer as shown in figure.



- When the instrument is disconnected from the supply, the control weight and the balance weight attached to the opposite end of the pointer make the pointer to be at zero position.
- When the instrument is connected to the supply, the pointer moves in a clockwise direction, thereby displacing the weights shown in figure.
- Due to the gravitational pull, the weights will try to come back to its original position.
- The pointer comes to rest at a position where controlling torque is equal to the deflecting torque. In this method, controlling torque (T_c) is proportional to the sine of angle of deflection (θ) i.e. $T_c \propto \sin\theta$.
- Because in this method controlling torque (T_c) is not directly proportional to the angle of deflection (θ) but it is proportional to sin θ therefore, gravity control instruments have non-uniform scales.

Spring control:

- In spring control, the controlling torque is produced by using springs as shown below.
- It is made up of two springs A and B, the inner ends of which are attached to the spindle.
- Both springs A and B are wound in opposite directions so that when pointer is deflecting, one spring winds up while the other unwinds. Therefore, the controlling force is produce due to the combined torsions of the springs.



- Here the controlling torque (T_c) is directly proportional to the angle of deflection of pointer (θ) i.e. $T_c \alpha \theta$.
- As the deflecting torque (T_d) depends upon the current flowing through the coil i.e., T_d increases with an increase in current and vice-versa. At steady state,

  $T_d = T_c$
  $KI = K\theta$ (K = constant)
  $\therefore I \propto \theta$

Since current is directly proportional to the deflection angle, uniform scales can be graduated.

Spring controlled instruments have the following advantages over the gravity controlled instruments.

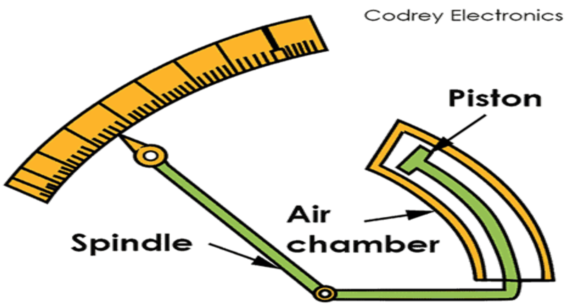
- The instruments can be used in any position
- The scale is uniform.

Damping force or Damping Torque:

- Damping torque is defined as the physical process of controlling the movement of a system by producing the motion such that it opposes the natural oscillation of the system.
- The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest.
- The time required to take the measurement is more. To damp out the oscillations quickly, a damping force is necessary.
- This force is produced by different systems. (a) Air friction damping (b) Fluid friction damping (c) Eddy current damping

Air Friction Damping

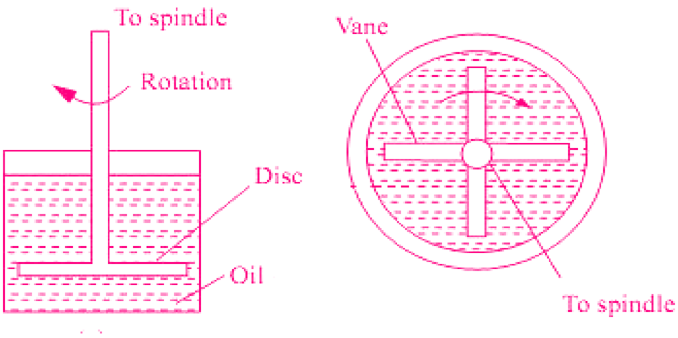
- The air friction damping is created in an air chamber by moving the piston in and out.
- As the piston enters the chamber, compression is caused inside the chamber.



- As the piston moves out of the chamber, a force is experienced by it.
- Air friction damping is the best suitable method of damping torque where the electric field is relatively weak. This is due to the absence of electric components in air damping friction which could deform the electric field.

Fluid Friction Damping

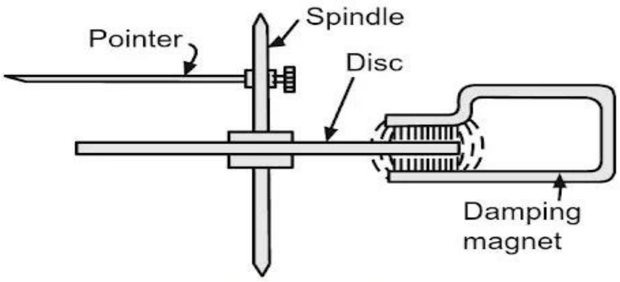
- The fluid friction damping is created due to the oscillation of the disk in and out of the liquid. The liquid that is generally used is oil.



- The working of the fluid friction damping is similar to that of the air friction damping. The only difference is that instead of air, fluid is used in the chamber.

Eddy Current Damping

- When a conductor moves in a magnetic field an EMF is induced in it and if a closed path is provided, a current (known as eddy current) flows.
- This current interacts with the magnetic field to produce an electromagnetic torque which opposes the motion.

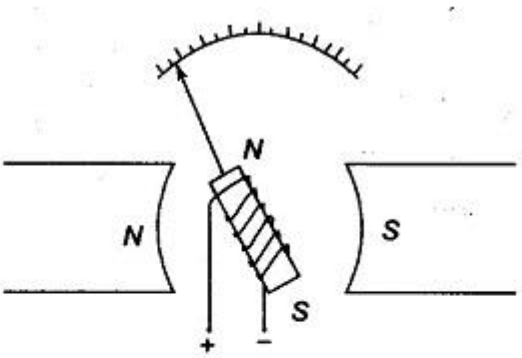


- This torque is proportional to the strength of the magnetic field and the current produced.
- The current is proportional to EMF which in turn is proportional to the velocity of the conductor.
- Thus, if the strength of the magnetic field is constant (if it is produced by a permanent magnet), the torque is proportional to the velocity of the conductor.

2.2 Basic principle of meter movement, permanent magnetic moving coil movement & its advantages & disadvantages.

Basic Meter Movement:

- A common type of meter movement measures current and voltage. This basic moving coil system is often called the D'Arsonval galvanometer or moving-coil galvanometer.
- The movement consists of a permanent-type magnet and a rotating coil in the magnetic field. An indicating needle is attached to the rotating coil

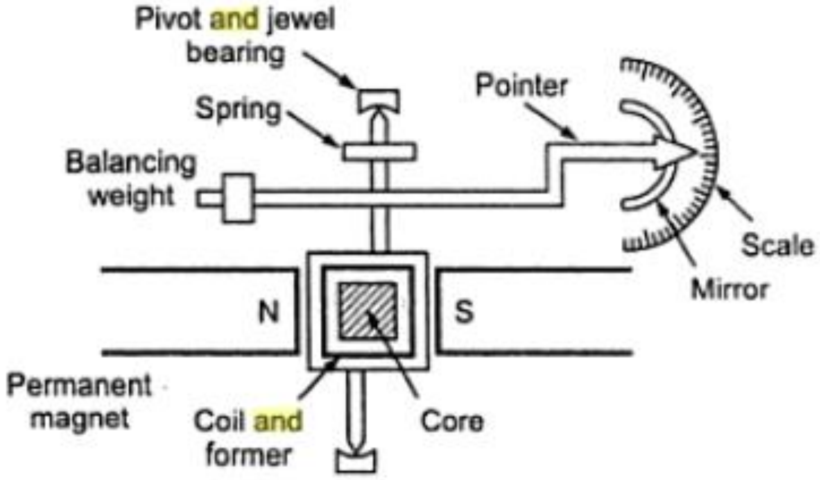


D'Arsonval Meter Movement Principle

- When a current passes through the moving coil, a magnetic field is produced. This field reacts with the stationary field and causes rotation (deflection) of the needle.
- This deflection force is proportional to the strength of the current flowing in the moving coil. It responds to dc current only, and has an almost linear calibration.
- When the current ceases to flow, the moving coil is returned to its "at rest" position by hairsprings. These springs are also connected to the meter coil.
- The deflecting force rotates the coil against the restraining force of these springs.

Permanent Magnet Moving Coil

- The instruments which use the permanent magnet for creating the stationary magnetic field between which the coil move is known as the permanent magnet moving coil or PMMC instrument.
- It operates on the principle that the torque is exerted on the moving coil placed in the field of the permanent magnet.
- The PMMC instrument gives the accurate result for DC measurement.



Construction

- It consists of permanent magnet which is stationary.
- Moving system consists of a spindle attached to a rectangular aluminum frame. A coil made up of thin copper wire is wound over the frame. The current to be measured is passed through this coil.
- A soft iron core is placed in the in the space within the aluminium frame. This core is stationary and is provided to reduce the reluctance of the magnetic path between two poles of the permanent magnet.
- Two spiral springs are mounted on the spindle to produce control torque. The control spring also serves an additional purpose and acts as control lead. Pointer is mounted on spindle. The spindle is supported by jeweled bearings.

Working Principle

- When D.C. supply is given to the moving coil, D.C. current flows through it.
- When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates.
- The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale.
- When the polarity is reversed a torque is produced in the opposite direction.
- The mechanical stopper does not allow the deflection in the opposite direction. Therefore, the polarity should be maintained with PMMC instrument.

Torque Equation

The force F acting on the coil due to the current flow is given as,
F = NBIL …………….(1)

Where,
N = No of Turns in coil.
L = Coil length
B = Flux Density
I = current flowing through the coil

Therefore, deflecting torque is given by,
T_d = F × Distance = F × D ………..(2)
Substituting equation 1 in 2, we get,

T_d = NBIL× D
But the area of the coil is given by,
A = L× D
So, T_d = NBIA
∴ T_d = GI (G = galvanometer constant = NBA)
The controlling torque is obtained by the spring control action.
∴ T_c = Kθ
Assuming θ as deflection and K as spring constant. At steady-state deflection, we know that $T_c = T_d$ i.e., Kθ = GI.
∴ Deflection, $\theta = \frac{G}{K} I$
This equation shows that the deflection (θ) of PMMC equipment is proportional to the current flow (I).

Advantages:

- Torque/weight is high
- Power consumption is less
- Scale is uniform
- Damping is very effective
- Since operating field is very strong, the effect of stray field is negligible
- Range of instrument can be extended

Disadvantages:

- Use only for D.C.
- Cost is high
- Error is produced due to ageing effect of PMMC
- Friction and temperature error are present

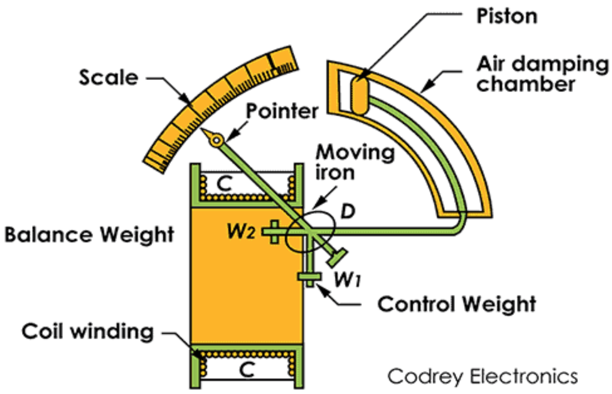
2.3 Operation of Moving Iron Instrument

- The **instrument** in which the **moving iron** is used for **measuring** the flow of **current or voltage** is known as the moving iron instrument.
- It works on the **principle** that the **iron place** near the **magnet attracts towards** it. The **force of attraction** depends on the **strength** of the **magnet field**.
- The moving iron type instrument supports both AC and DC.

Moving iron instruments are of two types, namely;

- Attraction type moving iron instruments.
- Repulsion type moving iron instruments.

Attraction type moving iron instruments



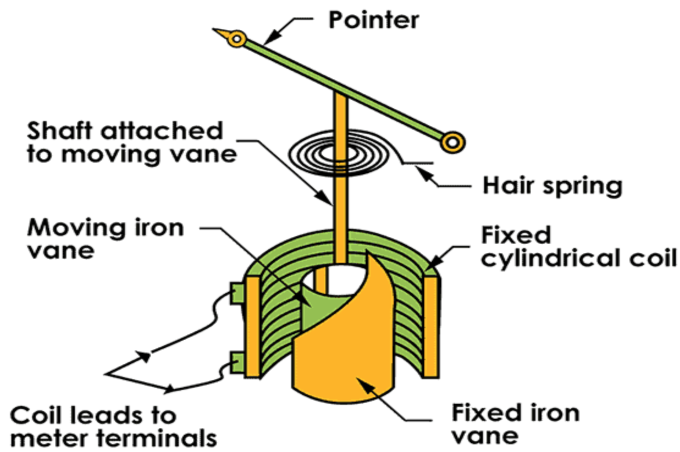
- Attraction type moving iron meter consists of a moving system which has soft iron and fixed coil wounded by a copper wire. Soft iron is free to move on the spindle and a pointer is also attached to the spindle.
- The current is passed through a coil placed near it. The moving iron is attracted to the coil which produces a magnetic field when a current flow through the coil.

Working Principle

- When the current flows through the coil, the moving iron attracted to the coil which causes the pointer to move.
- The pointer will come to zero position where deflecting torque is equal to the controlling torque.
- The strength of the deflection is directly proportional to the magnitude of the current flow through it.
- When the current in the coil is changed, the direction of the magnetic field also changed and the moving iron will get magnetize in such a way that it is pulled inwards.
- Hence these types of instruments can be used for both AC and DC currents.
- Here the air friction damping is provided by the air chamber because the magnets can affect the deflection of the pointer and the readings can be changed.
- Controlling torque is provided by the spring.

Repulsion type moving iron instruments

The basic principle of a *repulsion type moving iron instruments* is that the repulsive forces will act when two similarly magnetized iron pieces, are placed near each other.



Construction

- It consists of a fixed cylindrical hollow coil which carries the operating current. Inside the coil, there are two soft iron pieces (rods or vanes) placed parallel to each other and along the axis, of the coil.
- One of the rod or vane is fixed and the other is movable connected to the spindle. A pointer is attached to the spindle which gives deflection on the scale.
- The controlling torque is provided by spring control method while damping torque is provided by air friction.

Working

- When the instrument is connected in the circuit, the operating current flows through the stationary (or fixed) coil.
- A magnetic field is setup along the axis of the coil, this field magnetizes both the pieces similarly i.e. both the pieces attain similar polarities.
- A force of repulsion acts between the two, therefore movable piece moves away from the fixed piece. Thus the pointer attached to the spindle deflects over the calibrated scale.
- If the current in the coil is reversed, the direction of magnetic field produced by the coil is reversed. Though the polarity of the magnetized soft iron pieces is reversed but sill they are magnetized similarly and repel each other.
- Hence, the direction of deflecting torque remains unchanged. **Thus, repulsion type moving iron instrument can be used on DC as well as on AC systems.**
- Since deflection θ is proportional to the square of current flowing through the coil, **therefore, the scale of repulsion type moving iron instruments is non-uniform, being crowded in the beginning.**
- However, by using tongue-shaped iron pieces, the scale of such instruments can be made uniform.

Advantages

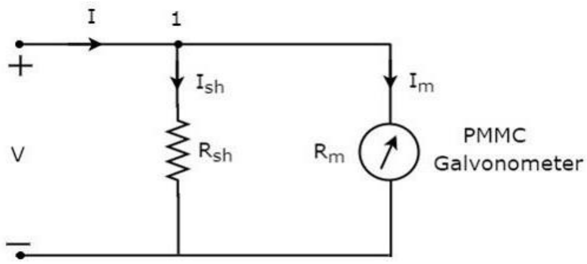
- MI can be used in AC and DC
- It is cheap
- Supply is given to a fixed coil, not in moving coil.
- Simple construction
- Less friction error.

Disadvantages:

- It suffers from eddy current and hysteresis error.
- Scale is not uniform
- It consumed more power
- Calibration is different for AC and DC operation

2.4 Basic principle of operation of DC Ammeter and Multi range Ammeter

- 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 a resistor connected 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.



- The DC ammeter is placed in series with the branch of an electric circuit, where the DC current is to be measured.
- The voltage across shunt resistor, R_{sh} and the voltage across galvanometer resistance, R_m is same, since those two elements are connected in parallel in above circuit.

Mathematically, it can be written as

$I_{sh}R_{sh}=I_mR_m$

$\Rightarrow R_{sh}=\frac{Im}{Ish} R_m$ …………(1)

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

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

Substitute the value of I_{sh} in Equation 1

$R_{sh}=\frac{Im}{I-Im} R_m$

So, $R_{sh}=\frac{Rm}{\frac{I}{Im}-1}$

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

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

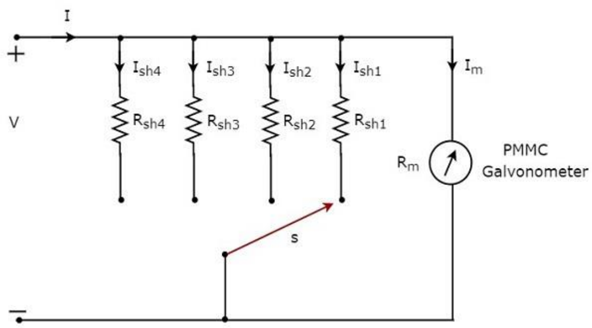
$m=\frac{I}{Im}$

$R_{sh}=\frac{Rm}{m-1}$

The value of shunt resistance is calculated by using above equations based on the available data.

Multi Range DC Ammeter

If the DC ammeter is use for measuring the Direct Currents of multiple ranges, then multiple parallel resistors connected 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 is connected 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.

Let, m_1, m_2, m_3 and m_4 are the multiplying factors of DC ammeter and the total Direct Currents to be measured as, I_1, I_2, $I_3$and I_4 respectively. Following are the formulae corresponding to each multiplying factor.

$m_1=\frac{I1}{Im}$, $m_2=\frac{I2}{Im}$, $m_3=\frac{I3}{Im}$, $m_4=\frac{I4}{Im}$

In above circuit, there are four shunt resistors, R_{sh1}, R_{sh2}, R_{sh3} and R_{sh4}.

Here $R_{sh1}=\frac{Rm}{m1-1}$, $R_{sh2}=\frac{Rm}{m2-1}$, $R_{sh3}=\frac{Rm}{m3-1}$ and $R_{sh4}=\frac{Rm}{m4-1}$

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

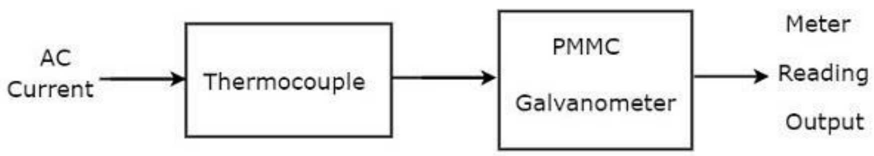
2.5 Basic principle of operation of AC Ammeter and Multi range Ammeter

- 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.

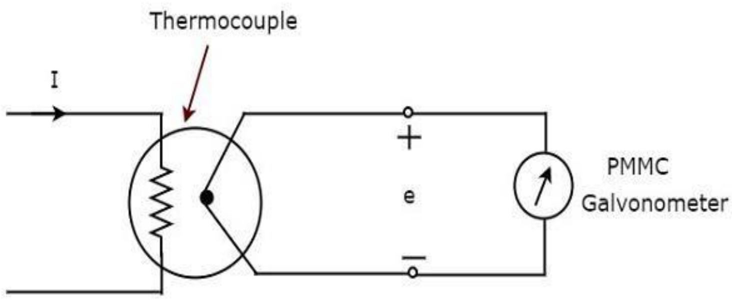
Example − Thermocouple type AC ammeter.

Thermocouple Type AC Ammeter

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



It consists of mainly two blocks: a thermocouple, and a PMMC galvanometer. The circuit diagram of thermocouple type AC ammeter will show in below figure



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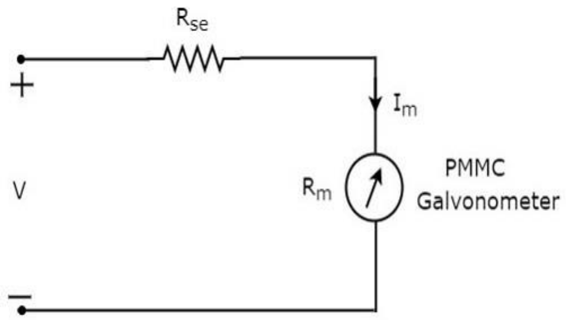
Thermocouple generates an EMF, e, whenever the Alternating Current, I flow through heater element. This EMF, e is directly proportional to the RMS value of the current, I that is flowing through heater element. To read RMS values of current, calibrate the scale of PMMC instrument

2-6 Basic principle of operation of DC Voltmeter and its applications

- DC voltmeter is a measuring instrument, which is used to measure the DC voltage across any two points of electric circuit.
- If a resistor is connected 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.



The DC voltmeter is placed across the two points of an electric circuit, where the DC voltage is to be measured.

Apply KVL around the loop of above circuit.

$V - I_m R_{se} - I_m R_m = 0$..........(1)

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

$\Rightarrow R_{se} = \frac{V - ImRm}{Im}$

$\Rightarrow Rse = \frac{V}{Im} - R_m$.............(2)

Where,

R_{se} is the series multiplier resistance
V is the full range DC voltage that is to be measured
I_m is the full scale deflection current
R_m is the internal resistance of galvanometer

The ratio of full range DC voltage that is to be measured, V and the DC voltage drop across the galvanometer, V_m is known as multiplying factor(m)

Mathematically, it can be represented as $m = \frac{V}{Vm}$ ....(3)
From Equation 1, the full range DC voltage V is
$V = I_m R_{se} + I_m R_m$ ....(4)

The DC voltage drop across the galvanometer, V_m is the product of full scale deflection current, I_m and internal resistance of galvanometer, R_m. Mathematically, it can be written as
$V_m = I_m R_m$ ....(5)

Substitute Equation 4 and 5 in Equation 3.

