EC504B : ELECTRICAL & ELECTRONICS MEASUREMENT
Contact: 3P
Credits: 3
Lectures: 34
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Course objectives:

The objective of this course is to acquire knowledge about the construction and working of Bridges to measure resistance , capacitance, inductors , analog and electronic measuring instrument , Sensor-transducer system , telemetry system ,data acquisition system and some advance instruments like Like OTDR , virtual instrument and PLC.

Course Outcome:

COs	CO Statement
CO1	Students able to explain the characteristics , construction and working principle analog instruments like : PMMC , MI , Electrodynamometer type and Energy meter
CO2	Students able to demonstrate the principle to measure resistance , capacitance , inductance with the help of Bridge balancing technique
CO3	Students able to describe the construction and working principle of electronic instrument like : DSO , DMM , spectrum analyzer ,distortion meter
CO4	Student able to illustrate the functionality of sensor and transducer element
CO5	Student able to demonstrate Telemetry System ,Display device ,Interface Standard , Data Acquisition system and Advanced Instruments Like OTDR , virtual instrument and PLC

Prerequisites: Basic analog and digital **electronic** circuits and principles. Basic electronics engineering, Basic electrical engineering,

Module 1

Characteristics of Instruments, Errors in Measurement, Units

1.1 Measurement Methods: Direct and Indirect

In direct measurement methods, the unknown quantity is measured directly. Direct methods of measurement are of two types, namely, deflection methods and comparison methods.

In deflection methods, the value of the unknown quantity is measured with the help of a measuring instrument having a calibrated scale indicating the quantity under measurement directly, such as measurement of current by an ammeter.

In comparison methods, the value of the unknown quantity is determined by direct comparison with a standard of the given quantity, such as measurement of emf by comparison with the emf of a standard cell.

1.2. Characteristics of Instrument &Measurement System:

Accuracy:Accuracy is the closeness with which the instrument reading approaches the true value of the variable under measurement. Accuracy is determined as the maximum amount by which the result differs from the true value

Precision:Precision is a measure of the reproducibility of the measurements, i.e., precision is a measure of the degree to which successive measurements differ from one another.

Sensitivity: The ratio of the change in output to a change of input or measured variable

Resolution: The resolution or discrimination of any instrument is the smallest change in the input signal (quantity under measurement) which can be detected by the instrument

Dynamic range : This indicates the minimum value and maximum value measured by the instrument

Linearity: The linearity property of the instrument can be explained with the help of the following fig1.1

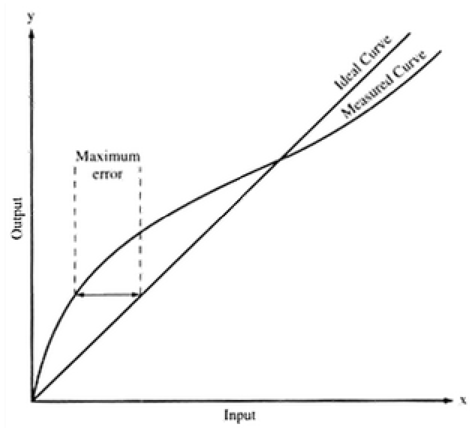


Fig.1.1 : Linearity property of instrument

Hysteresis:

Hysteresis property can be understood using the following curve

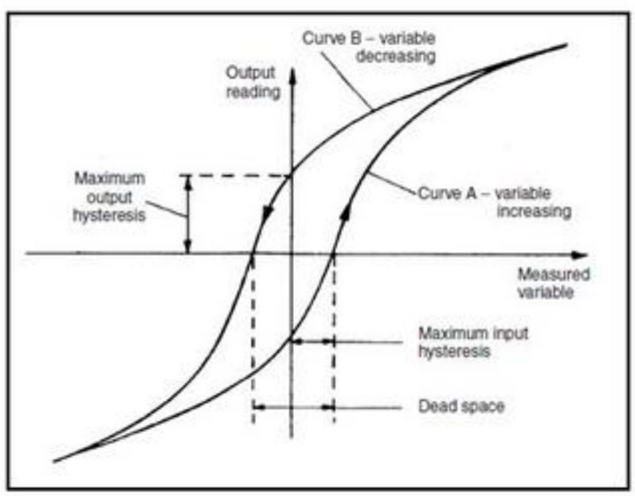


Fig. 1.2 .: Hysteresis property of instrument

Repeatability:

The instrument should reproduce the same output signal when the same input signal is applied again and again under unchanged environmental conditions, e.g., temperature, pressure, humidity, etc.

Loading effect:

When an instrument of lower sensitivity is used with a heavier load the measurement it makes is erroneous, this effect is known as loading effect

1.3. Types of Error (concept)

Gross Errors:

The errors occur because of mistakes in observed readings, or using instruments and in recording and calculating measurement results. These errors usually occur because of human mistakes and these may be of any magnitude and cannot be subjected to mathematical treatment

Systematic Errors:

These are the errors that remain constant or change according to a definite law on repeated measurement of the given quantity. These errors can be evaluated and their influence on the results of measurement can be eliminated by the introduction of proper correction. There are two types of systematic errors:
• Instrumental error
• Environmental error

Random Error:

These errors are of variable magnitude and sign and do not maintain any known law. The presence of random errors become evident when different results are obtained on repeated measurements of one and the same quantity

1.4. Units and Standard in measurements– Concept of Calibration

Units: At the time of measuring a physical quantity, we must express the magnitude of that quantity in terms of a unit and a numerical multiplier

In science and engineering, two kinds of units are used:
• Fundamental units
• Derived units

Fundamentals units are : Mass , Length , Time

All other units which can be expressed in terms of the fundamental units are called derived units.
Example : Area , Current , voltage , watte.t.c.

Standards : Different classifications of standards are followings

1.International standards
2. Primary standards
3. Secondary standards
4. Working standards
5. Current standards
6. Voltage standards
7. Resistance standards
8. Capacitance standards
9. Time and frequency standards

Calibration: Instrument calibration is one of the primary processes used to maintain instrument accuracy. Calibration is the process of configuring an instrument to provide a result for a sample within an acceptable range

Calibration in measurement technology and metrology is the comparison of measurement values delivered by a device under test with those of a calibration standard of known accuracy. Such a standard could be another measurement device of known accuracy, a device generating the quantity to be measured such as a voltage, or a physical artefact, such as a metre rule .

MCQ type Questions

Q1.1

i) Which of the following quantities consists of S.I. unit as Hertz?
(a) Charge (b)Force (c) Frequency (c)Power

ii) Which one of the following units is a fundamental unit?
(a) Newton (b) Ampere (c)Watt (d) Joule/sec

iii) The Metric System is also called as:
(a) CGS (b) MKS system (c) SI (d) None of the above

iv) Which of the quantity consists of unit as kg m/sec ?
(a) Speed (b) Momentum (c)Acceleration (d) Impulse

Short Answer Type Questions

Q1.2

i) What do you mean by direct and indirect measurement

ii) Describe the following characteristics of instruments : Accuracy , linearity , sensitivity

iii) Derive Voltage in terms of MLT unit .

Module 2

Analog Instruments

2.1 Construction and operation of PMMC and Moving Iron Type Instrument: Its application to measure current, voltage and resistance.