$m = \frac{ImRse + ImRm}{ImRm}$

$\Rightarrow m = \frac{Rse}{Rm} + 1$

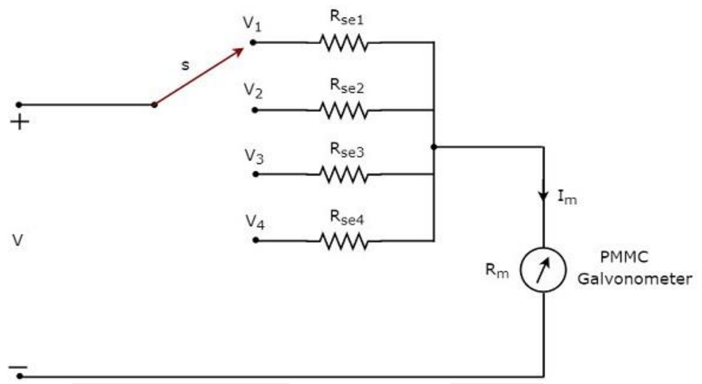
$\Rightarrow m - 1 = \frac{Rse}{Rm}$

$R_{se} = R_m(m-1)$.............(6)

The value of series multiplier resistance calculated by using either Equation 2 or Equation 6 based on the available data.

Multi Range DC Voltmeter

If the DC voltmeter is used for measuring the DC voltages of multiple ranges, then connect 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 is placed across the two points of an electric circuit, where the DC voltage of required range is to be measured. The desired range of voltages is chosen by connecting the switch 'S' to the respective multiplier resistor.

Let, m_1, m_2, m_3 and m_4 are the multiplying factors of DC voltmeter. The full range DC voltages to be measured as, V_1, V_2, $V_3$and V_4 respectively.

So $m_1 = \frac{V1}{Vm}$, $m_2 = \frac{V2}{Vm}$, $m_3 = \frac{V3}{Vm}$, and $m_4 = \frac{V4}{Vm}$

In above circuit, there are four series multiplier resistors, R_{se1}, R_{se2}, R_{se3} and R_{se4}.

$R_{se1} = R_m(m_1-1)$, $R_{se2} = R_m(m_2-1)$, $R_{se3} = R_m(m_3-1)$, $R_{se4} = R_m(m_4-1)$

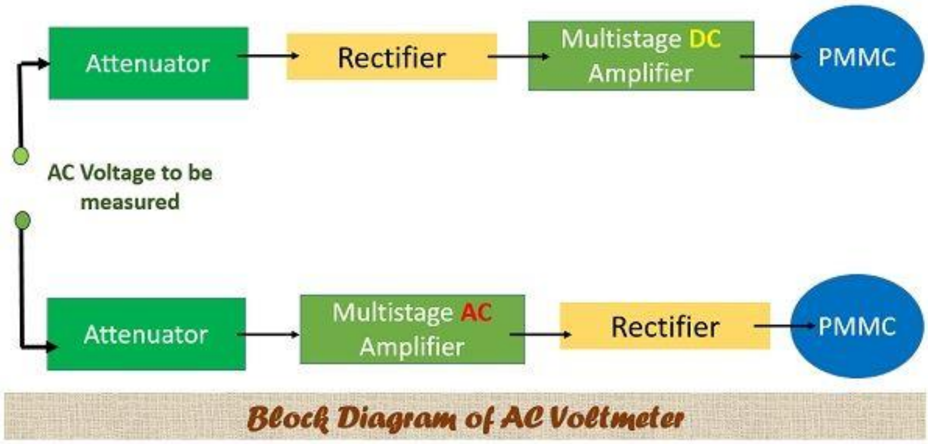
So, the resistance values of each series multiplier resistor by using above formulae.

2.7 Basic principle of operation of AC Voltmeter and its application

- **AC voltmeters** are designed in a manner so that they can measure the AC voltage under measurement.
- The main difference between AC voltmeter circuit and DC voltmeter circuit is the usage of a **rectifier.** The rectifier is used in order to transform the AC voltage into DC voltage.

Block Diagram of AC Voltmeter

- The input to be measured is given to the **attenuator circuit** which performs the operation of selection of a particular range of voltage. The output of attenuator is given to rectifier which converts the AC voltage into pulsating DC voltage. Then the final output of DC amplifier is given to the PMMC meter.



- The rectifier can be used before the **multistage amplifier** or after the amplifier. This depends on the type of amplifier used in AC voltmeter.

- For multistage AC amplifier, the rectifier circuit will be used after the amplifier. On the contrary, if the multistage amplifier used is DC, then the rectifier should be used before it.

- The amplifier is a vital component because it amplifies the signal which got attenuated during the measurement procedure. The usage of the amplifier increases the cost of the circuit.

2.8 Basic principle of Ohm Meter (Series & Shunt type)

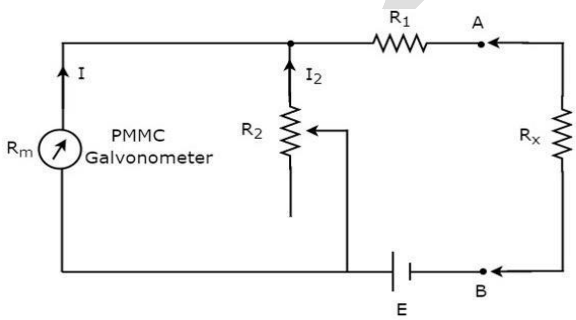
- The instrument, which is used to measure the value of resistance between any two points in an electric circuit is called ohmmeter.
- The units of resistance are ohm and the measuring instrument is meter. So, the word “ohmmeter” is obtained by combining the words “ohm” and “meter”.

Ohmmeters are two types

- 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 part of the circuit, which is left side of the terminals A & B is series ohmmeter. The unknown resistance is measure by placing it to the right side of terminals A & B.

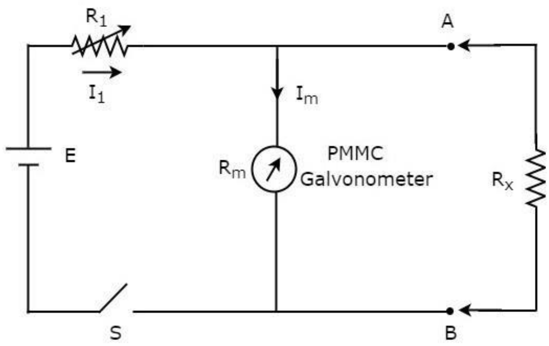
- If R_x=0 Ω then the terminals A & B will be short circuited with each other. So, the meter current gets divided between the resistors, R_1 and R_2. Now, vary the value of resistor, R_2 in such a way that the entire meter current flows through the resistor, R_1 only. In this case, the meter shows full scale deflection current. Hence, this full scale deflection current of the meter can be represented as 0Ω.

- If Rx=∞Ω, then the terminals A & B will be open circuited with each other. So, no current flows through resistor, R_1. 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. 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 part of the circuit, which is left side of the terminals A & B is **shunt ohmmeter**. The unknown resistance is measured by placing it to the right side of terminals A & B.

- If Rx=0Ω, then the terminals A & B will be short circuited with each other. Due to this, the entire current, I_1 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.
- 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, I_1 flows through PMMC galvanometer. If required vary (adjust) the value of resistor, R_1 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
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.

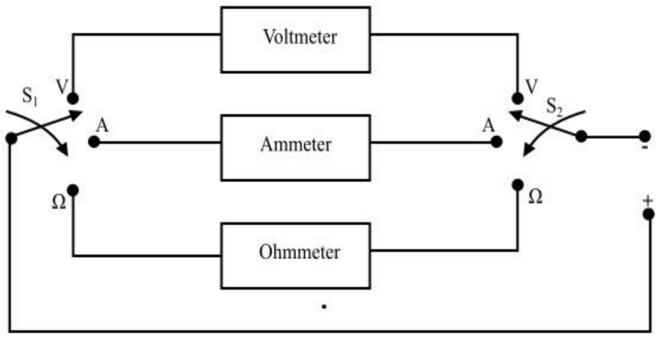
2.9 Basic principle of Analog Multimeter, its types & applications

A multimeter is a measuring instrument that can measure multiple electrical properties. A typical multimeter can measure voltage, resistance, and current. On the basis of output representation, there are two types of multimeter –

- Analog multimeter
- Digital multimeter

Analog Multimeters

- An analog *multimeter* is a permanent magnet moving coil (PMMC) meter type measuring instrument. It works on the principle of D'Arsonval galvanometer.
- The analog multimeter has an analog display that uses the deflection of a pointer on the scale to indicate the level of measurement being made.
- A pointer is attached with the coil. The pointer deflects from its initial position increasingly as the measuring quantity increases.
- Since, the analog multimeter is a PMMC types instrument, so when a current is passed through its coil, the coil moves in a magnetic field produced by the permanent magnet.
- Deflecting torque acts on the coil that will rotate it by an angle, so the pointer moves over a scale.
- A pair of hairsprings is attached to the spindle to provide the controlling torque.
- The Block Diagram of Analog Multimeter consists of two switches S1 and S2 are used to select the desired meter. It also has a rotary range-selector switch to choose a particular range of current, voltage and resistance.



Applications of Multimeter

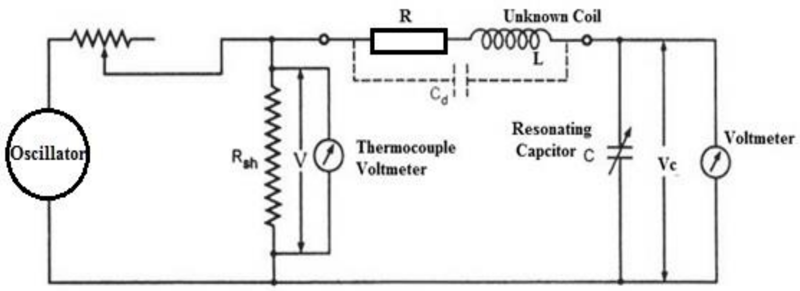
- AC/DC voltage measurement
- AC/DC current measurement
- Resistance & continuity measurement
- To check diode
- Measurement of capacitance
- To test batteries
- A broken power cable can be determined
- The switch can be tested
- Measurement of time & frequency

2-10 Operation of Q meter and its essentials

- The instrument which **measures** the **storage factor** or **quality factor** of the electrical **circuit** at **radio frequencies**, such type of device is known as the Q-meter.
- The **quality factor** is one of the **parameters** of the **oscillatory system**, which shows the **relation** between the **storage and dissipated energy.**

Working Principle of Q meter

- Here thermocouple meter is used to calculate the voltage across the shunt resistance whereas an electronic voltmeter is used to calculate the voltage across the capacitor. These meters can be calibrated to read 'Q' directly.



- In the circuit, the energy of the oscillator can be supplied to the tank circuit. This circuit can be adjusted for the resonance through unstable 'C' until the voltmeter reads the utmost value.

- The output voltage of resonance is 'V', equivalent to 'Vc' The coil is connected to the two test terminals of the instrument to determine the coil's inductance

- This circuit is adjusted to resonance through changing either the oscillator frequency otherwise the capacitance. Once the capacitance is changed, then the frequency of the oscillator can be adjusted to a specified frequency & resonance is attained.

- If the value of capacitance is already fixed to a preferred value, then the frequency of the oscillator will be changed until resonance takes place.

- The Q meter works on series resonant. The resonance is the condition exists in the circuit when their inductance and capacitance reactance are of equal magnitude. They induce energy which is oscillating between the electric and magnetic field of the capacitor and inductor respectively.

At resonant frequency f_0, $X_L = X_C$

Where capacitance reactance is $X_C = \frac{1}{2\pi f0C} = \frac{1}{\omega 0C}$ and Inductive reactance, $X_L = 2\pi f_0 L = \omega_0 L$

Current at resonance, $I_0 = \frac{V}{R}$

Voltage across capacitor, $V_c = I_0 X_C = I_0 X_L = I_0 \omega_0 L$

Input voltage, $V = I_0 R$, So, $\frac{Vc}{V} = \frac{\omega 0L}{R} = Q$

Therefore, $V_c = QV$

- The above equation shows that the input voltage V is Q times the voltage appears across the capacitor

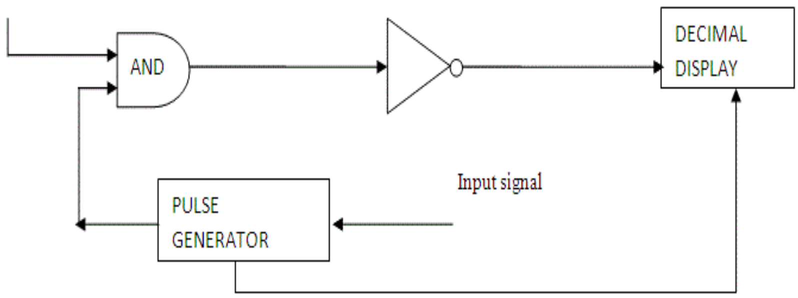
- The reading of 'Q' on the output meter is multiplied through the setting of an index to get the actual 'Q' value. The coil's inductance is calculated from known values of the coil frequency as well as the resonating capacitor.

- The specified Q is not the definite Q, as the losses of the voltmeter, inserted resistance & resonating capacitor are all incorporated in the circuit. Here, the definite 'Q' of the calculated coil is a bit larger than the specified Q.

UNIT-3: DIGITAL INSTRUMENTS

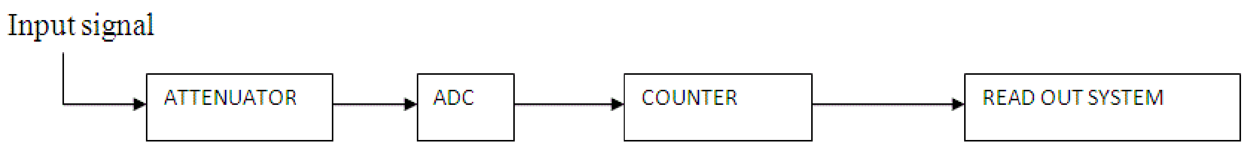
- The instrument which represents the measurand value in the form of the digital number is known as the digital instruments.
- It works on the principle of quantization. The quantization is the process of converting the continuous input signal into a countable output signal.
- The digital multimeter, digital voltmeter, digital frequency meter, etc. are the examples of the digital instruments.
- Digital Voltmeter abbreviated as DVM is an instrument used to measure the electrical potential difference between two points in a circuit. The voltage could be an alternating current (AC) or direct current (DC). It measures the input voltage after converting the analog voltage to digital voltage and displays it in number format using a convertor.

Working Principle of Digital Voltmeter



- Unknown voltage signal is fed to the pulse generator which generates a pulse whose width is proportional to the input signal.
- Output of pulse generator is fed to one leg of the AND gate.
- The input signal to the other leg of the AND gate is a train of pulses.
- Output of AND gate is positive triggered train of duration same as the width of the pulse generated by the pulse generator.
- This positive triggered train is fed to the inverter which converts it into a negative triggered train.
- Output of the inverter is fed to a counter which counts the number of triggers in the duration which is proportional to the input signal i.e. voltage under measurement.
- Thus, counter can be calibrated to indicate voltage in volts directly.

The working of digital voltmeter is nothing but an analog to digital converter which converts an analog signal into a train of pulses, the number of which is proportional to the input signal. So a digital voltmeter can be made by using any one of the A/D conversion methods.



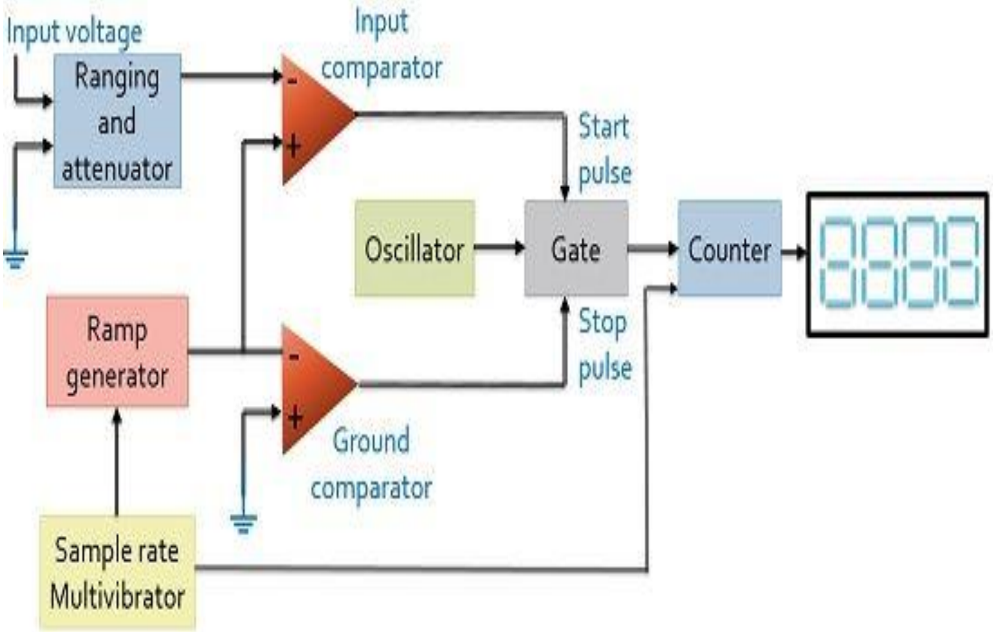
On the basis of A/D conversion method used digital voltmeters can be classified as:

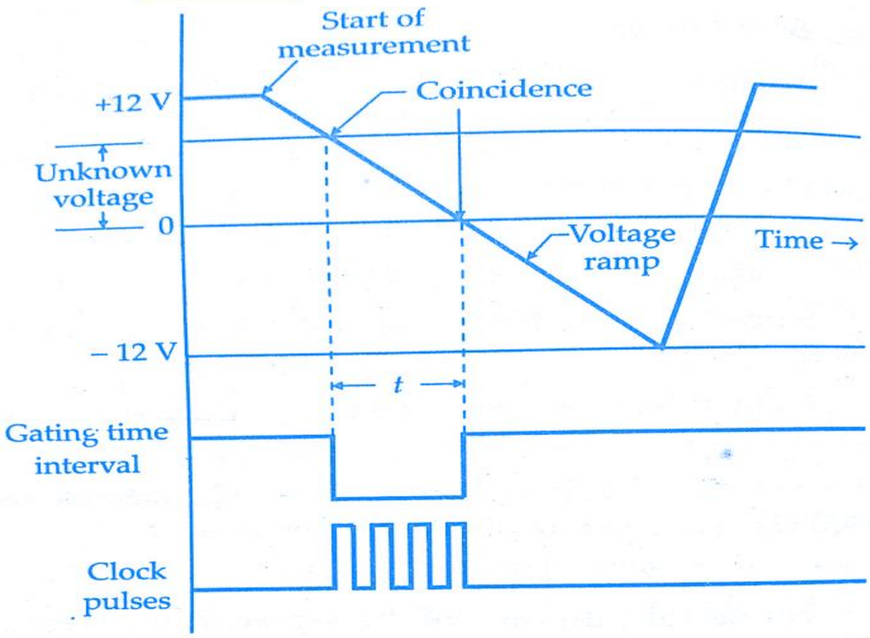
- Ramp type digital voltmeter
- Integrating type voltmeter

- Potentiometric type digital voltmeters
- Successive approximation type digital voltmeter
- Continuous balance type digital voltmeter

3.1 Principle of operation of Ramp type Digital Voltmeter & applications

The block diagram of ramp type digital voltmeter(DVM) consist of ramp generator that generate a waveform which is representing a ramp. Therefore, it is called ramp type digital voltmeter(DVM).





- The operating principle of the ramp type DVM is based on the measurement of the time taken by the DVM 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 period is measured with an electronic time-interval counter and the count is displayed as a number of digits on a digital display.
- At the start of measurement, a ramp voltage is initiated. The ramp voltage can be negative or positive.
- The above figure shows a negative-going ramp, this ramp is continuously compared with the unknown input voltage.

- At the instant that the ramp voltage equals the unknown voltage to be measured, a coincidence circuit or comparator generates a pulse to open the gate. The ramp voltage continues to decrease with time until it finally reaches 0 V. At this instant the ground comparator generates an output pulse to close the gate.
- The time between opening and closing of the gate is t as shown in Fig. During this time interval pulses from a clock pulse generator pass through the gate and are counted and displayed.
- An oscillator generates clock pulses that are allowed to pass through the gate to a number of counting units which totalize the number of pulses passed through the gate.
- The sampling rate multivibrator determines the rate at which the measurement cycles are initiated. The sample-rate circuit provides an initiating pulse for the ramp generator to start its next ramp voltage.

Advantages of Ramp-Type DVM

1. The circuit is easy to design and low in cost.
2. Output pulse can be transmitted over long distances.

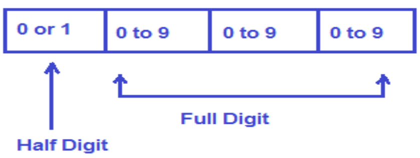
Disadvantages of Ramp-Type DVM

1. Single ramp requires excellent characteristics regarding linearity of ramp and time measurement.
2. Large errors are possible when noise is superimposed on the input signal.
3. Input filters are required for this type of converter.

3.2 Operation of display of 3 1/2, 4 1/2– Digital Multimeter & Resolution and Sensitivity

- Basically, there are two types of digits in digital display: Full digit and Half Digit.
- A full digit is something which can take any value from 0 to 9. Thus it can have a total of 10 different states. This means a full digit may have any value 0, 1, 2,….., or 9.
- A half digit is something which can either have a value of 0 or 1. This digit is basically the most significant digit and hence has limited use for displaying any number or reading.

3½ digit displays have four digits: one half digit and three full digits. As half digit is the most significant digit and can either have value 0 or 1 and full digit can take any value (0 to 9), therefore the range of digital display will be 0 to 1999.
Since negative sign can be displayed by the readout, the range will be -1999 to 1999.



4½ digit display have five digits: 1 half digit and 4 full digits. Thus as discussed in 3.5 digit display, the range of the display will be 0 to 19999. As negative sign can also be displayed by the instrument, the range will be -19999 to 19999.

Resolution

- It is defined as the number of digit positions or simply the number of digits used in a meter.
- Hence a three digit display on the digital meter for 0-1 V range will be able to indicate from 000 to 999mV, with smallest increment of 1mV.
- If the number of full digits is n, then resolution, R= $\frac{1}{10n}$

Sensitivity

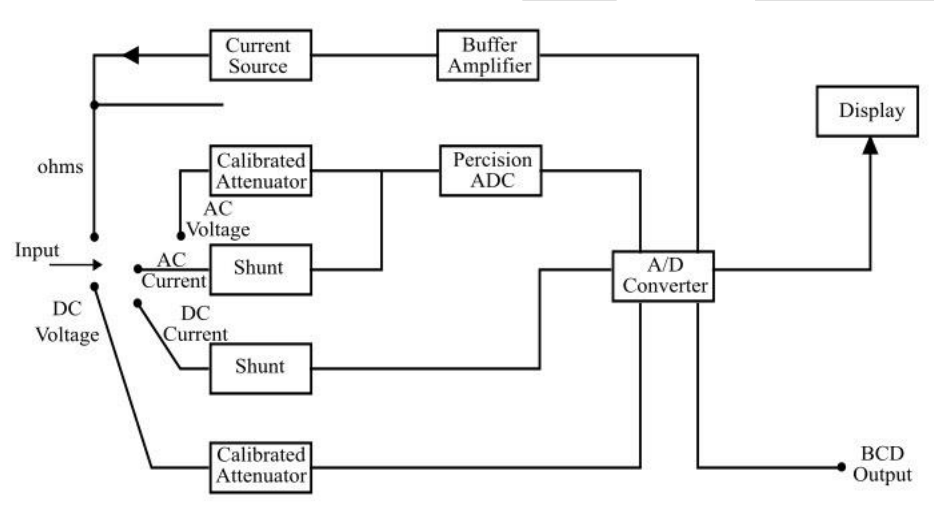
- It is the smallest change in input which is a digital meter is able to detect.
- Thus it is the full scale value of the lowest voltage range multiplied by the resolution of the meter. Sensitivity is given as $S=(f_s)_{min}$ X R

Where (fs)min is the lowest full scale value of digital meter, and R is the resolution in decimal.

3.3 Basic principle of operation of working of Digital Multimeter types & applications

- A measuring instrument that is used to measure different electrical properties like resistance, voltage and current is known as a multimeter. This is also called a VOM or volt-ohm-milliammeter.
- Multimeters are two types 1. Analog Multimeter 2. Digital Multimeter
- A digital multimeter (DMM) is a multifunctional meter that displays its electrical quantitative values on an LCD screen.
- It is basically a digital voltmeter and may be used for the measurement of voltage, current (d.c & a.c) and resistance.
- All quantities other than dc voltage are first converted into an equivalent dc voltage by some device. It measures electrical values quickly without any computations.

Block Diagram of Digital Multimeter



- For measurement of ac voltage, the input is converted into a dc voltage by means of a rectifier. A compensated attenuator is employed. Many manufacturers provide the same attenuator for both dc and ac measurements.
- For measurement of resistance a constant current, depending on the range, supplied from a battery or a constant current source is passed through the resistance under measurement and the voltage developed across it is measured. The resistance value is displayed in ohms.
- For measurement of current, the unknown current is passed through a precision resistor in many commercial digital Multimeters and the voltage developed across the precision resistor is measured. The current value is displayed in mA.
- For measurement of current, a current to voltage converter may also be used.

There are three types of digital Multimeters (DMM):

1. A fluke digital multimeter is used mainly for calibration efforts. It can be used to calibrate volts, currents, and other electrical units.

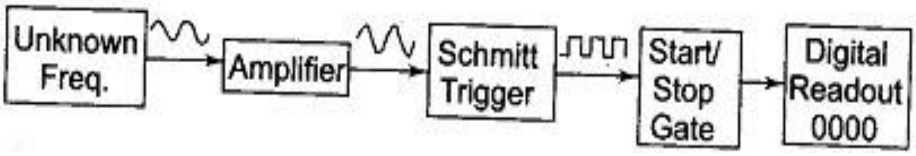
2. A clamp digital multimeter uses built-in tools to measure electrical flow. This highly differs from the fluke digital multimeter in that it uses a clamp in order to measure this flow.
3. An autoranging digital multimeter is used for easier projects. It usually just measures one component at a time.

3.4 Basic principle of operation of working of Digital Frequency Meter

- A digital frequency meter is an electronic instrument that can measure even the smaller value of frequency up to 3 decimals of a sinusoidal wave and displays it on the counter display.
- It counts the frequency periodically.
- The entire concept is based on the conversion of sinusoidal voltage into continuous pulses along a single direction.

Basic Circuit of a Digital Frequency Meter

The block diagram of a basic circuit of a digital frequency meter is shown in Fig.



- The signal may be amplified before being applied to the Schmitt trigger. The Schmitt trigger converts the input signal into a square wave with fast rise and fall times, which is then differentiated and clipped.
- As a result, the output from the Schmitt trigger is a train of pulses, one pulse for each cycle of the signal.
- The output pulses from the Schmitt trigger are fed to a START/STOP gate. When this gate is enabled, the input pulses pass through this gate and are fed directly to the electronic counter, which counts the number of pulses.
- When this gate is disabled, the counter stops counting the incoming pulses. The counter displays the number of pulses that have passed through it in the time interval between start and stop. If this interval is known, the unknown frequency can be measured.

$\mathbf{F} = \frac{N}{t}$

Where,

F = Unknown frequency.

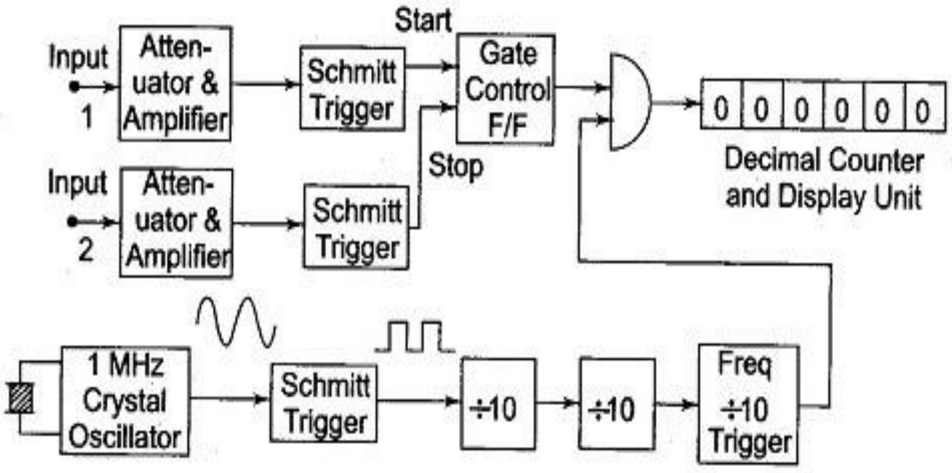
N = Number of counts.

t = Time interval between start and stop condition of the gate.

3.5 Operation of working of Digital Measurement of Time

- In the low frequency range, it is necessary to measure the time period rather than the frequency.
- The circuit used for measuring frequency can be used for the measurement of time period if the counted signal and gating signal are interchanged.
- The gating signal is derived from the unknown input signal, which now controls the enabling and disabling of the main gate.
- The number of pulses which occur during one period of the unknown signal are counted and displayed by the decade counting assemblies.

➢ The only disadvantage is that for measuring the frequency in the low frequency range, the operator has to calculate the frequency from the time by using the equation f = 1/T.



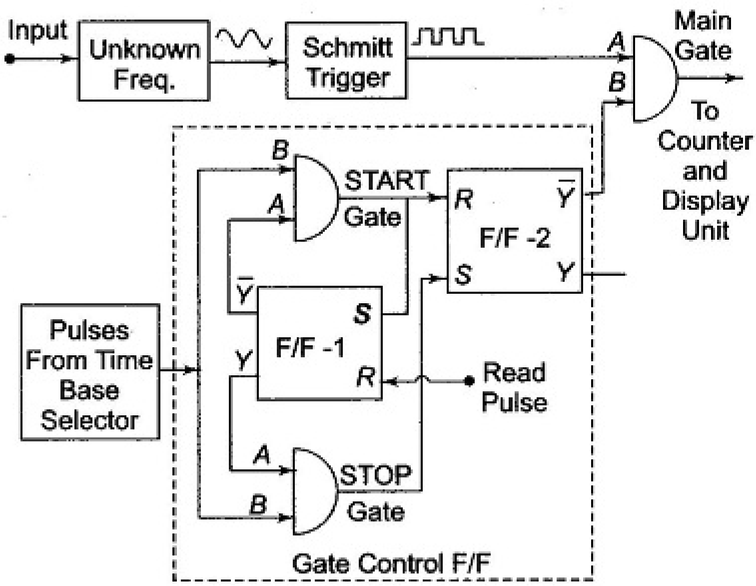
➢ The accuracy of the period measurement and hence of frequency can be greatly increased by using the multiple period average mode of operation. In this mode, the main gate is enabled for more than one period of the unknown signal. This is obtained by passing the unknown signal through one or more-decade divider assemblies (DDAs) so that the period is extended by a factor of 10,000 or more.

➢ Hence the digital display shows more digital of information, thus increasing accuracy.

➢ However, the decimal point location and measurement units are usually changed each time an additional decade divider is added, so that the display is always in terms of the period of one cycle of the input signal, even though the measurements may have lasted for 10,100 or more cycles.

3.6 Measurement of Frequency.

Basic Circuit for Frequency Measurement



➢ When an input signal is applying to the meter, the amplifier present in it starts amplifying the signal. The amplification is done in order to strengthen the weak magnitude of input signal.

➢ The amplified input is now given to Schmitt trigger which then converts the input signal into square wave.

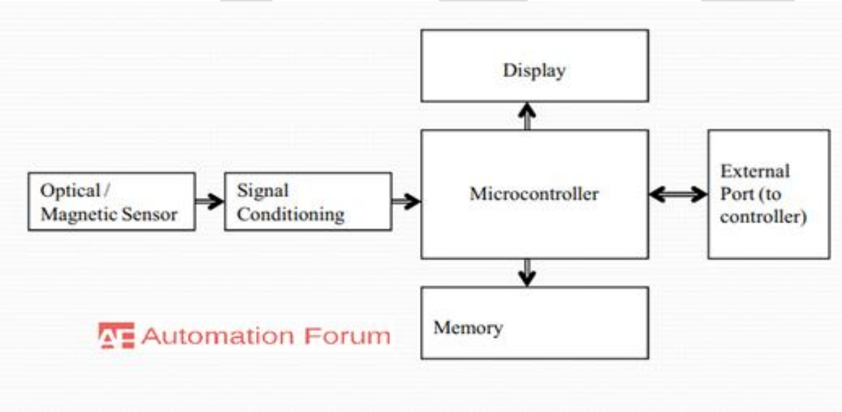
➢ The square waves are then separated and clipped to obtain a train of pulses.

- Similarly, the oscillator produces a sine wave which is then converted into square wave which produces a square wave and is applied to the flip-flop.
- Now, the first pulse activates the gate control FF connected after the Schmitt trigger which enables the AND gate.
- Now, the train of pulses is then applied to AND gate due to which AND gate produces an Output.
- This Output is then given to the decimal counter which counts the first decimal number.
- Now when the second pulse is given to the Gate Flip-flop which removes the AND gate to "turn ON".
- Thus, when the third pulse arrives at the flip-flop the AND gate is then enabled until then the counter shows the previous counted decimal.
- The decimal counter and display unit shows the output corresponding to the train of pulses received for a precise time interval.

Thus, the counter output shows only the frequency of signal.

3.7 Principle of operation of working of Digital Tachometer

- The word tachometer is derived from two Greek words: tachos mean "speed" and metron means "to measure".
- A digital tachometer is a digital device that measures and indicates the speed of a rotating object.
- A digital tachometer circuit comprises LCD or LED readout and a memory for storage.
- The operational set up of a digital tachometer consists of various blocks such as an optical or magnetic sensor, a signal conditioning unit, a microcontroller, a memory, a display, and an external port, as shown in the figure.



Optical sensing: An optical sensor consists of an optical disk placed near the motor which generates pulses proportional to the rotating shaft. A slotted disk and IR emitter are used to generate these pulses.

Magnetic sensing: In this type of sense, there is a possibility to use either Hall Effect sensors or magnetic sensors. Hall Effect principle generates the pulses proportional to the speed of the shaft and magnetic sensors are used to generate pulses by making use of variable reluctance.

Signal Conditioning: The output signals from the sensors are noisy, and therefore, are filtered, amplified, and digitized so that the microcontroller recognizes these signals for further action.

Microcontroller: A microcontroller is used to analyze and process the readings from the sensors. It sends that information to a display device, and when the speed is reduced or increased to a predefined level, it alerts the user by taking appropriate action.

Memory: The memory unit stores the data from the microcontroller.

Display Unit: The function of the display unit is to view the stored values transmitted from the microcontroller.

3.8 Principle of operation of working of Automation in Digital Instruments (Polarity Indication, Ranging, Zeroing & Fully Automatic)

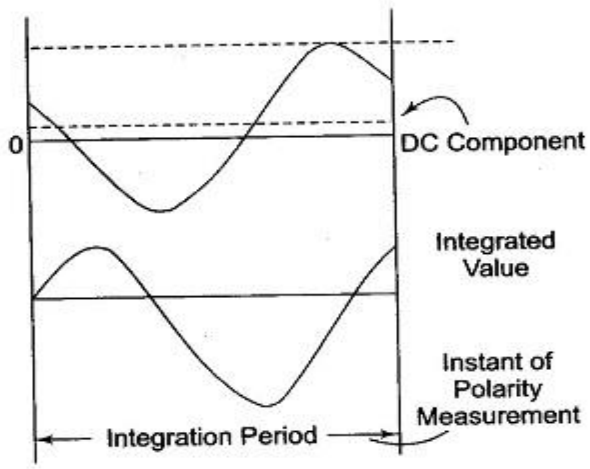
Automation in Digital Instruments:

Automation in Digital Instruments – One of the advantages of digital Multimeters is their ease of operation. The reading is easy to take and does not lend itself to errors of interpretation. Moreover, the number of ranges is limited because the ranges move in steps of 10 (instead of the √10 steps used for analog instruments).

This automation includes automatic polarity indication, automatic ranging, and automatic zeroing.

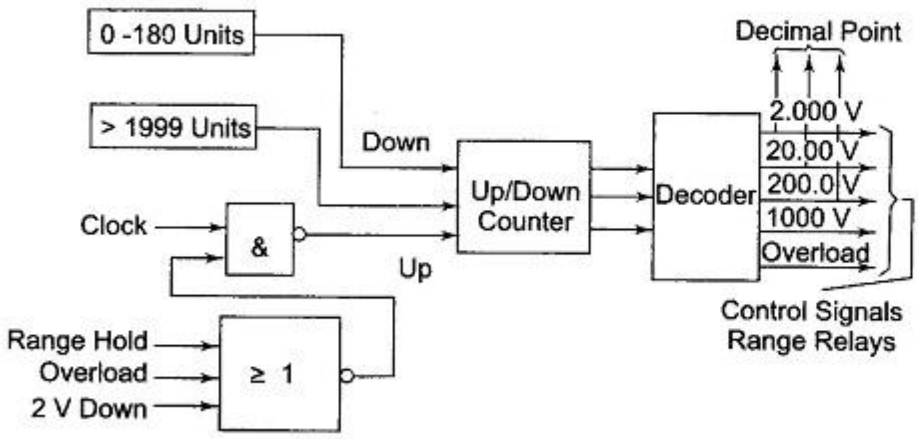
Automatic Polarity Indication

- The polarity indication is generally obtained from the information in the ADC.
- For integrating ADCs, only the polarity of the integrated signal is of importance. The polarity should thus be measured at the very end of the integration period (see Fig.).
- As the length of the integration period is determined by counting a number of clock pulses, it is logical to use the last count or some of the last counts to start the polarity measurement.
- The output of the integrator is then used to set the polarity flip-flop, the output of which is stored in memory until the next measurement is made.



Automatic Ranging

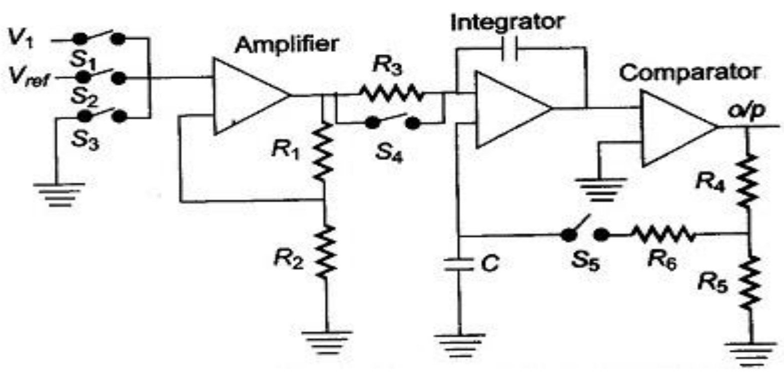
- The object of automatic ranging is to get a reading with optimum resolution under all circumstances.
- The design of an automatic ranging system is indicated in the block diagram in Fig.



- The information contained in the counter of the ADC yields a control pulse for down ranging when the count is less than 180 and one for up ranging when the count exceeds 1999 units.
- The Up/Down counter of the automatic ranging circuit reacts to this information at the moment that a clock pulse (a pulse at the end of the measuring period, also used to transfer new data to memory), is applied, and the new information is used to set the range relays via the decoder.
- At the same time the decimal point in the display is adapted to the new range, when more than range step has to be made, several measuring periods are needed to reach the final result. Clock pulses, and so automatic ranging, can be inhibited, for example, by a manual range hold command, by a signal that exceeds the maximum range (only for up counts), and course by reaching the most sensitive range, but then only for down counts.

Automatic Zeroing

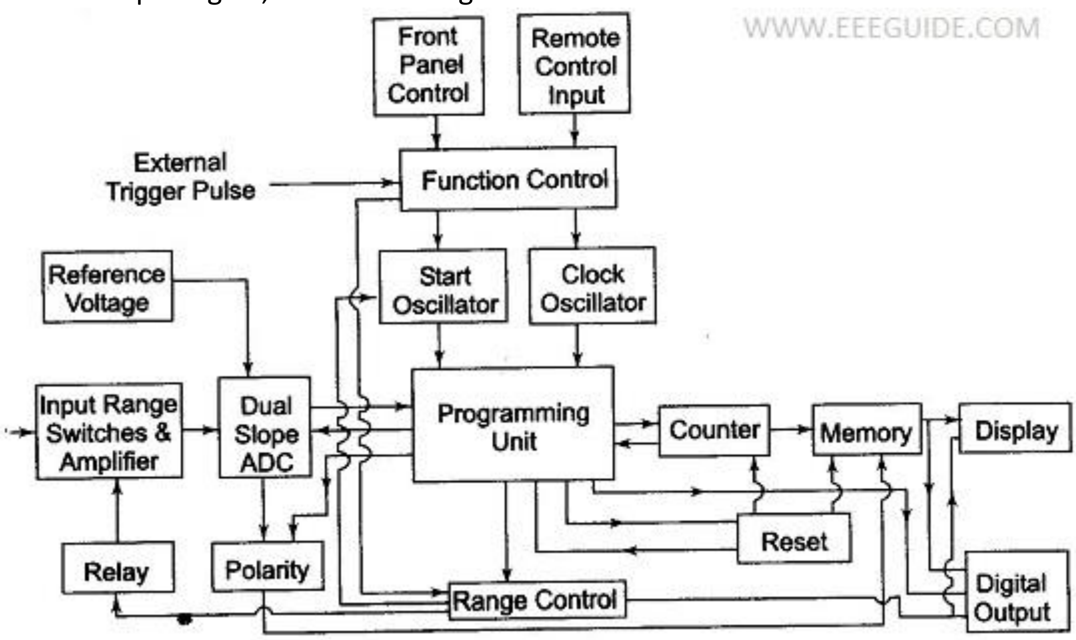
- Each user of a voltmeter expects the instrument to indicate zero when the input is short-circuited.
- In a digital voltmeter with a maximum reading of 1999, a zero error of 0.05% of full scale deflection is sufficient to give a reading of 0001. For this reason, and in the interests of optimum accuracy with low valued readings, a zero adjustment is necessary.
- To increase the ease of operation, many instruments now contain an automatic zeroing circuit.
- In a system used in several Multimeters, the zero error is measured just before the real measurement and stored as an analog signal. A simplified circuit diagram of a circuit that can be used for this purpose is given in Fig, for a dual slope ADC.



- Before the real measurement is made, switches S_3, S_4 and S_5 are closed, say for 50 ms, thus grounding the input, giving the integrator a short RC time, and connecting the output of the comparator to capacitor C.
- This capacitor is now charged by the offset voltages to the amplifier, the integrator and the comparator.
- When switches S_3, S_4 and S_5 are opened again to start the real measurement, the total offset voltage of the circuit (equal to zero error) is stored in this capacitor, and the real input voltage is measured correctly.