2.1.1 Permanent Magnet Moving Coil (PMMC) instrument

Basic range: 10 μA-100 mA
Coil resistance: 10 Ω-1 kΩ
Usage:

- DCPMMC ammeters and voltmeters
- AC PMMC ammeters and voltmeters (with rectifiers)

Construction &Operation :The principle on which a Permanent Magnet Moving Coil (PMMC) instrument operates is that a torque is exerted on a current-carrying coil placed in the field of a permanent magnet. A PMMC instrument is shown in Figure 2.1 Thecoil C has a number of turns of thin insulated wires wound on a rectangular aluminium former F. The frame is carried on a spindle S mounted in jewel bearings J1, J2. A pointer PR is attached to the spindle so that it moves over a calibrated scale. The whole of the moving system is made as light in weight as possible to keep the friction at the bearing to a minimum. The detail construction is shown in fig 2.1

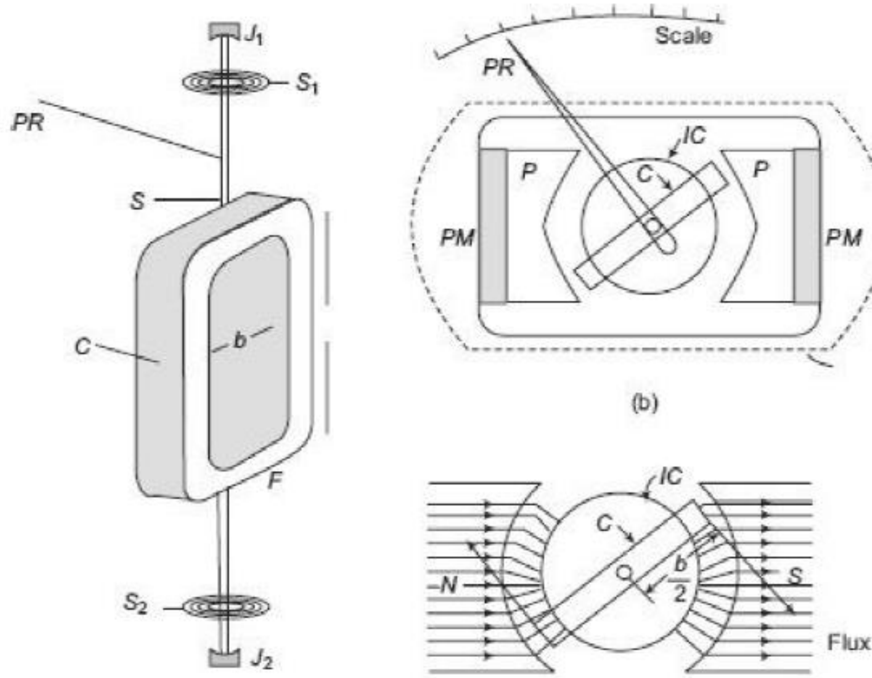


Fig. 2.1 : Construction of PMMC

Deflecting Torque Equations

Let, B = flux density in the air gap (wb/m2)
i = current in the coil (A)
l = effective axial length of the coil (m)
b = breadth of the coil (m)
n = number of turns of the coil.
Force on one side of the coil is

F=Biln (N)
Torque on each side of the coil,

T= Force × distance from axis of rotation
=F × (b/2)

Therefore total deflecting torque exerted on the coil

T_D= 2 × T =Biln b

- Some other torque are controlling torque and damping torque . At steady state condition deflecting torque equals to controlling torque.

- PMMC instruments can be extended to use as an Ammeter by connecting shunt resistance and as voltmeter by connecting a resistance in series .

Swamping Resistor

The coil of the instrument is made of copper. Its resistance varies with temperature. A resistor of low temperature coefficients, called the swamping resistor, is connected in series with the coil. Its resistance practically remains constant with temperature. Hence the effect of temperature on coil resistance is swamped by this resistor.

Advantages of PMMC Instruments

1. Sensitive to small current
2. Very accurate and reliable
3. Uniform scale up to 270° or more
4. Very effective built in damping
5. Low power consumption, varies from 25 μW to 200 μW
6. Free from hysteresis and not effected by external fields because its permanent
magnet shields the coil from external magnetic fields
7. Easily adopted as a multirange instrument

Disadvantages of PMMC Instruments

1. This type of instrument can be operated in direct current only. In alternating current, the instrument does not operate because in the positive half, the pointer experiences a force in one direction and in the negative half the pointer experiences the force in the opposite direction. Due to the inertia of the pointer, it retains it's zero position.
2. The moving system is very delicate and can easily be damaged by rough handling.
3. The coil being very fine, cannot withstand prolonged overloading.
4. It is costlier.
5. The ageing of the instrument (permanent magnet and control spring) may introduce some error
some errors.