Fully Automatic Digital Instrument

- A multimeter with automatic polarity indication, automatic zero correction and automatic ranging (of course coupled with automatic decimal point indication) only needs a signal applied to its input, and a command as to what quantity (V_{dc}, V_{ac}, **I** or R**)** to measure; it does all the rest itself.
- The digital part of a typical instrument is organized so as to produce a display or a digital output signal, as shown in Fig.



- Before a measurement can begin, the functions of the instrument must be set, that is, we must select the quantity to be measured (e.g. voltage), the ranging mode (automatic or manual), and the start mode (internal or with an external trigger signal).
- This can be done by the front panel controls, or via a remote control input. In both cases, the signals are fed to the function control unit, while the information on ranging is passed to the range control unit.
- An incoming trigger pulse causes the start oscillator to deliver a pulse to the programming unit, and a measurement is started.
- The programming unit starts both the counter and the ADC. The ADC is connected to the input.
- The counter counts the clock pulses to determine the integration time and sends two signals back to the programming unit, one just before the end of the integration period, and the other at the end of this period.
- The first signal is used by the programming unit to activate the polarity detector, which determines the polarity of the integrated signal, while the second serves to switch the ADC input from the reference signal.

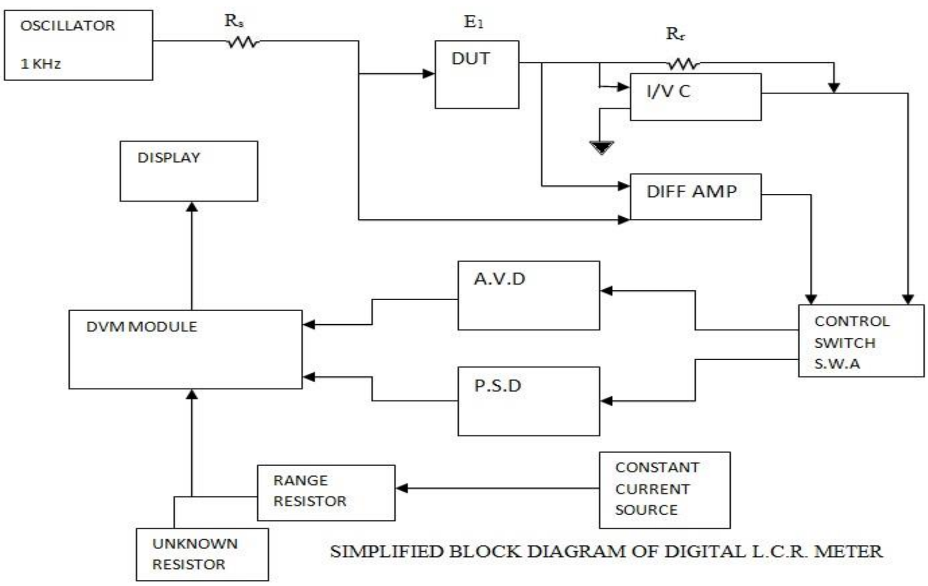
- At the same time, the counter is reset to zero and starts counting the down integration time of the ADC until it is stopped by the zero-detector signal of the ADC.
- At that moment, the programming unit compares the counter reading with the automatic ranging limits, and passes an up or down signal to the range control, if necessary.
- This unit switches the input range switches via a relay and triggers the start oscillator for a new measurement in a more sensitive or less sensitive range. In the meantime, the programming unit will also have reset the counter.
- This process continues until a measurement which is within the automatic ranging limits has been made.
- The programming unit then transfers the new data from the counter to the memory, together with the polarity information so as to make them available to the display unit and the digital output.
- Finally, the programming unit delivers a transfer pulse to the digital output, to warn an instrument connected to this output (e.g. a printer) that new data has been made available.

3.9 Block diagram of LCR meter & it's working principle.

Digital LCR meter is an electronic test equipment used to measure the inductance(L), capacitance(C) and resistance (R) of an electronic component.

Description of Block Diagram:

- The digital L.C.R. bridge or L.C.R. meter consists of a 1 kHz oscillator and a current to voltage converter; it is nothing but an operational amplifier.
- The oscillator output reaches the current to voltage converter through a selectable source resistance R_s and the component under test (DUT).
- The output of the current to voltage converter and the differential amplifier along with the associated feedback circuit goes to the control switch. From the control switch the output is fed to the average voltage detector and the phase sensitive detector.
- These two outputs of the A.V.D. and P.S.D. act as reference and input signals respectively to the digital voltmeter module.
- The digital voltmeter, displays the value of inductance or capacitance depending on the component connected to the test terminals.



SIMPLIFIED BLOCK DIAGRAM OF DIGITAL L.C.R. METER

- In addition to the above blocks it consists of a constant current source, a range selector and two terminals for the unknown resistance. They are connected appropriately to the D.V.M. module. This arrangement is exclusively for the measurement of resistance. The measurement of resistance is done as is done in the case of Digital Multimeters.

Working Principle Involved in Measuring L and C:

- In the block diagram illustrated in Figure, DUT represents device under test that is the component under test. A capacitor, or an inductance can be connected across these terminals to estimate its value.
- An oscillator working at 1 kHz frequency is used to apply a test signal to the component under test through a selectable source resistance R_S.
- An operational amplifier works as a current to voltage convertor. It has a range selector resistor R_r , incorporated in its feedback path. The operational amplifier drives the junction of component under test and R_r. to a virtual ground. Therefore R_r, will not change the current through the unknown component (or the component under test or device under test DUT).
- Therefore the voltage across the unknown component is E_1 , as is marked in the block diagram. The signal current will flow through R_r . It produces a voltage across R_r , which is proportional to the current through the unknown component.
- The voltages E_1 and E_2, are vector quantities. Therefore, they define the characteristics of the device at a given test frequency and signal level.

Mathematically, $E_1 \alpha V$ and $E_2 \alpha I$
The capacitance $C \alpha 1/V \alpha E_2/E_1$
The inductance $L \alpha V/I \alpha E_1/E_2$

- These ratios are adopted in the measurement modes and are displayed using dual slope converter module.

Working of the digital L.C.R. meter:

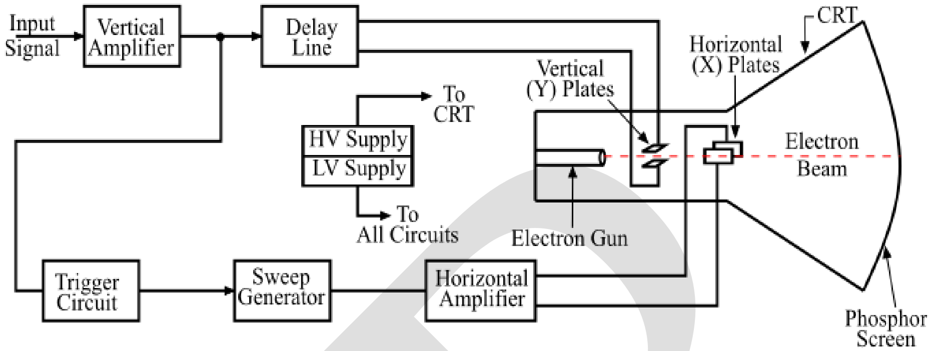
- The values of R_s and R_r will be selected depending on the impedance of the unknown component.
- Inductance is measured in the series equivalent mode. The impedance of the unknown inductance is usually low at the test frequency. The value of R_s , is selected to be much higher than the impedance of unknown inductance's impedance. This results in a constant current drive through the unknown inductance. The magnitude of current will be given by the value of R_s.
- Capacitance will be measured in the parallel equivalent mode of operation. The impedance will be high, Hence R_s, will be a much lower value, than the impedance offered by the capacitor at the test frequency. This results in the constant voltage drive.
- The values of R_s and R_r, in any selected range are equal. Therefore, equal voltage drops are obtained across R_s and R_r, with same signal current flowing through them.
- The signal voltage E_1, is allowed through the differential amplifier. Then it is given to a control switch SWA. This signal voltage E2, is also given to the control switch SWA, supplies the greater of E_1 or E_2 to the average voltage detector. The lesser one is given to the phase sensitive detector P.S.D.
- The outputs of A.V.D. and P.S.D. are steady voltages (D.C. voltages). They are given to the D.V.M. module as reference and input signals. Hence the D.V.M displays the value.

UNIT-4: OSCILLOSCOPE

4.1 Basic principle of Oscilloscope& its Block Diagram

An oscilloscope is a device which allows the amplitude of electrical signals (current, voltage, power etc.) to be display as a function of time.
An oscilloscope is a laboratory instrument commonly used to display and analyze the waveform of electronic signals.

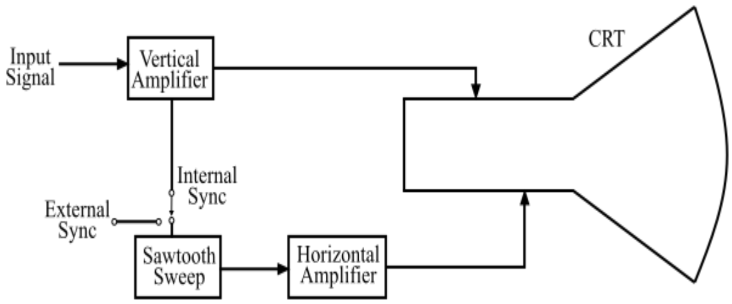
Oscilloscope Parts and their Function



- Cathode Ray Tube (CRT) – The CRT displays the quantity being measured. It generates and accelerates an electron beam, deflects the beam to create the image and contains a phosphor screen where the electron beam eventually becomes visible.
- Vertical Amplifier –The vertical amplifier amplifies the waveform of the signal to be viewed.
- Horizontal Amplifier – The horizontal amplifier is fed with a saw-tooth voltage which is then applied to horizontal deflection plates.
- Sweep / Time Base Generator – It produces the saw-tooth voltage waveform, which is used for horizontal deflection of the electron beam.
- Trigger Circuit – The trigger circuit produces trigger pulses to start horizontal sweep.
- High & Low Voltage Supply –
    - Low Voltage (LV) Supply – It supplies the required operating voltages (of the order of few hundred volts) to the all circuits of the oscilloscope.
    - High Voltage (HV) Supply – It supplies the high voltages (of the order of few thousand volts) required by CRT, for acceleration as well as relatively low voltage for the heater of the electron gun, which emits the electrons.
- Delay Line – The purpose of the delay line is to delay the vertical signal enough to keep it from reaching the CRT deflection plates before the horizontal circuits are running. This line presents in the vertical amplifiers of high frequency oscilloscopes.

Oscilloscope Working Principle

The signal is to be viewed on the screen being applied across the Y-plates of CRT. To see the waveform of the input signal, it is essential to spread it horizontally from left to right, which is done by applying a saw-tooth voltage wave to X-plates. Under these conditions, the electron beam would move uniformly thereby graphing vertical vibrations of input signal with respect to time.



Due to repetitive tracing of the viewed waveform, a continuous display is obtained because of persistence of vision. To get a stable stationary display on the screen, the input signal across the Y-plates must be synchronised with the horizontal sweeping of the beam.

4.2 Basic principle & Block diagram of CRO, Dual Trace Oscilloscope & its specification

CRO

The cathode ray oscilloscope (CRO) is a type of electrical instrument which is used for showing the measurement and analysis of waveforms and others electronic and electrical phenomenon. It converts electrical signals to a visual display.
A general purpose oscilloscope consists of the following parts:

Cathode Ray Tube - It is the heart of the oscilloscope. When the electrons emitted by the electron gun strikes the phosphor screen, a visual signal is displayed on the CRT.

Vertical Amplifier - The input signals are amplified by the vertical amplifier. Usually, the vertical amplifier is a wide band amplifier which passes the entire band of frequencies.

Delay Line - As the name suggests, this circuit is used to delay the signal for a period of time in the vertical section of CRT. The input signal is not applied directly to the vertical plates because the part of the signal gets lost, when the delay time is not used. Therefore, the input signal is delayed by a period of time.

Time Base (Sweep) Generator - Time base circuit uses a uni-junction transistor, which is used to produce the sweep. The saw tooth voltage produced by the time base circuit is required to deflect the beam in the horizontal section. The spot is deflected by the saw tooth voltage at a constant time dependent rate.

Horizontal Amplifier - The saw tooth voltage produced by the time base circuit is amplified by the horizontal amplifier before it is applied to horizontal deflection plates.

Trigger Circuit - The signals which are used to activate the trigger circuit are converted to trigger pulses for the precision sweep operation whose amplitude is uniform. Hence input signal and the sweep frequency can be synchronized.

Power supply - The voltages required by CRT, horizontal amplifier, and vertical amplifier are provided by the power supply block. It is classified into two types -

Low Voltage (LV) Supply – It supplies the required operating voltages (of the order of few hundred volts) to the all circuits of the oscilloscope.
High Voltage (HV) Supply – It supplies the high voltages (of the order of few thousand volts) required by CRT, for acceleration as well as relatively low voltage for the heater of the electron gun, which emits the electrons.

Working Principle:

- The cathode ray is a beam of electrons which are emitted by the heated cathode (negative electrode) and accelerated toward the fluorescent screen. The assembly of the cathode, intensity grid, focus grid, and accelerating anode (positive electrode) is called an electron gun
- Its purpose is to generate the electron beam and control its intensity and focus. Between the electron gun and the fluorescent screen are two pair of metal plates - one oriented to provide horizontal deflection of the beam and one pair oriented to give vertical deflection to the beam. These plates are thus referred to as the horizontal and vertical deflection plates
- The combination of these two deflections allows the beam to reach any portion of the fluorescent screen. Wherever the electron beam hits the screen, the phosphor is excited and light is emitted from that point. This conversion of electron energy into light allows us to write with points or lines of light on an otherwise darkened screen

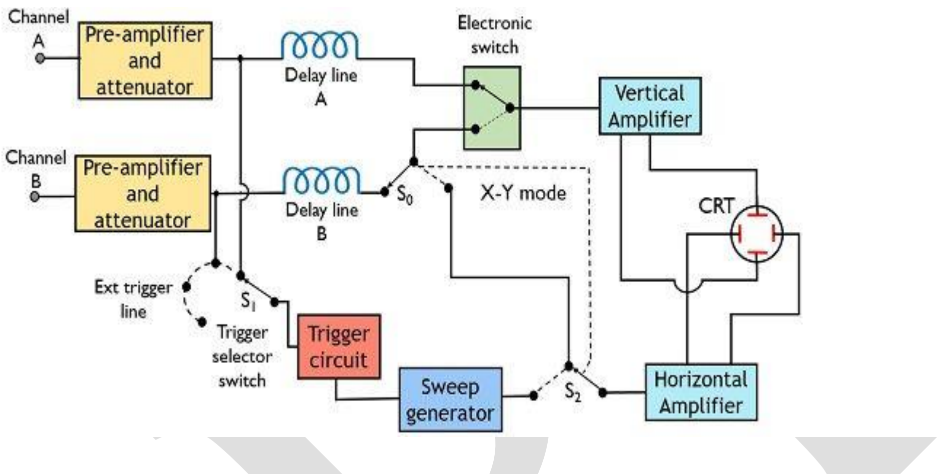
- The linear deflection or sweep of the beam horizontally is accomplished by use of a sweep generator that is incorporated in the oscilloscope circuitry.
- In the most common use of the oscilloscope, the signal to be studied is first amplified and then applied to the vertical (deflection) plates to deflect the beam vertically, and at the same time, a voltage that increases linearly with time is applied to the horizontal (deflection) plates, thus causing the beam to be deflected horizontally at a uniform rate
- The signal applied to the vertical plates is thus displayed on the screen as a function of time. The horizontal axis serves as a uniform time scale

Dual Trace Oscilloscope

In dual trace oscilloscope, a single electron beam generates 2 traces, that undergoes deflection by two independent sources. In order to produce two separate traces, basically, 2 methods are used, known as alternate and chopped mode.

Block diagram and Working of Dual Trace Oscilloscope

The figure below shows the block diagram of a dual trace oscilloscope**:**



- ➢ As we can see in the above figure that it has two individual vertical input channels namely A and B.
- ➢ Both the inputs are separately fed to the preamplifier and attenuator stage. The outputs of the two separate preamplifiers and attenuator stage are then provided to the electronic switch. This switch only passes a single channel input particularly at a time to the vertical amplifier.
- ➢ The circuit also has a trigger selector switch that permits the circuit triggering with either A or B channel input or with the externally applied signal.
- ➢ The signal from the horizontal amplifier is fed to the electronic switch by either sweep generator or channel B by switch S_0 and S_2.
- ➢ In this way, the vertical signal from channel A and horizontal signal from channel B is provided to the CRT for the operation of the oscilloscope.
- ➢ This is the X-Y mode of the oscilloscope and permits accurate X-Y measurements.
- ➢ Basically, the modes of operation of the oscilloscope rely on the choice of front panel controls. Like either the trace of channel A is needed, channel B is needed or separately trace of channel A or B is required.

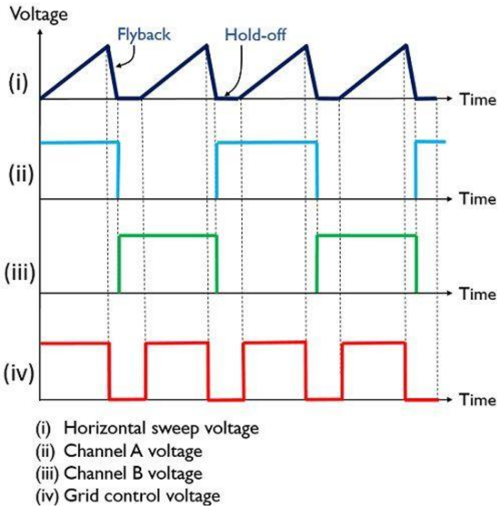
As we have already discussed that there exist two modes of operation of dual trace oscilloscope.

Alternate mode of Dual Trace Oscilloscope

- ➢ Whenever the alternate mode is activate, then it permits the connection between both the channels alternately. This alternation or switching between the channels A and B takes place at the beginning of each upcoming sweep.

- Also, there exists synchronization between the switching rate and the sweep rate. This leads to the spotting of traces of each channel on one sweep. In this way, the alternate connection of the two-channel input with the vertical amplifier is performed.
- Hence a complete sweep signal from one vertical channel will be displayed at the screen. While for the next sweep, the signal from another vertical channel will be displayed.

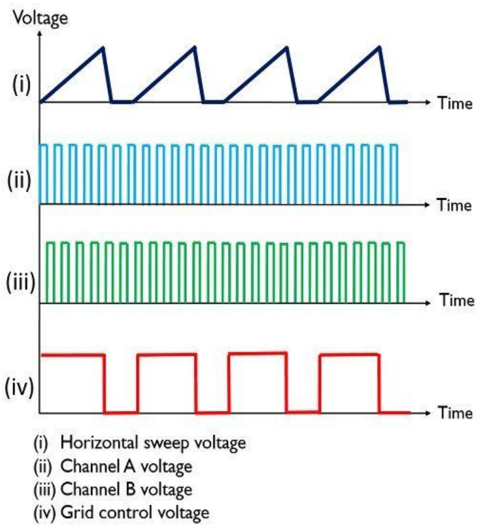
The figure below represents the waveform the oscilloscope output operating in alternate mode:



Chopped mode of Dual Trace Oscilloscope

- In this mode of operation during a single sweep, several times switching between the two channels occurs. And this switching is so quick that even for the very small segment the display is available at the screen.
- When the chopping rate is faster than the rate of horizontal sweep, then the separately chopped segments will be merged and recombine to form originally applied channel A and B waveform at the screen of CRT.

The figure below shows the waveform representation in case of chopped mode:



4.3 CRO Measurements, Lissajous figures

Lissajous figure is the pattern which is displayed on the screen, when sinusoidal signals are applied to both horizontal & vertical deflection plates of CRO. These patterns will vary based on the amplitudes, frequencies and phase differences of the sinusoidal signals, which are applied to both horizontal & vertical deflection plates of CRO.

The two sinusoidal curved axes are perpendicular to each other or maintained at right angles to each other.

The Lissajous figure's uses mainly consists of

- 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

Suppose f_H and f_V are the frequencies of sinusoidal signals, which are implemented to the horizontal and vertical deflection plates of CRO, respectively. The relationship between known and unknown frequencies, i.e., f_H and f_V can be mathematically expressed as below:

$$\Rightarrow \frac{fV}{fH} = \frac{nH}{nV}$$

From the above equation, the frequency of sinusoidal signal applied to the vertical deflection plates of CRO can be drawn which is given below:

$$\Rightarrow f_V = \frac{nH}{nV} f_H \ldots(1)$$

where, n_H is the number of horizontal squares

n_V is the number of vertical squares

The values of n_H and n_V also can be obtained from the Lissajous figure. Now, if we substitute the value of n_H and n_V in equation (1), we can determine the unknown frequency of sinusoidal signal 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 resulted in a straight line that is inclined at an angle of 45° with the positive x-axis of the CRO display, then the phase difference between the two sinusoidal signals used will be 0°. This implies that no phase difference is present between those two sinusoidal signals used.
- If the Lissajous figure resulted in a straight line that is inclined at an angle of 135° with the positive x-axis of the CRO display, then the phase difference between the two sinusoidal signals used will be around 180°. This implies that the sinusoidal signals used are out of phase.
- If the Lissajous figure resulted in a circular shape, then the phase difference between the two sinusoidal signals used will be either 90° or 270°.

We can estimate the phase difference between the two sinusoidal signals (Lissajous figures phase difference) by applying formulae when the constructed Lissajous figures are of elliptical shape, i.e., Lissajous ellipse.

- If the major axis of an elliptical Lissajous figure is inclined at angles between 0° and 90° with the positive x-axis of the CRO display screen, then the phase difference between the two sinusoidal signals can be determined using the following equation:

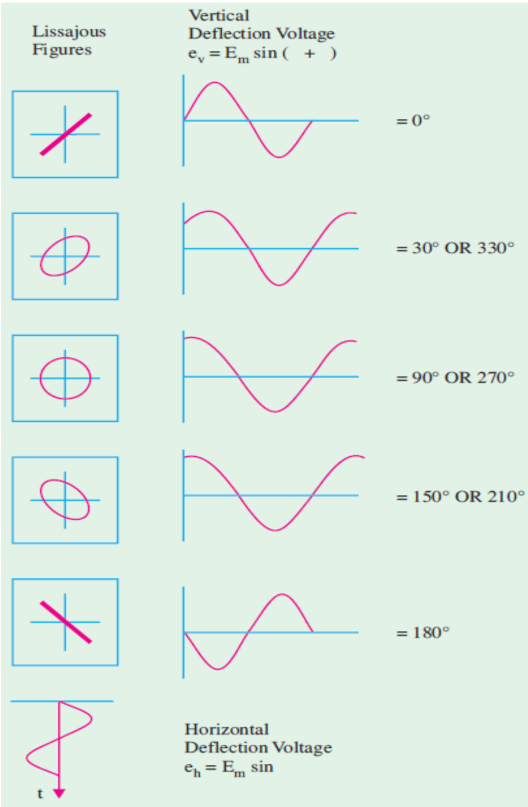
$$\Rightarrow \phi = \sin^{-1}\left(\frac{x1}{x2}\right) = \sin^{-1}\left(\frac{y1}{y2}\right)$$

- If the major axis of an elliptical Lissajous figure is inclined at angles between 90° and 180° with the positive x-axis of the CRO screen, then the phase difference between the two sinusoidal signals can be calculated using the following equation:

$$\Rightarrow \phi = 180 - \sin^{-1}\left(\frac{x1}{x2}\right) = 180 - \sin^{-1}\left(\frac{y1}{y2}\right)$$

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



4.4 Applications of Oscilloscope (Voltage, period & frequency measurement)

Measurements by using CRO

The following measurements are done by using CRO.

- Measurement of Amplitude
- Measurement of Time Period
- Measurement of Frequency

Measurement of Amplitude

CRO displays the voltage signal as a function of time on its screen. The amplitude of that voltage signal is constant, but we can vary the number of divisions that cover the voltage signal in vertical direction by varying volt/division knob on the CRO panel. Therefore, we will get the amplitude of the signal, which is present on the screen of CRO by using following formula.

$A = j \times n_v$

Where,

A is the amplitude
j is the value of volt/division
n_v is the number of divisions that cover the signal in vertical direction.

Measurement of Time Period

CRO displays the voltage signal as a function of time on its screen. The Time period of that periodic voltage signal is constant, but we can vary the number of divisions that cover one complete cycle of voltage signal in horizontal direction by varying time/division knob on the CRO panel.

Therefore, we will get the Time period of the signal, which is present on the screen of CRO by using following formula.

$T = k \times n_h$

Where,

T is the Time period
j is the value of time/division
n_h is the number of divisions that cover one complete cycle of the periodic signal in horizontal direction.

Measurement of Frequency

The frequency, f of a periodic signal is the reciprocal of time period, T. Mathematically, it can be represented as

$f = \frac{1}{T}$

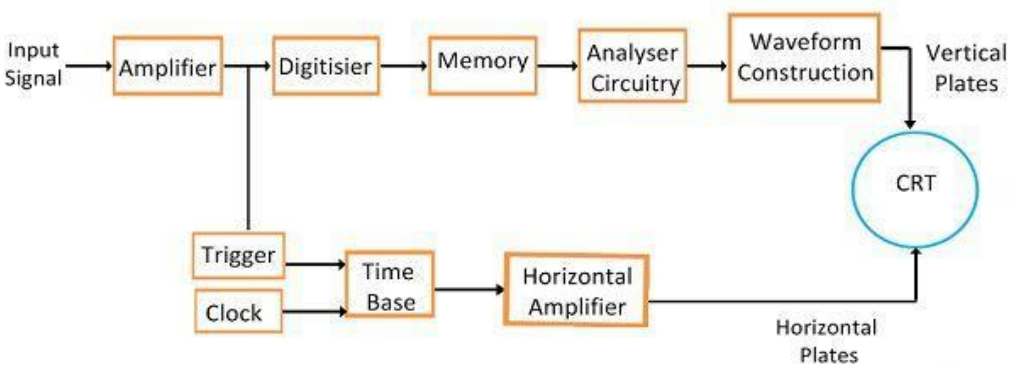
So, we can find the frequency, f of a periodic signal by following these two steps.

- Step1 − Find the Time period of periodic signal
- Step2 − Take reciprocal of Time period of periodic signal, which is obtained in Step1

4.5 Operation of Digital Storage Oscilloscope& High frequency Oscilloscope

It is an electronic device that stores and analyses the signal in the digital format is known as Digital Storage Oscilloscope (DSO). When the input signal is given to the DSO, then it is processed, stored in the memory, and displayed on the screen. It stores the signal in the form of digital data as either 1 or 0.

Block Diagram of Digital Storage Oscilloscope



- At first the analog input signal is amplified by amplifier if it has any weak signal. After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory.

- The analyzer circuit process the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).
- The cathode ray tube has two inputs they are vertical input and horizontal input. The vertical input signal is the 'Y' axis and the horizontal input signal is the 'X' axis.
- The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal. Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate. On the CRT screen, we will get the waveform of the input signal versus time.
- The digitizing occurs by taking a sample of the input waveform at periodic intervals. The process of digitizing or sampling should follow the sampling theorem. The sampling theorem says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal.
- When the analog signal is properly converted into digital then the resolution of the A/D converter will be decreased. When the input signals stored in analog store registers can be read out at a much slower rate by the A/D converter, then the digital output of the A/D converter stored in the digital store, and it allows operation up to 100 mega samples per second.
  This is the working principle of a digital storage oscilloscope.
- The digital storage oscilloscope works in three modes of operations they are roll mode, store mode, and hold or save mode.

i. **Roll Mode:** In roll mode, very fast varying signals are displayed on the display screen.
ii. **Store Mode:** In the store mode the signals stores in memory.
iii. **Hold or Save Mode:** In hold or save mode, some part of the signal will hold for some time and then they will be stored in memory.

UNIT-5: BRIDGES

When 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.

5.1 Types of Bridges (DC& AC Bridges)

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

- DC Bridges
- AC Bridges

The two types of D.C bridges

1. Wheatstone Bridge
2. Kelvin Bridge

The various types of A.C Bridges are,

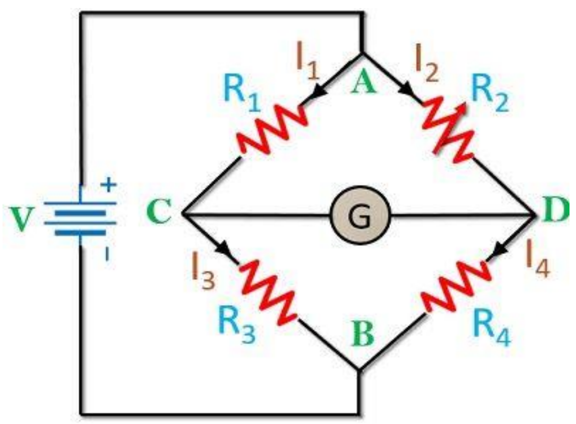
1. Maxwell's Bridge
2. Hay's Bridge
3. Schering Bridge
4. **De Sauty's bridge**
5. Wien Bridge

5.2 DC Bridges (Measurement of Resistance by Wheatstone's Bridge)

- Wheatstone bridge is a type of dc bridge that is used for the measurement of unknown resistance. It is a series-parallel combination of 4 resistances that provides zero difference voltage at the balanced condition. The principle of null indication is the basis of working of Wheatstone bridge and thus provides high accuracy in measurements.
- It consists of four resistances, out of which 2 are known resistances, one is variable resistance that is used to balance the bridge and another one is unknown resistance whose value is to be measured.
- Under the balanced condition, the ratio of the values of two known resistances becomes equivalent to the ratio of the variable resistance and the unknown resistance value. Thus, allows us to calculate the unknown value of the resistance employed in the electrical circuit.

Circuit construction and theory of Wheatstone bridge

It consists of 4 arms namely AC, AD, BC and BD each containing resistance R_1, R_2, R_3 and R_4. Here, R_2 is the variable resistance and R_4 is the unknown resistance.



- A galvanometer is placed at one arm which detects the flow of current through the circuit on providing the supply voltage at another arm of the circuit.
- In the absence of any current through the galvanometer, the bridge gets balanced. In other words, the bridge gets balanced when the voltage difference between the two points C and D are equal. Thus, providing 0 voltage across the galvanometer.

In order to determine the bridge balance equation,

$I_1R_1 = I_2R_2$

The following condition must be fulfilled in order to have null current through the galvanometer.

$$I_1 = I_3 = \frac{V}{R_1 + R_3}$$

$$I_2 = I_4 = \frac{V}{R_2 + R_4}$$

On substituting the above value in previously defined equation

$$\frac{V\,X\,R_1}{R_1+R_3} = \frac{V\,X\,R_2}{R_2+R_4}$$

$$R_1X\,(R_2 + R_4) = R_2X\,(R_1 + R_3)$$

$$R_1R_2 + R_1R_4 = R_2R_1 + R_2R_3$$

Thus, on cancelling like terms from both the sides, we will have,

$$R_4 = \frac{R_2R_3}{R_1}$$

Hence, we can determine the value of unknown resistance in balanced condition using known resistances.

Applications of Wheatstone bridge

- It is used to measure dc resistance.
- Wheatstone bridge is widely used in cable faults identification by telephone companies.
- It can measure physical quantities like light, temperature etc when used with an op-amp.

Limitations of Wheatstone Bridge

- Wheatstone bridge is a very sensitive device. The measurements may not be precise in an off-balance condition.
- Wheatstone bridge is generally used for measuring resistances ranging from a few ohms to a few kilo-ohms.

5.3 AC bridges (Measurement of inductance by Maxwell's Bridge & by Hay's Bridge)

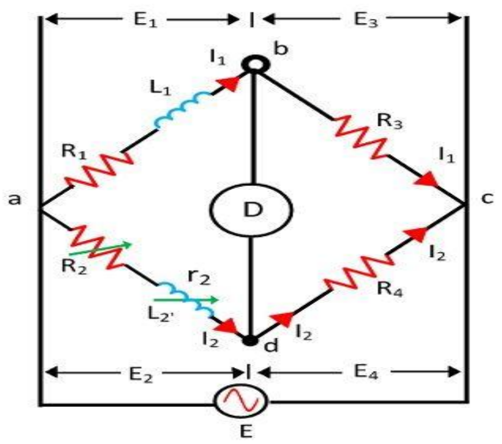
Maxwell's Bridge

The **bridge** used for the **measurement** of **self-inductance** of the **circuit** is known as the Maxwell bridge. It is the advanced form of the Wheatstone bridge. The Maxwell bridge **works** on the **principle** of the **comparison**, i.e., the value of **unknown inductance** is determined by **comparing** it with the known value or standard value.

Two methods are used for determining the self-inductance of the circuit. They are

1. Maxwell's Inductance Bridge
2. Maxwell's inductance Capacitance Bridge

In Maxwell's inductance bridge the unknown self-inductance to be measured is compared with the known inductance. Hence the unknown self-inductance and internal resistor of an inductor can be measured with Maxwell's inductance bridge. The circuit diagram is shown in the below figure.



Let,

L_1 = Unknown inductance to be measured
R_1 = Resistance of the Unknown inductance
R_3, & R_4 = Standard non-inductive resistances
R_2 = Standard Variable resistance
L_2 = Standard Variable inductance with fixed resistance r_2.
From the above figure, the impedances of the respective arms are given as,

$$Z_1 = (R_1 + j\omega L_1)$$

$$Z_2 = (R_2 + r_2 + j\omega L_2)$$

$$Z_3 = R_3$$

$$Z_4 = R_4$$

Under balanced condition (i.e., when detector shows null deflection), we have,

$$Z_1 Z_4 = Z_2 Z_3$$

$$(R_1 + j\omega L_1) \times R_4 = (R_2 + r_2 + j\omega L_2) \times R_3$$

$$R_1R_4 - R_2R_3 - r_2R_3 + j\omega(L_1R_4 - L_2R_3) = 0$$

On equating the real and imaginary parts on both sides, we get,

$$R_1R_4 - R_2R_3 - r_2R_3 = 0$$

$$R_1R_4 = R_2R_3 + r_2R_3$$

$$R_1 = \frac{R_3}{R_4}(R_2 + r_2)$$

$$Also,\ L_1R_4 - L_2R_3 = 0$$

$$L_1R_4 = L_2R_3$$

$$L_1 = L_2 \times \frac{R_3}{R_4}$$

Hence, the unknown self-inductance and resistance of the inductor are obtained in terms of known standard values. Also, both the equations are independent of frequency term.

Advantages of the Maxwell's Bridges

1. The balance equation of the circuit is free from frequency.
2. Both the balance equations are independent of each other.
3. The Maxwell's inductor capacitance bridge is used for the measurement of the high range inductance.

Disadvantages of the Maxwell's Bridge

1. The Maxwell inductor capacitance bridge requires a variable capacitor which is very expensive. Thus, sometimes the standard variable capacitor is used in the bridges.
2. The bridge is only used for the measurement of medium quality coils.

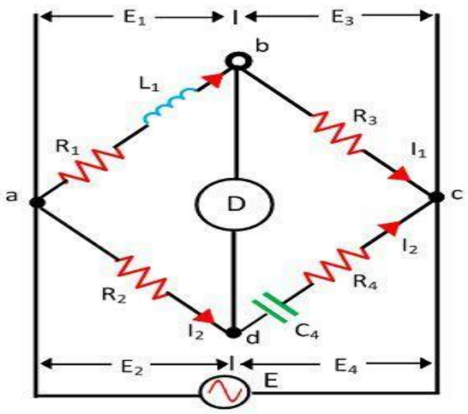
Hay's Bridge

The **Hay's bridge** is used for **determining** the **self-inductance** of the **circuit**. The bridge is the **advanced form** of **Maxwell's bridge**. The Maxwell's bridge is only appropriate for measuring the medium quality factor. Hence, for **measuring** the **high-quality factor** the **Hays bridge** is used in the circuit.

In **Hay's bridge**, the **capacitor** is **connected** in **series** with the **resistance**, the voltage drop across the capacitance and resistance are varied. Thus, the magnitude of a voltage pass through the resistance and capacitor is equal.

Construction of Hay's Bridge

The unknown inductor L_1 is placed in the arm **ab** along with the resistance R_1**.** This unknown inductor is compared with the standard capacitor C_4 connected across the arm **cd**. The resistance R_4 is connected in series with the capacitor C_4. The other two non-inductive resistor R_2 and R_3 are connected in the arm **ad** and **bc** respectively.



The C_4 and R_4 are adjusted for making the bridge in the balanced condition. When the bridge is in a balanced condition, no current flows through the detector which is connected to point **b** and **c** respectively. The potential drops across the arm **ad** and **cd** are equal and similarly, the potential across the arm **ab** and **bc** are equal.

Hay's Bridge Theory

Let,
L_1 – unknown inductance having a resistance R_1
R_2, R_3, R_4 – known non-inductive resistance.
C_4 – standard capacitor

Here
$Z_1=R_1+j\omega L_1$
$Z_2=R_2$
$Z_3=R_3$
$Z_4=R_4-j/\omega C_4$

At balance condition,

$Z_1Z_4=Z_2Z_3$

$$(R_1 + j\omega L_1)(R_4 - j/\omega C_4) = R_2R_3$$

$$R_1R_4 + \frac{L_1}{C_4} + j\omega L_1R_4 - \frac{jR_1}{\omega C_4} = R_2R_3$$

Separating the real and imaginary term, we obtain

$$R_1R_4 + \frac{L_1}{C_4} = R_2R_3 \quad and\ L_1 = \frac{-\ R_1}{\omega^2 R_4C_4}$$

Solving the above equation, we have

$$L_1 = \frac{R_2R_3C_4}{1 + \omega^2R_4^2C_4^2}$$

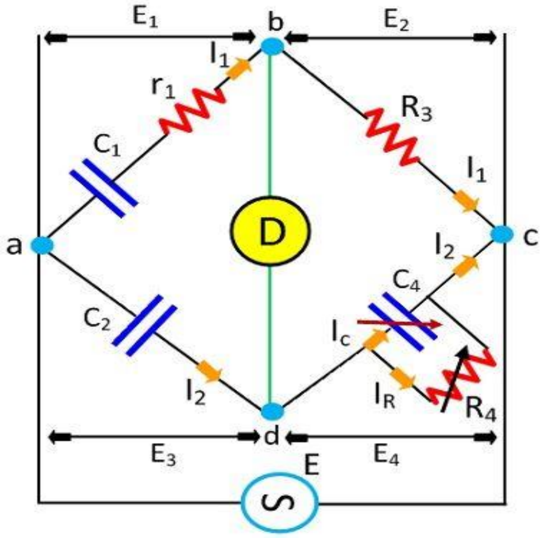
$$R_1 = \frac{\omega^2C_4^2R_2R_3R_4}{1 + \omega^2R_4^2C_4^2}$$

5.3 Measurement of capacitance by Schering's Bridge & DeSauty Bridge.

Schering Bridge

The Schering bridge use for measuring the capacitance of the capacitor, dissipation factor, properties of an insulator. It is one of the most commonly used AC bridge. The Schering bridge works on the principle of balancing the load on its arm.

Let, C_1 – capacitor whose capacitance is to be determined,
r_1 – a series resistance, representing the loss of the capacitor C_1.
C_2 – a standard capacitor (The term standard capacitor means the capacitor is free from loss)
R_3 – a non-inductive resistance
C_4 – a variable capacitor.
R_4 – a variable non-inductive resistance parallel with variable capacitor C_4.



When the bridge is in the balanced condition, zero current passes through the detector, which shows that the potential across the detector is zero.

Here

$Z_1=r_1+1/j\omega C_1$

$Z_2=1/j\omega C_2$

$Z_3=R_3$

$Z_4=R_4 || 1/j\omega C_4$

At balance condition
$Z_1Z_4 = Z_2Z_3$

$$\left(r_1+\frac{1}{jwC_1}\right)\left(\frac{R_4}{1+j\omega C_4R_4}\right)=\frac{1}{j\omega C_2}.R_3$$

$$\left(r_1+\frac{1}{jwC_1}\right)R_4=\frac{R_3}{jwC_2}(1+j\omega C_4R_4)$$

So, $$r_1R_4-\frac{jR_4}{\omega C_1}=-j\frac{R_3}{\omega C_1}+\frac{R_3R_4C_4}{C_2}$$

Equating the real and imaginary parts, we get the equation (1) and (2) are the balanced equation, and it is free from the frequency.

$$r_1=\frac{R_3C_4}{C_2}\dots\dots\dots.equ(1)$$

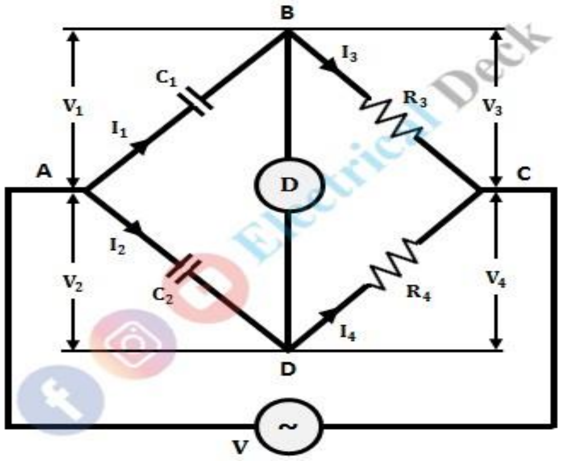
$$C_1=C_2\left({R_4}/{R_3}\right)\dots\dots\dots equ(2)$$

Desauty's Bridge

Desauty's bridge is the simplest AC bridge circuit used for the measurement of unknown capacitance. The bridge gives a fair degree of accuracy for measuring capacitance over a wide range. It can be also used for comparing two capacitance.

Construction & Theory of Desauty's Bridge :

The bridge consists of four branches or arms. Two capacitors C_1 and C_2 are placed in branches AB and AD respectively. The branches BC and CD consist of resistors R_3 and R_4 respectively. An AC source is connected between terminals A and C. The circuit diagram of the bridge is shown in the below figure.



A null indicator is connected across terminals B and D, which indicates null deflection when the bridge is balanced.