Problem 1.1.:The coil of a PMMC instrument has 60 turns, on a former that is 18 mm wide, the effective length of the conductor being 25 mm. It moves in a uniform field of flux density 0.5 Tesla. The control spring constant is 1.5 $\times 10^{-6}$ Nm/degree. Calculate the current required to produce a deflection of 100 degree.

Problem 1.2.:A PMMC instrument has a coil of dimensions 15 mm × 12 mm. The flux density in theair gap is 1.8 $\times 10^{-3}$wb/m2 and the spring constant is 0.14 $\times 10^{-6}$N-m/rad. Determine the number of turns required to produce an angular deflection of 90° when a current of 5 mA is flowing through the coil.

Problem 1.3.:The coil of a moving-coil voltmeter is 40 mm long and 30 mm wide and has 100 turns on it. The control spring exerts a torque of 240 × 10-6 N-m when the deflection is 100 divisions on full scale. If the flux density of the magnetic field in the air gap is 1 wb/m2, estimate the resistance that
Must be put in series with the coil to give one volt per division. The resistance of the voltmeter coil may be neglected

Problem 1.4.:A moving-coil voltmeter has a resistance of 100 Ω. The scale is divided into 150 equal divisions. When a potential difference of 1 V is applied to the terminals of the voltmeter a deflection of 100 divisions is obtained. Explain how the instrument could be used for measuring up to 300 V.

Problem 1.5.:A moving coil instrument has a resistance of 5 Ω and gives a full scale deflection of 10 mv. Show how the instrument may be used to measure (a) voltage up to 50 v, and (b) current up to 10 A.

2.1.2. Moving Iron

Basic range: 10 mA-100 A Usages
• dc MI ammeters and voltmeters
• ac MI ammeters and voltmeters

Moving-Iron or MI instruments can be classified as
• Attraction-type moving-iron instruments
• Repulsion-type moving-iron instruments

The current to be measured, in general, is passed through a coil of wire in the moving iron instruments. In case of voltage measurement, the current which is proportional to the voltage is measured. The number of turns of the coil depends upon the current to be passed through it. For operation of the instrument, a certain number of ampere turns is required. These ampere turns can be produced by the product of few turns and large current or reverse.

The construction of attraction type and repulsion type moving iron instruments are shown in figure 2.2 and 2.3 respectively.