Let,
C_1 = Unknown capacitance
C_2 = Known standard capacitance
R_3 = Known standard non-inductive resistance
R_4 = Known standard non-inductive resistance.
From the above figure, the impedances in each arm is given as,

$$Z_1 = \frac{1}{j\omega C_1}$$

$$Z_2 = \frac{1}{j\omega C_2}$$

$$Z_3 = R_3$$

$$Z_4 = R_4$$

When the bridge is balanced, we have,

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(\frac{1}{j\omega C_1}\right) \times R_4 = \left(\frac{1}{j\omega C_2}\right) \times R_3$$

$$\frac{R_4}{C_1} = \frac{R_3}{C_2}$$

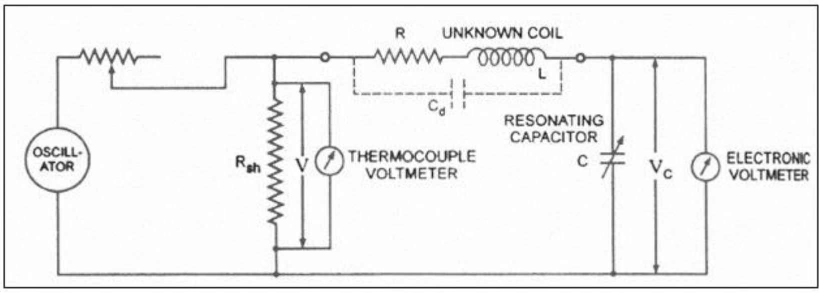
$$C_1 = \frac{R_4}{R_3} \times C_2$$

It is the easiest method for the measurement of capacitance as it has a simple circuit and only one variable element. In order to bring the bridge into a balanced condition, either R_3 or R_4 can be chosen as a variable element.

5.5 Working principle of Q meter its circuit diagram & measurement of Low impedance
5.6 Measurement of frequency

The quality factor or Q-factor of a resonant circuit is a measure of the "goodness" or quality of a resonant circuit. A higher value for this figure of merit corresponds to a narrower bandwidth, which is desirable in many applications. More formally, Q is the ratio of power stored to power dissipated in the circuit reactance and resistance.

A practical application of "Q" is that voltage across L or C in a series resonant circuit is Q times total applied voltage. In a parallel resonant circuit, current through L or C is Q times the total applied current.



- The Q-meter is an instrument designed for the measurement of Q-factor of the coil as well as for the measurement of electrical properties of coils and capacitors.
- This instrument operates on the principle of series resonance i.e. at resonate condition of an AC series circuit voltage across the capacitor is equal to the applied voltage times of Q of the circuit. If the voltage applied across the circuit is kept constant, then voltmeter connected across the capacitor can be calibrated to indicate Q directly.

- Circuit diagram of a Q-meter is shown is figure. A wide-range oscillator with frequency range from 50 kHz to 50 MHz is used as a power supply to the circuit.
- The output of the oscillator is shorted by a low-value resistance, Rsh usually of the order of 0.02 ohm. So it introduces almost no resistance into the oscillatory circuit and represents a voltage source with a very small or of almost negligible internal resistance.
- The voltage across the low-value shunt resistance Rsh, V is measured by a thermo-couple meter and the voltage across the capacitor, Vc is measured by an electronic voltmeter.
- For carrying out the measurement, the unknown coil is connected to the test terminals of the instrument, and the circuit is tuned to resonance either by varying the frequency of the oscillator or by varying the resonating capacitor C.
- Readings of voltages across capacitor C and shunt resistance Rsh are obtained and Q-factor of the coil is determined as follows:
  By definition Q-factor of the coil,

  $Q=X_L/R$
  And when the circuit is under resonance condition
  $X_L=X_C$
  And the voltage applied to the circuit
  $V=IR$
  So $Q=X_L/R=(IX_L)/R=V_C/V$
  The inductance of the coil can also be computed from the known values of frequency f and resonating capacitor C as follows.

  At resonance,

  $X_L=X_C$ OR $2\pi FL=1/2\pi FC$ OR $L=1/(2\pi F)2$
- In the circuit, the energy of the oscillator can be supplied to the tank circuit. This circuit can be adjusted for the resonance through unstable 'C' until the voltmeter reads the utmost value.
- This circuit is adjusted to resonance through changing either the oscillator frequency otherwise the capacitance. Once the capacitance is changed, then the frequency of the oscillator can be adjusted to a specified frequency & resonance is attained.
- If the value of capacitance is already fixed to a preferred value, then the frequency of the oscillator will be changed until resonance takes place.
- The reading of 'Q' on the o/p meter is multiplied through the setting of an index to get the actual 'Q' value. The coil's inductance is calculated from known values of the coil frequency as well as the resonating capacitor.
- The specified Q is not the definite Q, as the losses of the voltmeter, inserted resistance & resonating capacitor are all incorporated in the circuit. Here, the definite 'Q' of the calculated coil is a bit larger than the specified Q. This dissimilarity is insignificant except wherever the coil's resistance is relatively minute compared to the 'Rsh' resistance.

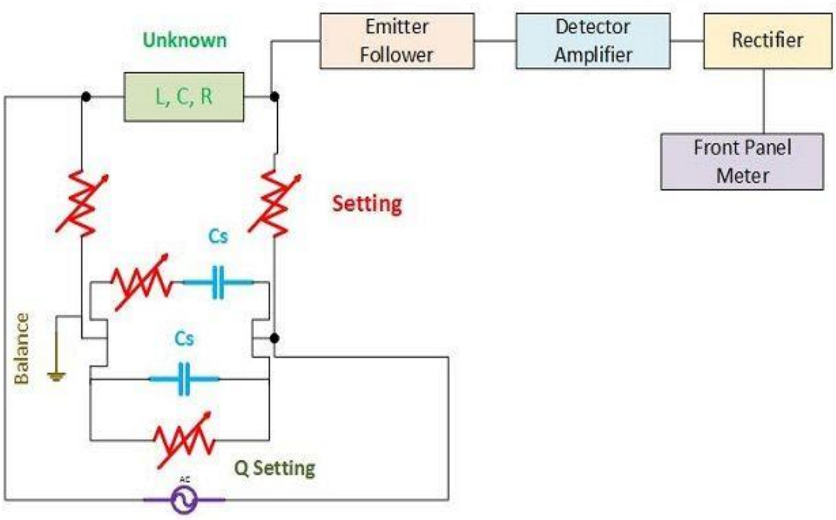
Applications of the Q-meter

- It is used to measure the quality factor of the inductor.
- By using this meter, unknown impedance can be measured using a series or shunt substitution method. If the impedance is small, the former technique is used and if it is large, then the latter technique is used.
- It is used to measure small capacitor values.
- By using this, inductance, effective resistance, self-capacitance, and bandwidth can be measured.

5.7 LCR Meter & its measurements

- LCR meters can be understood as a multimeter, this is because it can measure resistance, inductance, capacitance as per the requirement. Thus, it is termed as LCR meter. L in its name signifies inductance, C stands for capacitance and R denotes resistance.

- The significant component of LCR meter is the Wheatstone bridge and RC ratio arm circuits. The component whose value is to be measured is connected in one of the arms of the bridge.
- For example, if the value of resistance is to be measured, then Wheatstone bridge comes into picture while the value of inductance and capacitance can be measured by comparing it with standard capacitor present in RC ratio arm circuit.



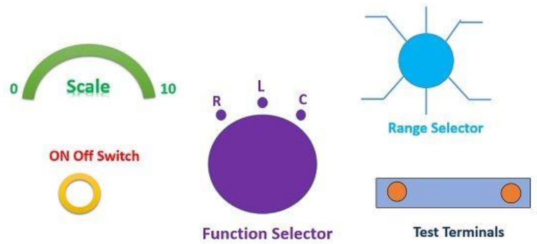
The above block diagram clearly defines the connection diagram of the LCR meter. The measurement of DC quantities will be done by exciting the bridge with DC voltage. On the contrary, the AC measurements require excitation of the Wheatstone bridge with AC signal.

Working of LCR Meter

- The bridge is adjusted in null position in order to balance it completely. Besides, the sensitivity of the meter should also be adjusted along with balancing of the bridge. The output from the bridge is fed to emitter follower circuit. The output from emitter follower circuit is given as an input to detector amplifier.
- The significance of detector amplifier can be understood by the fact that if the measuring signal is low in magnitude, it will not be able to move the indicator of PMMC meter. Thus, in order to achieve the sustainable indication, we need to have a high magnitude measuring signal.
- But it is often observed that while dealing with the measurement process, the magnitude of the measuring signal falls down due to attenuation factor. The problem to this solution is to utilize an amplifier.
- The rectifier is used in the circuit to convert the AC signal into DC signal. When the bridge is provided with AC excitation then at the output end of the bridge the AC signal needs transformation into DC signal.

Front Panel of LCR meter

The component which is to be measured is placed across the test terminals of LCR meter, after which according to the type of component the measurement is performed. To understand the procedure of measurement by LCR meter, the functional controls on front panel needs to be understood.



1. ON/OFF Switch: The ON/OFF switch can be used to turn on or off LCR meter. When the switch is positioned to ON state, the main supply is connected with LCR meter. After this, it is crucial to leave the meter for 15 minutes so that it can warm up. The indicator on the front panel will start glowing to indicate that the LCR meter is ON.
2. Test Terminals: The two points on the front panel are test terminals. The component which is to be measured is connected to this test terminals.
3. Function Selector: The function selector is used for setting the meter in the mode in order to measure the particular type of the component. If resistance is to be measured, then the function selector is to be set at R mode, if inductance is to be measured it is to be adjusted to L mode and similarly in case of capacitance it is to be adjusted at C mode.
4. Range Selector: The range selector provides an extent of measuring range so that component of high magnitude or low magnitude values can be measured easily. The range selector should be adjusted properly in order to have correct measurement. For example: if a resistor of 10 mega ohms is under measurement and the range selector is in the range of ohms, then it will not show reliable and accurate results.

The range of instrument can be increased by using multipliers in the circuit. The multipliers should consist of higher precision resistors made up of the metal film. In addition to this, it should possess high-temperature stability.

5. Scale: The scale calibrated on the LCR meter will show the final values of the measurement. The indicator will move across the calibrated scale to show the measured value.

UNIT-6: TRANSDUCERS & SENSORS

A transducer is an electronic device that converts energy from one form to another. The process of converting energy from one form to another is known as transduction.

Some common examples of transducers include loudspeakers, microphones, thermometers and LEDs.

A transducer consists of the following two important parts:

- Sensing element
- Transduction element

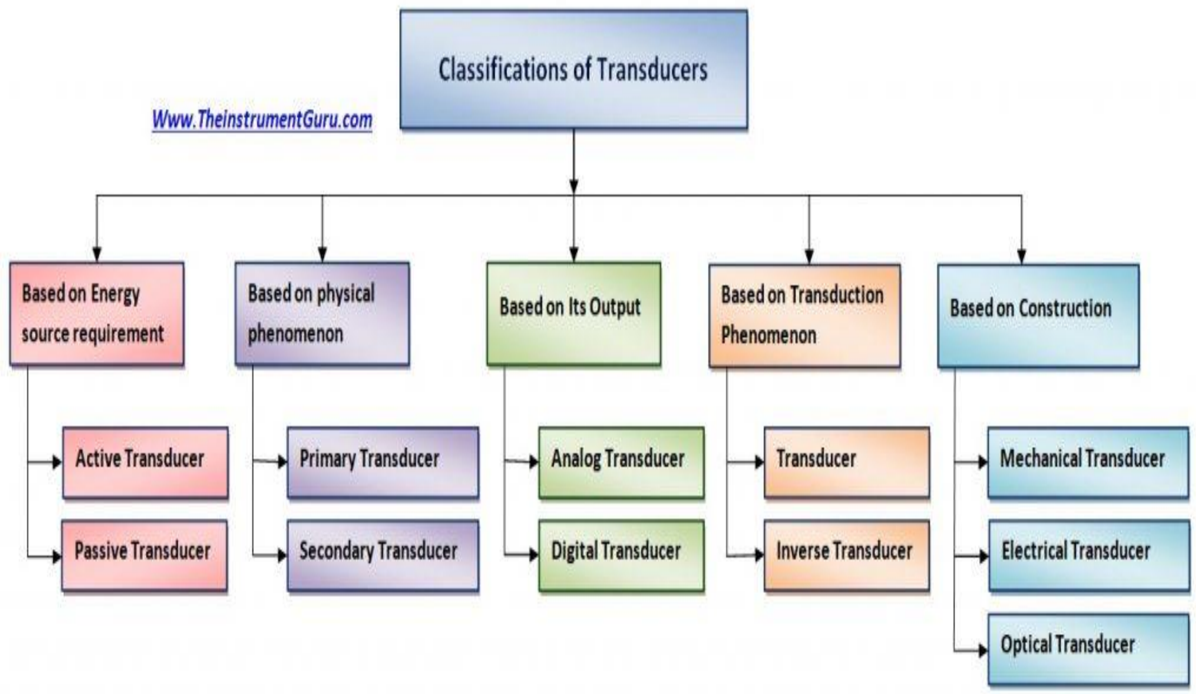
Transducers have other vital parts such as signal processing equipment, amplifiers and power supplies.

Sensing Element

It is the part of a transducer that responds to the physical sensation. The response of the sensing element depends on the physical phenomenon.

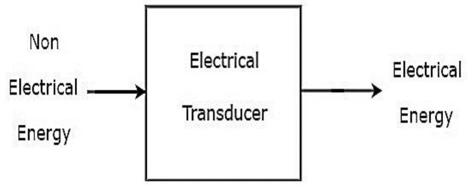
Transduction Element

The transduction element of the transducer converts the output of the sensing element into an electrical signal. The transduction element is also called the secondary transducer.



Electrical transducer

The transducer, which converts non-electrical form of energy into electrical form of energy is known as electrical transducer.



As shown in the figure, electrical transducer will produce an output, which has electrical energy. The output of electrical transducer is equivalent to the input, which has non-electrical energy.

Resistive Transducer

The resistive transducer converts the physical quantities into variable resistance which is easily measured by the meters.

The resistive transducer element works on the principle that the resistance of the element is directly proportional to the length of the conductor and inversely proportional to the area of the conductor.

$$R = \rho L/A$$

Where R – resistance in ohms.
A – cross-section area of the conductor in meter square.
L – Length of the conductor in meter square.
ρ – the resistivity of the conductor in materials in ohm meter.
The resistive transducer is designed by considering the variation of the length, area and resistivity of the metal.
Examples

- **Potentiometer**: The resistance is varied with the variation in their length and hence is used for measurement of displacement
- **Strain gauge**: Resistance is changed when applying strain and this property is used for measuring pressure, force etc.
- **Thermistors** (Resistance thermometers): Resistance changes with change in temperature and is used as thermometers.

6.1 Parameter, method of Selecting & advantage of Electrical Transducer & Resistive Transducer

Parameters of a Transducer

1. **Ruggedness:** Transducers have overload withstanding ability and comes with safety stops for protecting from overloads.
2. **Linearity:** The output of the transducer should be linearly proportional to the input quantity under measurement. It should have linear input - output characteristic.
3. **Repeatability:** Transducer has the ability to reproduce the same output signal for the same input physical quantity measured repeatedly that is being measured under same environmental situations.
4. **Dynamic Response:** Transducer exhibits good dynamic response with output changing with the input as a function of time.
5. **High stability and reliability:** The output of the transducer should be highly stable and reliable so that there will be minimum error in measurement. The output must remain unaffected by environmental conditions such as change in temperature, pressure, etc.

Transducer Selection Factors

1. Operating Principle: Transducers are selected for different applications depending on the operating principle involved in it. These principles may be inductive, resistive, piezo-electric, capacitive, resistive etc.
2. Range of Operation: Range requirement is maintained by the transducer and over the entire range it should possess good resolution.
3. Sensitivity and Cross-sensitivity: To generate a detectable output transducer should possess enough sensitivity. In case of measuring mechanical quantities cross-sensitivity need to be taken into account. This comes into scene when quantity to be measured is in one plane and transducer is in another plane subjected to variations.
4. Accuracy and Errors: Transducer assures high accuracy and maintains an input-output relationship as expected from the transfer function thereby avoiding errors.
5. Loading Effects: High input impedance and lower output impedance avoids loading effects in transducers.
6. Compatibility: Transducer working under specific environmental situations are assured of reliable input-output relationship and must be break-down free.
7. Behavior towards unwanted signals: Transducers have minimum sensitivity towards unwanted signals and maximum sensitivity towards desired signals.

6.2 Working principle of Strain Gauges, define Strain Gauge (No mathematical Derivation)

- A strain gauge is a passive transducer, that converts mechanical displacement into the change of resistance.
- When an external force is applied on an object, due to which there is a deformation occurs in the shape of the object. This deformation in the shape is both compressive or tensile is called strain, and it is measured by the strain gauge.
- When an object deforms within the limit of elasticity, either it becomes narrower and longer or it become shorter and broadens. As a result of it, there is a change in resistance end-to-end.

Strain Gauge Working Principle

- The foil type strain gauges (Figure #1) are very common in which a resistive foil is mounted on a backing material. These are available in a variety of shapes and sizes for different applications.
- The resistance of the foil changes as the material to which the gauge is attached undergoes tension or compression due to change in its length and diameter.
- This change in resistance is proportional to the applied strain. As this change in resistance is very small in magnitude so its effect can be only sensed by a Wheatstone bridge. This is the basic *strain gauge working principle*.

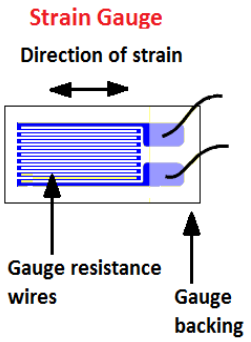


Figure #1

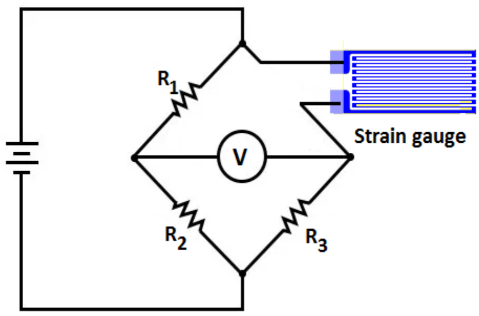


Figure #2

- In circuit diagram 2, a strain gauge is connected into a Wheatstone bridge. This circuit is so designed that when no force is applied to the strain gauge, R_1 is equal to R_2 and the resistance of the strain gauge is equal to R_3. In this condition the Wheatstone bridge is balanced and the voltmeter shows no deflection.
- But when strain is applied to the strain gauge, the resistance of the strain gauge sensor changes, the Wheatstone bridge becomes unbalanced, a current flow through the voltmeter. Since the net change in the resistance is proportional to the applied strain, therefore, resultant current flow through the voltmeter is proportional to the applied strain. So, the voltmeter can be calibrated in terms of strain or force.
- In the above circuit, only one strain gauge used. This is known as 'quarter bridge' circuit. It can also use two strain gauges or even four strain gauges in this circuit. Then this circuit is called 'half bridge' and 'full bridge' respectively. The full bridge circuit provides greater sensitivity and least temperature variation errors.

6.3 Working principle of LVDT

LVDT

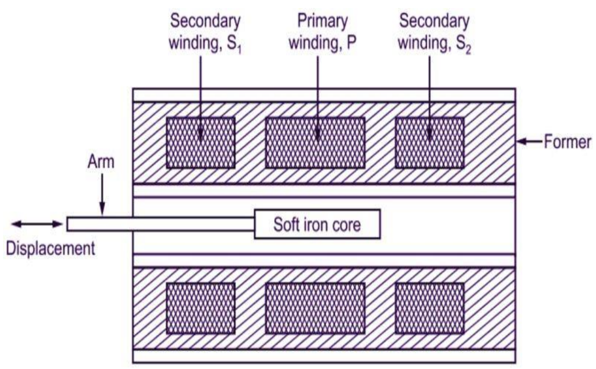
An LVDT is also known as Linear Voltage Differential Transformer is a passive transducer which translates the linear motion into an electrical signal.

OR

Linear Variable Differential Transformer (LVDT) is an Electromechanical type Inductive Transducer that converts rectilinear displacement into the AC Electrical Signal. Since LVDT is a secondary transducer, hence physical quantities such as Force, Weight, Tension, Pressure, etc are first converted into displacement by a primary transducer and then LVDT is used to measure it in terms of the corresponding Electrical signal.

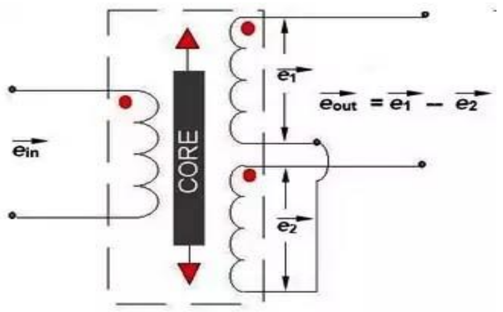
CONSTRUCTION

- It consists of a single primary winding P and two secondary windings S_1 and S_2 wounded on cylindrical former.
- A movable soft iron core is placed inside the former.
- The displacement to be measured is applied to an arm connected to the core.
- The assembly is placed in a stainless steel housing and the end lids provide electrostatic and electromagnetic shielding.
- Both the secondary windings have the equal number of turns and are wound on both sides of the primary winding exactly alike. These windings are connected in series opposition so that EMF induced in each coil opposes each other
- Since the primary winding is connected to an AC source it produces an alternating magnetic field which induces AC voltages in two secondary windings.



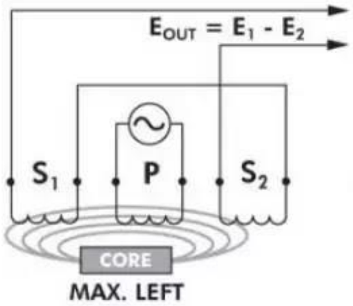
LVDT working principle

- The working principle of LVDT is based on the mutual induction principle.
- When AC is applied to the primary winding, then a magnetic field is produced. This magnetic field induces a mutual current in secondary windings. Due to this, the induced voltages in secondary windings (S1 & S2) are E1 & E2 respectively.
- Since both the secondary windings are connected in series opposition, So the net output voltage will be the difference of both induced voltages (E1 & E2) in secondary windings.
- Hence Differential Output of LVDT will be E**0 = E1 – E2**



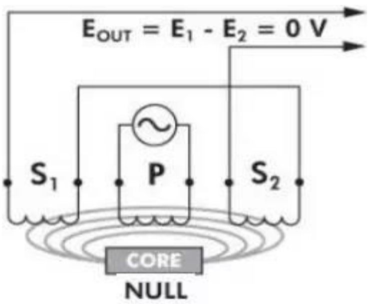
Now according to the position of the core, there are three cases that arise.