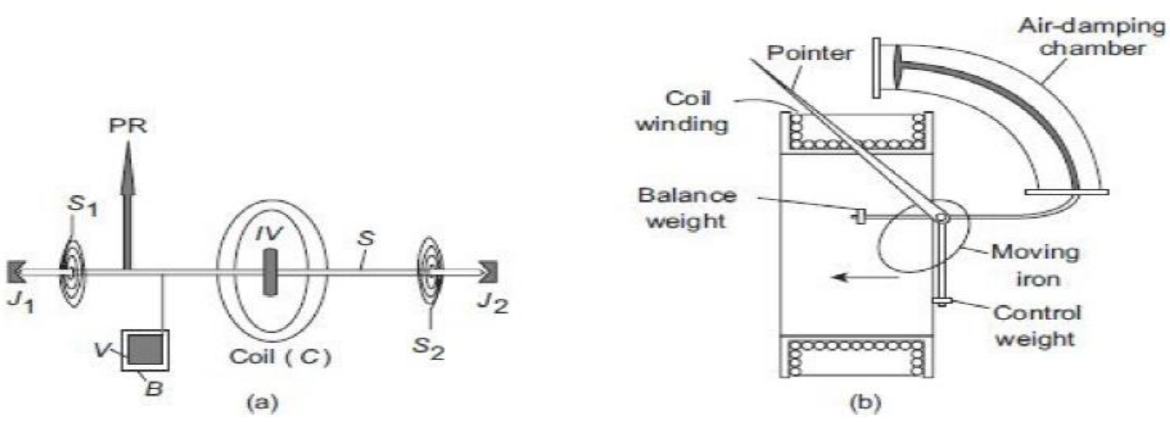


Fig 2.2. Attraction type MI

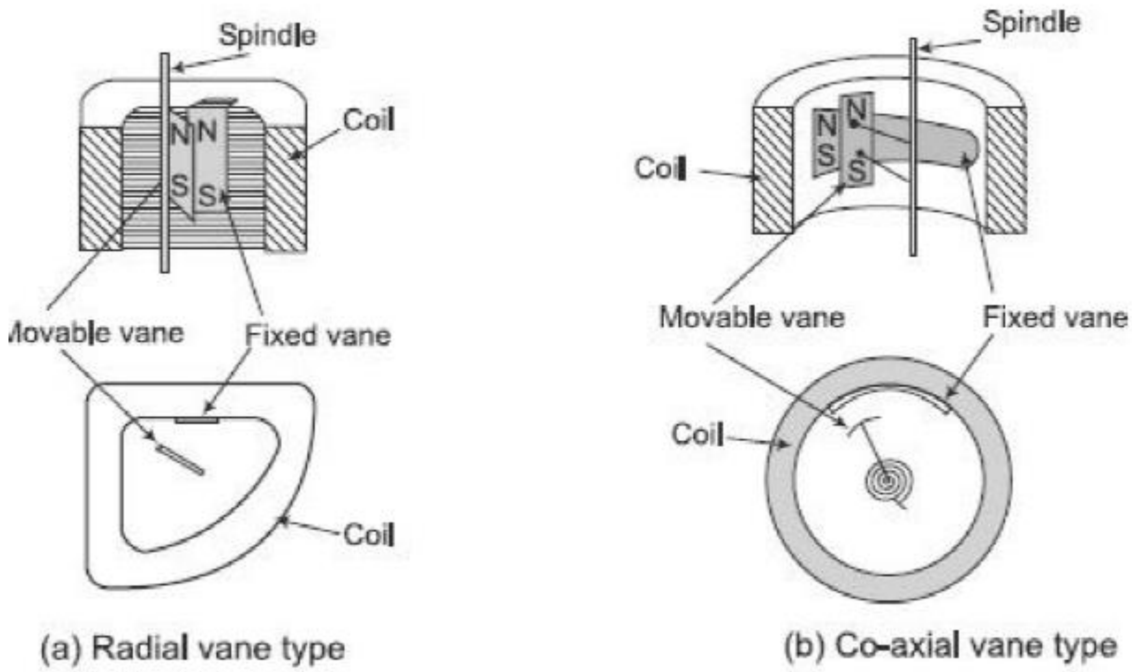


Fig. 2.3. Repulsion Type MI

Deflection torque of MI can be expressed as

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

Where current I is in Ampere , L in Henry , θ is in radians .

In steady state deflecting torque = controlling torque(T_c)

Therefore deflection θ can be expressed as

$$\boxed{\therefore \text{ deflection} \qquad \theta = \frac{1}{2} \frac{I^2}{k} \frac{dL}{d\theta}}$$

Advantages of MI Instruments

1. Robust construction and relatively cheap
2. Suitable for measuring both dc and ac
3. Can withstand overload momentarily

Disadvantages of MI Instruments

1. As the deflection is proportional to I^2, hence the scale of the instrument is not uniform. It is cramped in the lower end and expanded in the upper portion.
2. It is affected by stray magnetic fields.

3. There is hysteresis error in the instrument. The hysteresis error may be minimized by using the vanes of nickel-iron alloy.

2.2 Basic Construction and operation of Electrodynamometer type, rectifier type, thermocouple type instrument

2.2.1 Electrodynamometer type instrument

The electrodynamometer is a transfer-type instrument. A transfer-type instrument is one that may be calibrated with a dc source and then used without modification to measure ac. This requires the transfer type instruments to have same accuracy for both dc and ac.

The electrodynamic or dynamometer-type instrument is a moving-coil instrument but the magnetic field, in which the coil moves, is provided by two fixed coils rather than by permanent magnets. The schematic diagram of electrodynamic instrument is shown in fig. 2.4

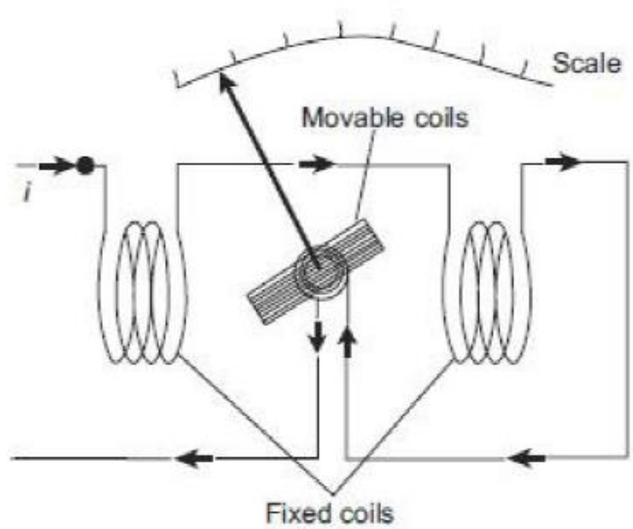


Fig.2.4. Electrodynamometer type instrument

Torque Equation of Electrodynamometer-type Instruments

Let us consider

i_1 = instantaneous value of current in the fixed coils, (A)

i_2 = instantaneous value of current in the moving coils, (A)

L_1 = self-inductance of fixed coils, (H)

L_2 = self-inductance of moving coil, (H)

M = mutual inductance between fixed and moving coils (H)

Flux linkage of Coil 1, $\psi_1 = L_1 i_1 + M_{i2}$

Flux linkage of Coil 2, $\psi_2 = L_2 i_2 + M_{i1}$

Instantaneous deflection torque can be expressed as

$$T_i = i_1 i_2 \frac{dM}{d\theta}$$

For D.C. operation deflecting torque can be expressed as

$$T_d = I_1 I_2 \frac{dM}{d\theta}$$

At steady state condition deflecting torque equals to controlling torque and deflection can be expressed as

$$\theta = \frac{I_1 I_2}{k} \frac{dM}{d\theta}$$

Advantages of Electrodynamometer-type Instruments

1. They can be used on ac as well as dc measurements.
2. These instruments are free from eddy current and hysteresis error.
3. Electrodynamometer-type instruments are very useful for accurate measurement of rms values of voltages irrespective of waveforms.
4. Because of precision grade accuracy and same calibration for ac and dc measurements these instruments are useful as transfer type and calibration instruments.

Disadvantages of Electrodynamometer-type Instruments

1. As the instrument has square law response, the scale is non-uniform.
2. These instruments have small torque/weight ratio, so the frictional error is considerable.
3. More costly than PMMC and MI type of instruments.
4. Adequate screening of the movements against stray magnetic fields is essential.

2.2.2 Rectifier type instrument.

The basic arrangement of a rectifier type of instrument using a full-wave rectifier circuit is shown in Figure 2.5. If this instrument is used for measuring ac quantity then first the ac signal is converted to dc with the help of the rectifier. Then this dc signal is measured by the PMMC meter. The multiplier resistance Rs, is used to limit the value of the current in order that it does not exceed the current rating of the PMMC meter.