Case 1: When the core moves towards S1 (Max Left).1



- When the core of LVDT moves toward Secondary winding **S1**. Then, in this case, the flux linkage with **S1** will be more as compared to **S2**. This means the emf induced in S1 will be more than the induced emf in **S2**.
- Hence **E1>E2** and Net differential output voltage **E0 = E1 – E2** will be positive.
- This means the output voltage **E0** will be in phase with the primary voltage.

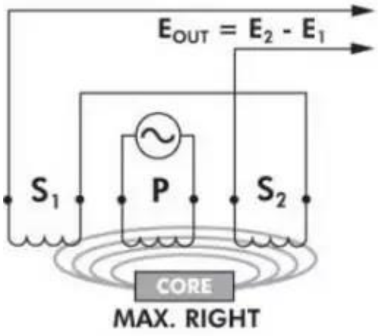
Case 2: When the core is at Null position.



- When the core is at the null position then the flux linkage with both the secondary windings will be the same. So the induced emf **(E1 & E2)** in both the windings will be the same.

- Hence the Net differential output voltage **E0 = E1 – E2** will be zero **(E0 = E1 – E2 = 0)**.
- It shows that no displacement of the core.

Case 3: When the core moves towards S2 (Max Right).



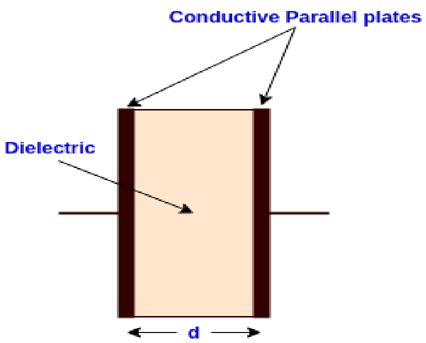
- When the core of LVDT moves toward Secondary winding **S2**. Then, in this case, the flux linkage with **S2** will be more as compared to **S1**. This means the emf induced in S2 will be more than the induced emf in S1.
- Hence **E2>E1** and Net differential output voltage **E0 = E1 – E2** will be negative. This means the output voltage **E0** will be in phase opposition (**180** degrees out of phase) with the primary voltage.

Advantages of LVDT:
- Smooth and Wide Range of Operation
- High Sensitivity
- Low Hysteresis Losses
- Low Friction Losses
- Rugged Operation
- Low Power consumption

Disadvantages of LVDT
- Since LVDT is Inductive Transducer, so it is sensitive to Stray Magnetic Field. Hence an extra setup is required to protect it from Stray Magnetic Field.
- Since it is an electromagnetic device, so it also gets affected by the vibrations and temperature variation.

6.4 Working principle of capacitive transducers (pressure)

- A capacitive transducer is a passive transducer that works on the principle of variable capacitances.
- It is used to measure physical quantities such as displacement, pressure, etc.
- A capacitive transducer contains two conducting parallel metal plates separated by a dielectric medium.



Working Principle of capacitive transducer

The capacitance between these two plates can be expressed as

$$C = \frac{\varepsilon A}{d}$$

Where ***ϵ*** is the permittivity of the medium, ***A*** is the area of the plates and ***d*** is the distance between two plates.

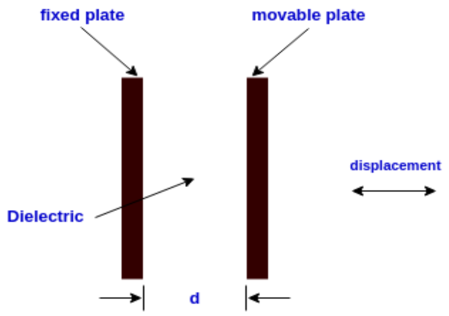
Any physical quantity which can cause a change in ***ϵ, A or d*** *can be measured by the capacitance gauge.*

The capacitance between two plates can be varied by any of the following methods.

- By changing the distance between two plates (**d**)
- By changing the permittivity of the dielectric medium (**ϵ**)
- By changing the area of overlapping of plates (**A**)

By changing the distance between two plates

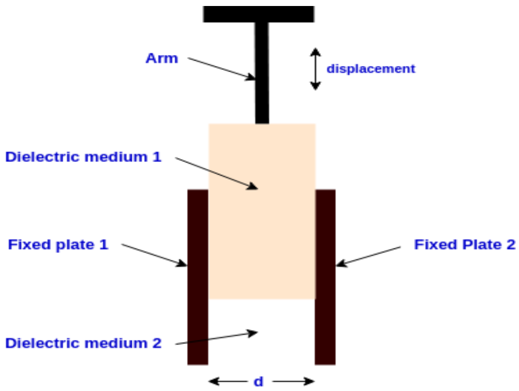
- The capacitance can be varied by changing the distance between two plates.
- From the equation for C, C and d are inversely proportional to each other. That is, the capacitance value will decrease with increasing distance and vice-versa.
- This principle can be used in a transducer by making the left plate fixed and the right plate movable by the displacement that is to be measured as shown in the figure.



- The change in distance between two plates will vary the capacitance of the transducer. Change in capacitance can be calibrated in terms of the measurand. These types of transducers are used to measure extremely small displacements.

By changing the permittivity of the dielectric medium

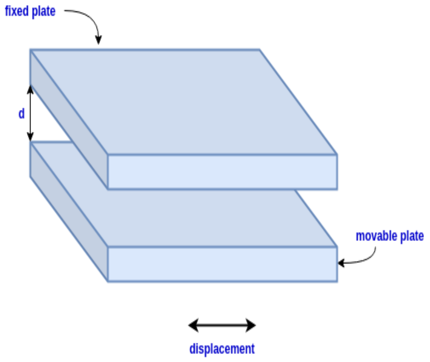
Another method to change the capacitance value is by changing the permittivity of the dielectric material (ϵ). The permittivity and capacitance value are directly proportional to each other.



In this arrangement, a dielectric material is filled into the space between the two fixed plates. It can be moved using the arm. This causes a variation in dielectric constant in the region. The change in dielectric constant will vary the capacitance of the transducer.

By changing the area of overlapping of plates

The capacitance can also be changed by varying the area of overlapping of plates.



- As shown in the figure, one plate is kept fixed and the other movable. When the plate is moved, the area of overlapping of plates changes, and the capacitance also changes.
- The capacitance value and area are directly proportional to each other.
- These types of transducers are used to measure relatively large displacements.

Advantages of capacitive transducer

- Sensitivity is high.
- Requires small power to operate.
- Loading effect is low because of high input impedance.
- Good frequency response.

6.5 Working principle of Load Cell (Pressure Cell)

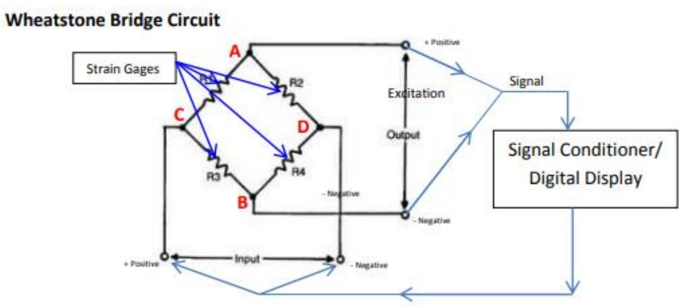
Load cell is a sensor or a transducer that converts a load or force acting on it into an electronic signal. This electronic signal can be a voltage change, current change or frequency change depending on the type of load cell and circuitry used.

Several types of load cells exist for varying applications:

- Strain Gauge Load Cells
- Hydraulic Load Cells
- Pneumatic Load Cells
- Capacitive Load Cells
- Piezoelectric Transducers

Strain Gauge Load Cells

- A load cell works only when the strain gauge has some change in its resistance and Wheatstone Bridge to measure this change.

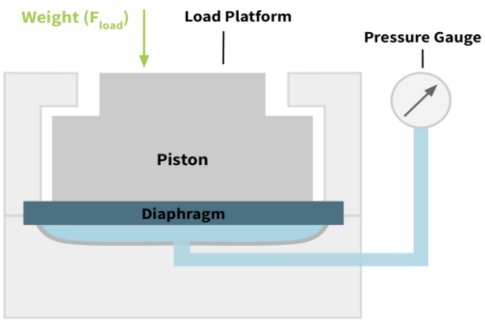


- Let us assume that a load cell sensor has four internal strain gauges i.e. A, B, C, and D as shown in the image above.
- The input voltage supplied by a signal conditioner or digital display is attached to the two opposite corners of the bridge i.e. C and D whereas, the output voltage is measured by joining the A and B resistors to the signal side of the digital display.
- When no load is applied to the load cell (Load=0), the circuit is said to be balanced. As soon as the load is applied to it, the strain gauge resistors will witness a change in its resistance, thereby altering the voltage flowing through the circuit.
- Hence, the voltage across A and B will change which will be displayed as the weight on the readout unit or the digital display.
- The output of the Wheatstone bridge or a load cell is an analogue data which is converted to readable units using an interpreter.

Hydraulic load cells

Hydraulic load cells convert a load to hydraulic pressure. Following are the components of Hydraulic load cells:

- An elastic diaphragm
- A piston connected to a load platform
- Hydraulic fluid which is usually oil or sometimes water
- Pressure gauge or gauges
- A tube connecting the chamber to the pressure gauge
- Steel housing for the assembly

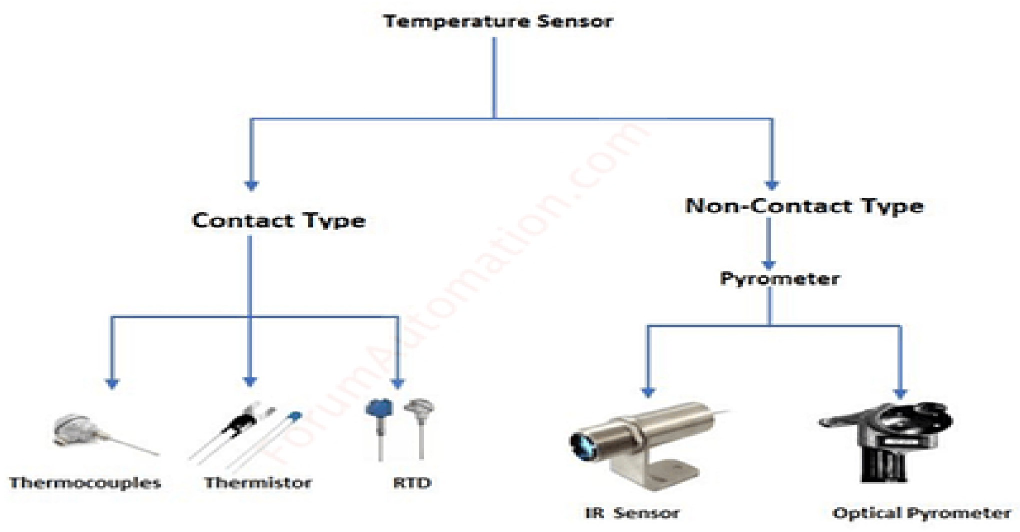


- The measured load is applied to a load platform attached to a piston. The piston sits in a closed chamber filled with fluid.
- When a load is applied, the action of the piston on the diaphragm pressurizes the liquid.
- The change in liquid pressure is directly proportional to the force applied by the load.
- This liquid pressure is readable through an attached bourdon tube pressure gauge.

6.6 Working principle of Temperature Transducer (RTD, Optical Pyrometer, Thermocouple, Thermister)

- The temperature transducer converts the thermal energy into a physical quantity likes the displacement, pressure and electrical signal etc.
- The main principle of the temperature transducer is to measure the heat and transfer the information after converting it into the readable form.

Types of Temperature Sensors



The temperature sensors are mainly classified into two. They are

- **Contact Type Temperature Sensors**
- **Non-Contact Type Temperature Sensors**

Contact Type Temperature Sensors

- There are some temperature sensors that can only measure the hotness or coldness of an object by being in contact with the object. Such temperature sensors are classified as contact-type.
- They can detect solids, liquids, or gases at a variety of temperatures.

Non-Contact Type Temperature Sensors

- Non-Contact Sensors can measure the temperature without being in contact with the object. This can be done by utilizing the radiation of the heat source.
- The common non-contact sensor is an infrared sensor (IR). IRs detect an object's energy remotely and send a signal to an electrical circuit, which uses a calibration diagram to determine the object's temperature.

The contact and non-contact temperature sensor are further classified into the following types.

- Thermocouples
- Thermistors
- Resistive Temperature Detectors (RTD)
- IR Temperature sensor
- Optical Pyrometer**.**

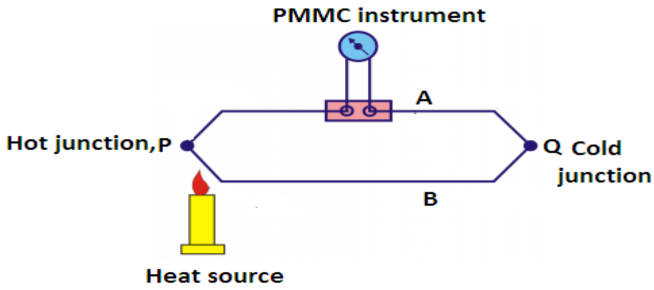
Contact Type Temperature Sensors

Thermocouples:

Thermocouples are the temperature sensors which are extensively used for the measurement of the temperature variations. They sense the temperature and the temperature is further measured by other instruments after sensing it.

Working of Thermocouple

- A typical circuit diagram of a thermocouple is shown in Figure. In the Figure, two dissimilar metals ‘A’ and ‘B’ are joined at the two junctions ‘P’ and ‘Q’. Here the ‘P’ junction is measuring junction or hot junction whereas the junction ‘Q’ is the reference junction or cold junction. And a PMMC instrument is connected in this arrangement as shown in Figure.



- When these junctions are kept at different temperatures, generally cold junction is kept at 0°C and measuring junction is kept at an unknown temperature which is to be measure (i.e. the temperature of the junction is raised by heating it).
- An e.m.f. will be generated in this circuit due to the temperature difference of the junctions.
- This e.m.f. is in the order of millivolts and the e.m.f. can be measured with the help of a PMMC instrument by connecting it in the circuit as shown in Figure.
- When both the junctions are at the same temperature, e.m.f. generated at both junctions will be the same. No current will flow through the circuit. And there will be no deflection in the meter.
- When both the junctions are at different temperatures, a current will flow through the meter. And the meter will show the deflection.
- As the generated e.m.f. is proportional to the temperature difference, the amount of current flow will also be proportional to the temperature difference. And therefore, the meter can be calibrated directly in terms of temperature.
- In this way, a thermocouple is used for temperature measurement. As it is converting a non-electrical quantity (temperature) into an electrical quantity (e.m.f.) it can also be used as a transducer. Since it does not require any power source to operate, it is a secondary transducer.

Thermistors:

- A thermistor is a special type of resistor whose resistance changes with the change in its body temperature.
- Thermistors are extremely small devices. It consists of a sensing element that can be glass or epoxy coated, as well as two wires that link to an electric circuit. Temperature is determined by measuring the change in resistance of an electric current.
- Thermistors are available in NTC or PTC configurations and are frequently inexpensive.

These are of two types:

- PTC Thermistor
- NTC Thermistor

PTC Thermistor

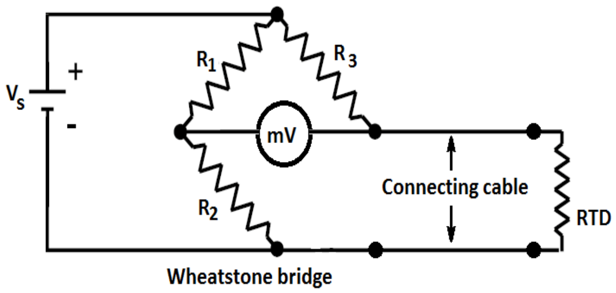
- Positive Temperature Coefficient (PTC) thermistor, is made up of a material having a positive temperature coefficient of resistance.
- In case of a material having a positive temperature coefficient of resistance, the resistance of the material increases with an increase in temperature. Therefore, the resistance of PTC thermistor increases with its body temperature.

NTC Thermistor

- **Negative Temperature Coefficient (NTC) thermistor is made up of a material having a negative temperature coefficient of resistance like manganese, nickel, cobalt, copper, iron and uranium, therefore, their resistance decreases with the increase in body temperature.**

Resistive Temperature Detectors (RTD)

- A Resistance Temperature Detector (also known as a Resistance Thermometer or RTD) is an electronic device used to determine the temperature by measuring the resistance of an electrical wire.
- RTDs work on a basic correlation between metals and temperature. As the temperature of a metal increases, the metal's resistance to the flow of electricity increases. Similarly, as the temperature of the RTD resistance element increases, the electrical resistance, measured in ohms (Ω), increases.



- The RTD (or its sensing element) is connected to a Wheatstone Bridge circuit by a suitable cable.
- The bridge circuit consists of three resistors and the RTD acts as the fourth resistor. This bridge circuit converts the variation in resistance into the variation in volts.
- In this way, we get the variation in temperature in the form of variation in voltage. The voltmeter is calibrated in terms of temperature to show the temperature readings.

Non-Contact Type Temperature Sensors

Pyrometer

A pyrometer is a type of remote-sensing thermometer used to measure the temperature of distant objects. Pyrometer are two type

- **Infrared Temperature Sensor**
- **Optical pyrometers**

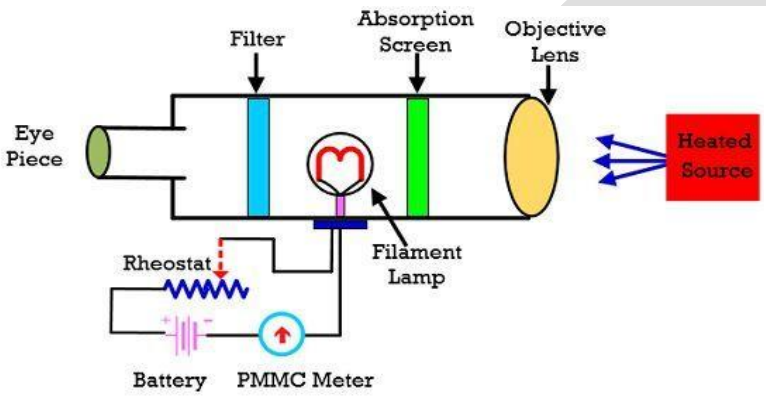
Optical Pyrometer

- The optical pyrometer is a non-contact type temperature measuring device.
- It works on the principle of matching the brightness of an object to the brightness of the filament which is placed inside the pyrometer.
- The optical pyrometer is used for measuring the temperature of the furnaces, molten metals, and other overheated material or liquids.

Working of Optical Pyrometer

- The optical pyrometer consists of lens which focuses the radiated energy from the heated object and targets it on the electric filament lamp.

- The intensity of the filament depends on the current passes through it. Hence the adjustable current is passed through the lamp.



- The magnitude of the current is adjusted until the brightness of the filament is similar to the brightness of the object.

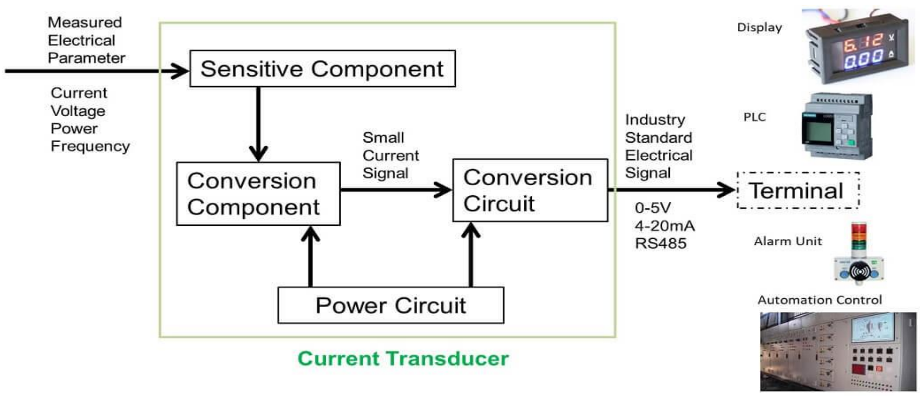
- When the brightness of the filament and the brightness of the object are same, then the outline of the filament is completely disappeared.

- The filament looks bright when their temperature is more than the temperature of the source.

- The filament looks dark if their temperature is less than that required for equal brightness

6.7 Working principle of Current transducer and KW Transducer.

- Current transducer is a device, which converts current into a proportional industrial standard electrical signal.
- Basically current transducer is formed by four parts i.e sensitive component, conversion component, conversion circuit, power circuit.



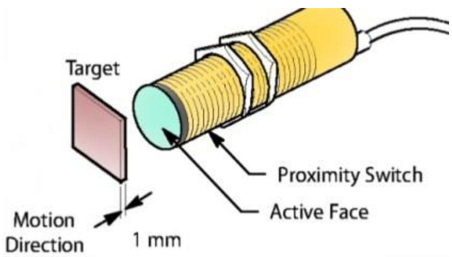
- The current goes in, usually it is current, voltage, frequency, power, etc. Then the sensitive component will detect the electrical parameter and give a signal.
- After that the signal will be passed to conversion component, which can convert the signal to a small current signal.
- Then it will be passed to conversion circuit, which process the small current signal and provide an industrial standard electrical signal.
- At the end the output signal goes to terminal equipment, such as display, PLC, alarm unit, automation control, etc.
- Current transducer usually has a power circuit, which provide the power to conversion component and conversion circuit.