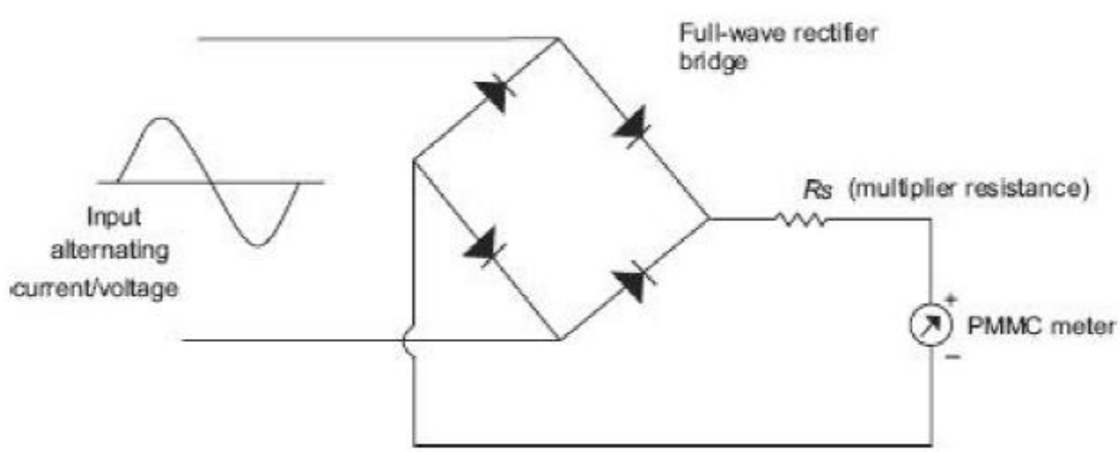


Fig. 2.5 . Rectifier type Instruments

Sensitivity of Rectifier-Type Instrument

The dc sensitivity of a rectifier-type instrument is$S_{dc} = 1/I_{fs}$, where I_{fs} is the current required to produce full-scale deflection .

Extension of Range of Rectifier Instrument as Voltmeter

It is intended to extend the range of a rectifier instrument which uses a PMMC instrument having a dc sensitivity of S_{dc}. Let, v = voltage drop across the PMMC instrument ,V = applied voltage Therefore, for dc operation, the values of series resistance (multiplier) needed can becalculated from Figure 2.6 as $V = R_S . I_{fs} + R_d . I_{fs} + R_m . I_{fs}$

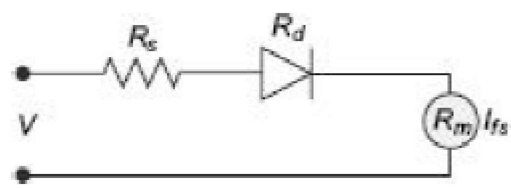


Fig. 2.6 : Range extension of Rectifier Instruments for voltmeter

Where R_m = meter resistance ,R_d = diode forward resistance

Limitations

1. Rectifier instruments are only accurate on the waveforms on which they are calibrated. Since calibration assumes pure sine waves, the presence of harmonics gives erroneous readings.
2. The rectifier is temperature sensitive, and therefore, the instrument readings are affected by large variations of temperature.

Applications

1. The rectifier instrument is very suitable for measuring alternating voltages in the range of 50–250 V.
2. The rectifier instrument may be used as a micrometer or low milliammeter (up to 10–15 mA). It is not suitable for measuring large currents because for larger currents the rectifier becomes too bulky and providing shunts is impracticable due to rectifier characteristics.
3. Rectifier instruments find their principal application in measurement in high-impedance circuits at low and audio frequencies. They are commonly used in communications circuits because of their high sensitivity and low power consumption.