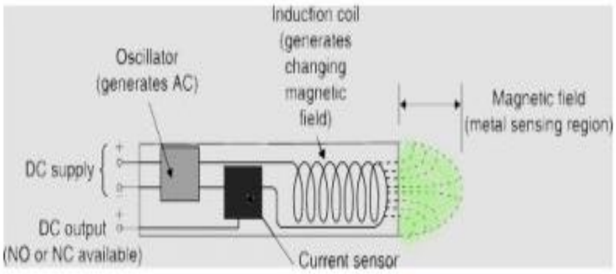
6.8 Working principle of Proximity & Light sensors.

- Proximity sensors are sensors that detect movement/presence of objects without physical contact and relay that information captured into an electrical signal.
- The proximity sensors are available in different categories as per their detection. Some proximity sensors are useful to detect materials; whereas some are useful to detect different environmental conditions.
- The two most commonly used proximity sensors are the inductive proximity sensor and the capacitive proximity sensor.

Inductive proximity sensor:

- Inductive sensors can be available in both ac and dc supply operated. They only detect metallic targets and therefore use a magnetic field to its presence. The inductive sensor consists of sensing coil which is ferromagnetic coil having copper turns.



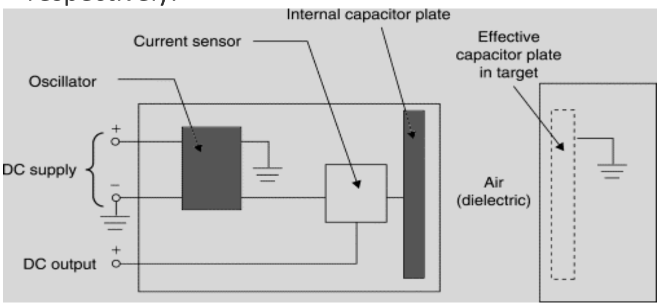


- The working principle of the inductive proximity sensor is based on the electromagnetic induction. The coil will generate high frequency oscillation field.
- Electrical currents known as eddy currents are induced on the metal surface when a ferrous metal material enters the magnetic field.
- These eddy current induce power loss within the oscillator circuit and in turned caused a reduction in the amplitude of the oscillations.
- This change in amplitude sends a signal to the switch changing it to its normally open or normally closed configuration respectively.
- When the metal target is removed from the proximity inductive sensor range the oscillator will return to its normal state and the switch will return to its normally closed or open output.

Capacitive Proximity sensors:

- Capacitive sensor can detect metallic and non-metallic objects material.
- There is no de-rating factor to be applied when sensing metal targets but other materials do affect sensing range.

- Generally, the sensing distance for proximity capacitive sensor is greater for larger or denser targets, but the effect on electrostatic field produced by the non-conductive material can be quite small. Usually sensing distances with this material is short.
- Two small plates located in the front of sensor form a capacitor as a target enter the sensors range the capacitance of the two plate's increases thus causing a change in the oscillator frequency which also activates the sensor output either normally open or normally closed respectively.



- Capacitive sensor can detect any target that has a dielectric constant greater than air. The dielectric constant is an electrostatic field generated by the oscillator circuit.
- If an object enters this field and causes interference, oscillation than begins. The oscillator output is monitored by detector or trigger circuit.
- When it detects the sufficient change in the field, it switches on the output circuit. The output circuit remains active when the target is in front of the sensor, the sensor will be active and the sensor will be in off state when the target is removed from the sensing field.

UNIT-7: SIGNAL GENERATOR, WAVE ANALYSER & DAS

7.1 General aspect & classification of Signal generators

A signal generator is an electronic test instrument that creates or generates either repeating or non-repeating waveforms. These waveforms can be of different shapes and amplitude. Signal generators of all types are mostly used in designing, manufacturing, servicing and repairing electronic devices.

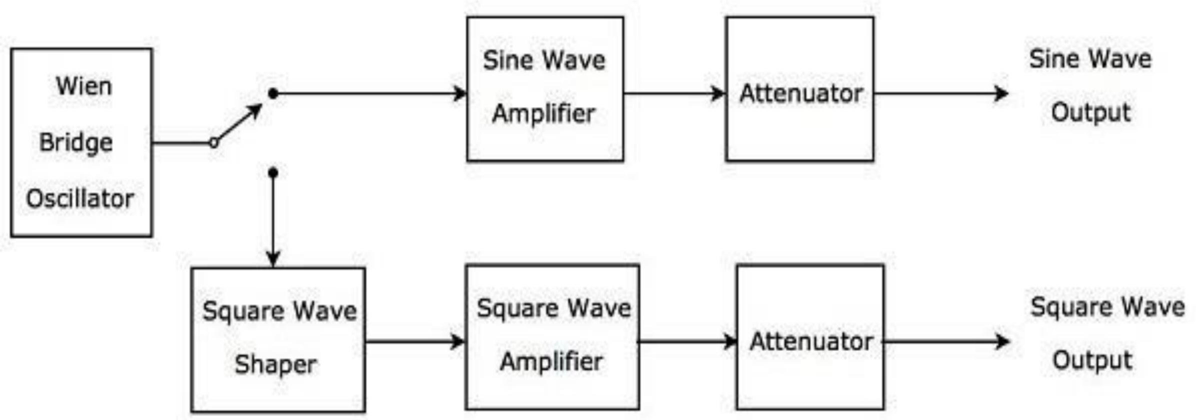
Types of signal generator

There are many different types of signal generator:

- Arbitrary waveform generator
- Audio signal generator
- function generator
- Pulse generator
- RF signal generator
- Vector signal generator

7.2 Working principle of AF Sine & 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 diagramis shown in below figure.



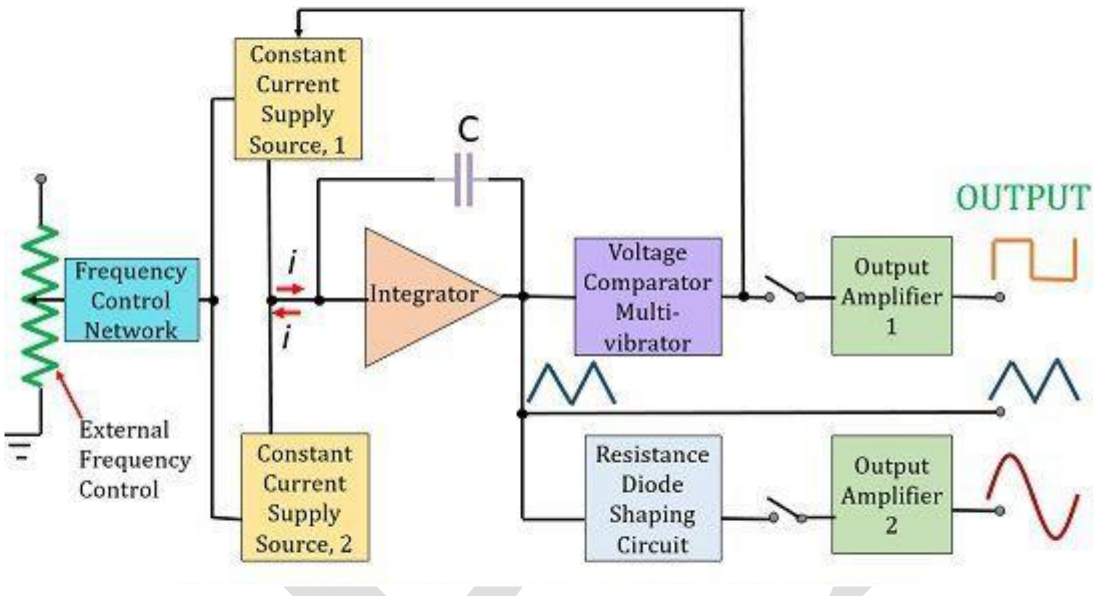
- The above block diagram consists of mainly two paths. Those are upper path and lower path. Upper path is used to produce AF sine wave and the lower path is used to produce AF square wave.
- Wien bridge oscillator will produce a sine wave in the range of audio frequencies. Based on the requirement, connect the output of Wien bridge oscillator to either upper path or lower path by a switch.
- 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. 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 above circuit can be used to produce either AF sine wave or AF square wave based on the requirement.

7.3 Working principle of the Function Generator

- *A function generator is a signal source that has the capability of producing different types of waveforms at the output.*
- It has the ability to produce waveforms such as sine wave, square wave, a triangular wave, sawtooth wave etc.
- The frequencies of such waveforms may be adjusted from a fraction of a hertz to several hundred kHz.

Working principle of Function Generator

The figure below shows the block diagram of the function generator-



- Frequency control knob adjust the frequency of the output waveforms as per our requirements. It basically nothing but a potentiometer. Its main function to vary the voltage to regulate the current source 1 and 2.
- Frequency Controlled Circuit consisting of resistors and capacitors. As per the charging and discharging rates of the capacitor, it regulates the two current sources (1 and 2).
- Current Source 1 and 2 are the constant current sources input to the signal integrator. Among these two current sources, source 1 provides a forward current supply, and source 2 provides a reverse current supply to the integrator. So using the current source 1 the signal integrator can create the positive half cycle of the waveform and using the current source 2 the signal integrator can create the negative half cycle of the waveform.
- Signal Integrator Mainly the signal integrator is a current to voltage converter circuit. In normal, it takes the current from source 1 and generates a triangular waveform. The frequency of the triangular waveform depends upon the current supplied by the constant current supply sources.
- The main function of the voltage comparator multivibratoris to control the magnitude or voltage level of the waveform. When the magnitude or voltage of the waveform reaches the maximum predetermined level in the positive half cycle, the voltage comparator switches the current sources means it cut off source 1. Again when the voltage level reaches the maximum predetermined level in the negative half cycle, the voltage comparator switches the current source into source 1.

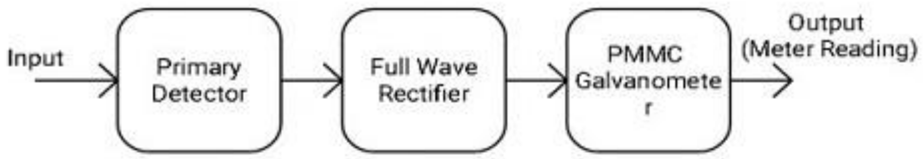
So, as the voltage comparator can control both the positive and negative half cycle of the waveform very precisely, it can generate the square wave electronic signal.

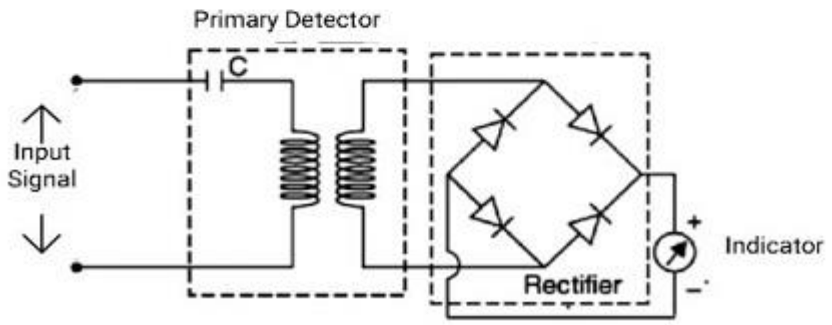
- Resistance Diode Shaping Circuit It takes the triangular wave signal from the signal integrator as an input and generates the sine wave signal. This Resistance diode shaping network changes the slope of the triangular wave. So the amplitude continuously changes with time and produces a sinusoidal wave having less than 1% distortion.

7.4 Function of basic Wave Analyser& Spectrum Analyser

Wave Analyser

- An electronic instrument that analyzes the signal or wave by measuring the amplitude of the frequency components or harmonics is called a Wave Analyzer.
- The wave analyzer block diagram is shown below. It contains a primary detector, full-wave rectifier, and PMMC galvanometer.





- Primary Detector: It is made up of an LC circuit. By adjusting the values of ‘L’ (inductor) and ‘C’, the particular frequency component of the signal is allowed to measure.
- Full-wave Rectifier: The input AC signal is converted into the DC signal and the average value of the signal is obtained
- PMMC Galvanometer: It is used to indicate the value of the signal i.e, the output of the full-wave rectifier.

Principle:

- It operates on the principle of a frequency selective voltmeter. It is tuned to the frequency of one signal and rejects all other signal components.
- The desired frequency is selected by a frequency calibrated dial to point maximum amplitude. The amplitude is indicated by a suitable voltmeter or a CRO.
- It consists of a primary detector made of an LC circuit. The LC circuit is adjusted for resonance at the frequency of the particular harmonic component to be measured.
- The intermediate stage is a full-wave rectifier. It is used to obtain the average value of the input signal, on the indicating meter.
- The indicating meter is a DC voltmeter calibrated to read the peak value of the input voltage.

Spectrum Analyser

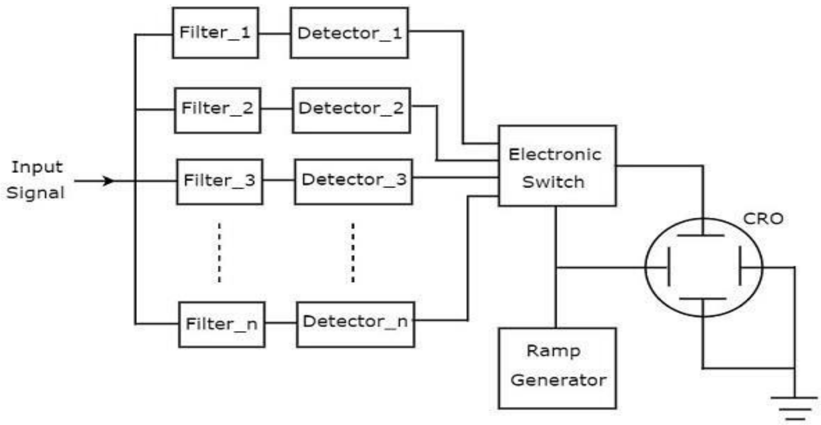
The electronic instrument, used for analyzing waves in frequency domain is called spectrum analyzer. Basically, it displays the energy distribution of a signal on its CRT screen. Here, x-axis represents frequency and y-axis represents the amplitude.

Spectrum analyzers classify into following two types.

- Filter Bank Spectrum Analyzer
- Superheterodyne 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.

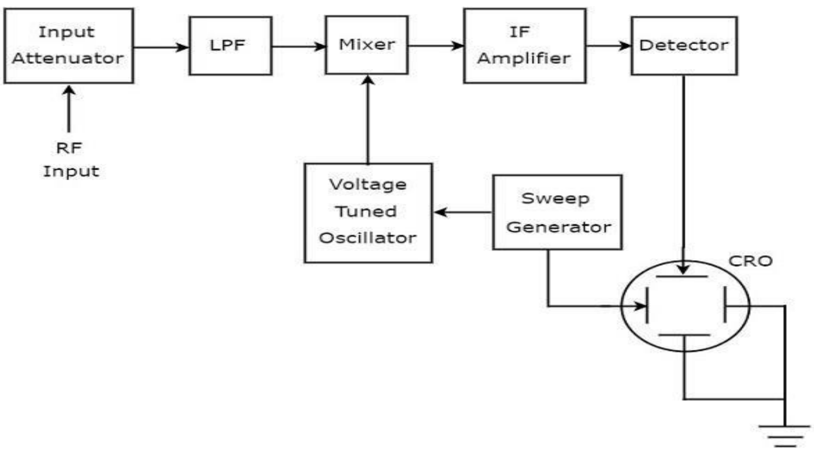


The working of filter bank spectrum analyzer is mentioned below.

- 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.

Superheterodyne Spectrum Analyzer

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

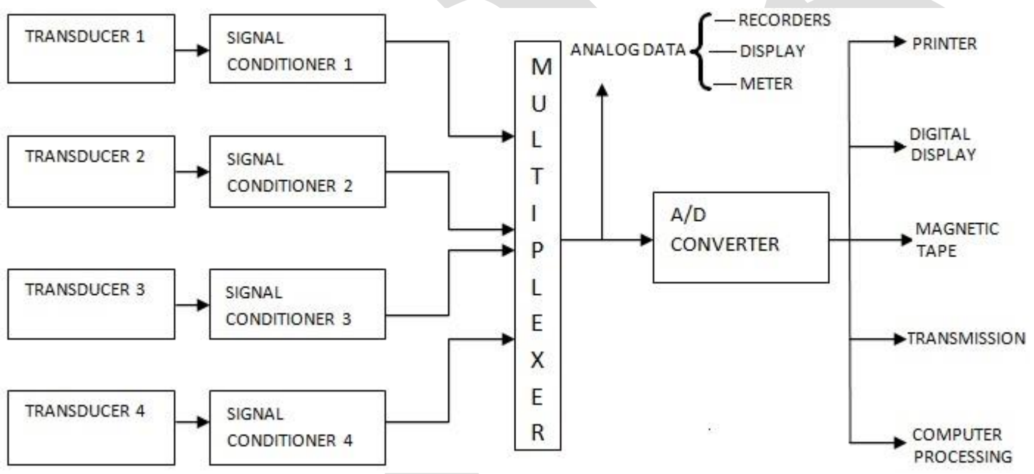


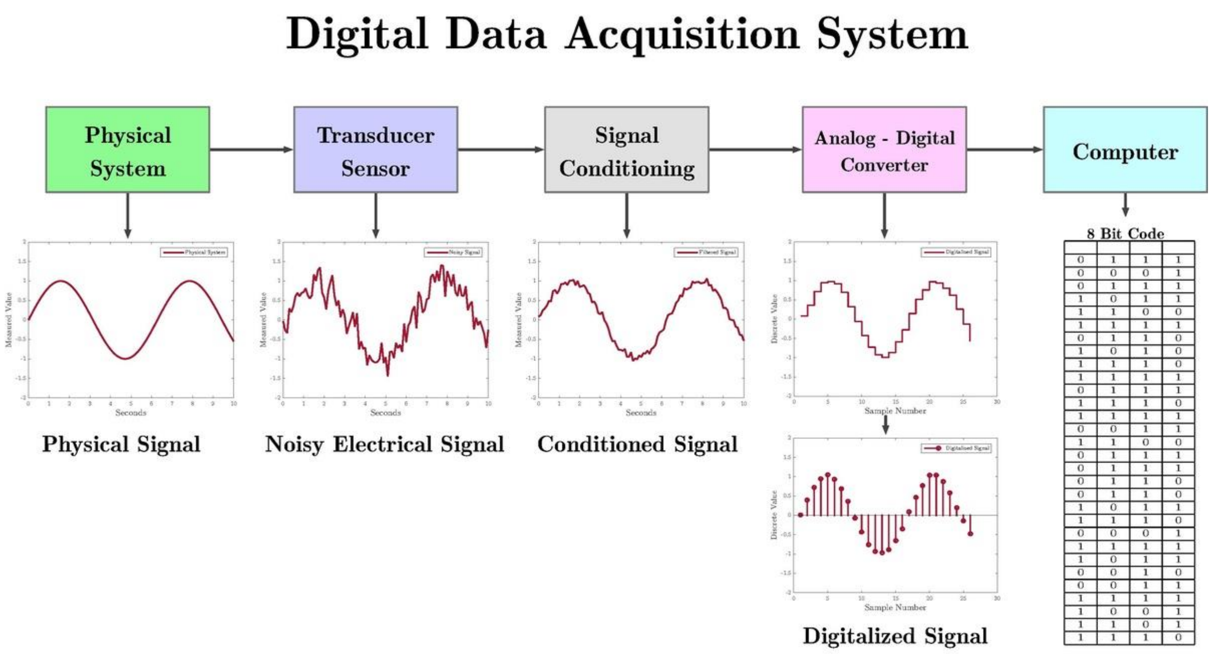
The working of superheterodyne spectrum analyzer is mentioned below.

- 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.
- 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.

7.5 Basic concept of Data Acquisition System (DAS)

Data Acquisition Systems shortened to DAS or DAQ, are systems designed to convert analog waveforms into digital values, so that they can be used for processing. In other words, they take abstract data and record it in such a way that humans can interpret it and use it.





It consists of the following elements.

1. Transducer
2. Signal conditioner
3. Multiplexer
4. Analog to Digital Converter
5. Recorders and Display devices

1. Transducer

A transducer is used to convert the physical parameters coming from the field intoelectrical signals or it is used to measure directly the electrical quantities such as resistance,voltage, frequency, etc.

2. Signal Conditioner

Usually the output signals of the transducer will be of very low level (weak) signalswhich cannot be used for further processing. In order to make the signals strong enough to drivethe other elements signal conditioners such as amplifiers, modifiers, filters etc., are used.

3. Multiplexer

The function of the multiplexer is to accept multiple analog inputs (after signalconditioning) and provide a single output sequentially according to the requirements.

4. A/D Converter

The analog-to-digital (A/D) converter is generally used to convert the analogdata into digital form. The digital data is used for the purpose of easy processing, transmission,digital display and storage.Processing involves various operations on data such as comparison,mathematical manipulations, data is collected, converted into useful form and utilized for variouspurposes like for control operation and display etc.

5. Recorders and Display Devices

In display devices the data is displayed in a suitable form in order tomonitor the input signals. Examples of display devices are oscilloscopes, numerical displays,panel meters, etc.

In order to have either a temporary or permanent record of the useful data recorders are used.