2.2.3 Thermocouple type instrument

When two metals having different work functions are placed together, a voltage is generated at the junction which is nearly proportional to the temperature of the junction. This junction is called a thermocouple. This principle is used to convert heat energy to electrical energy at the junction of two conductors as shown in Fig 2.7

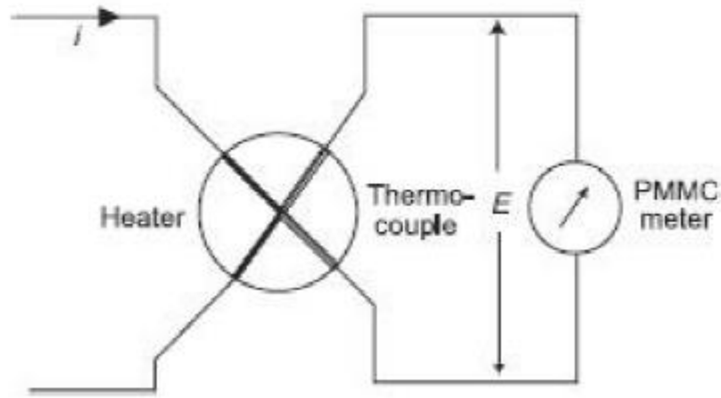


Fig.2.7.Thermocouple type instruments

The heat at the junction is produced by the electrical current flowing in the heater element while the thermocouple produces an emf at its output terminals, which can be measured with the help of a PMMC meter. The emf produced is proportional to the temperature and hence to the rms value of the current. Therefore, the scale of the PMMC instrument can calibrate to read the current passing through the heater

Advantages of Thermocouple-type Instruments

1. These are not affected by stray magnetic fields.
2. They have very high sensitivity.
3. The indication of these instruments are practically unaffected by the frequency and waveform of the measuring quantity. Hence these instruments can be used for measurement of currents upto frequencies of 50 MHz and give accuracy as high as 1%.
4. These instruments are very useful as transfer instruments for calibration of dc instruments by potentiometer and a standard cell.

Disadvantages of Thermocouple-Type Instruments

1. Considerable power losses due to poor efficiency of thermal conversion.
2. Low accuracy of measurement and sensitivity to overloads, as the heater operates at temperatures close to the limit values. Thus, the overload capacity of such instrument is approximately 1.5 times of full-scale current.
3. The multi-voltmeters used with thermo-elements must be necessarily more sensitive and delicate than those used with shunts, and therefore, requires careful handling.

2.3 Construction and operation of Electrodynamometer type wattmeter and single phase induction type energy meter

2.3.1Electrodynamometer type wattmeter

The design and construction of electrodynamometer type wattmeter is similar to electrodynamometer type instrument. The schematic diagram of Electrodynamometer type wattmeter is shown in fig.2.8.

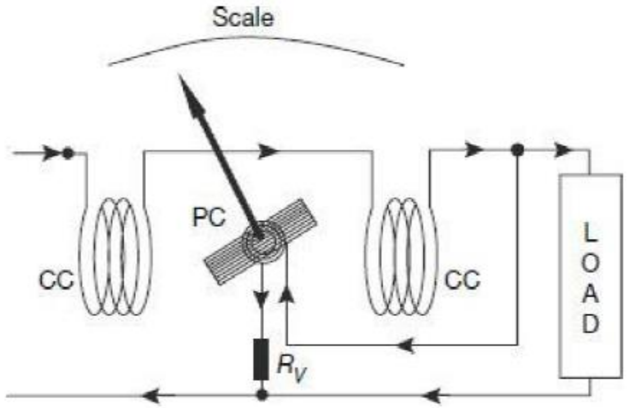


Fig. 2.8 : Schematic diagram of Electrodynamometer type wattmeter

Such an instrument has two coils connected in different ways to the same circuit of whichpower is to be measured. The fixed coils or the field coils are connected in series with the load so as to carry the same current as the load. The fixed coils are hence, termed as the Current Coils (CC) of the wattmeter. The main magnetic field is produced by these fixed coils.

The moving coil that is connected across the load carries a current proportional to the voltage. Since the moving coil carries a current proportional to the voltage, it is called the voltage coil or the pressure coil or simply PC of the wattmeter. The moving coil is entirely embraced by the pair of fixed coils.

Operation of Electrodynamometer-type Wattmeter

The schematic operational circuit of an electrodynamometer-type wattmeter being used for measurement of power in a circuit is shown in Figure 2.9.

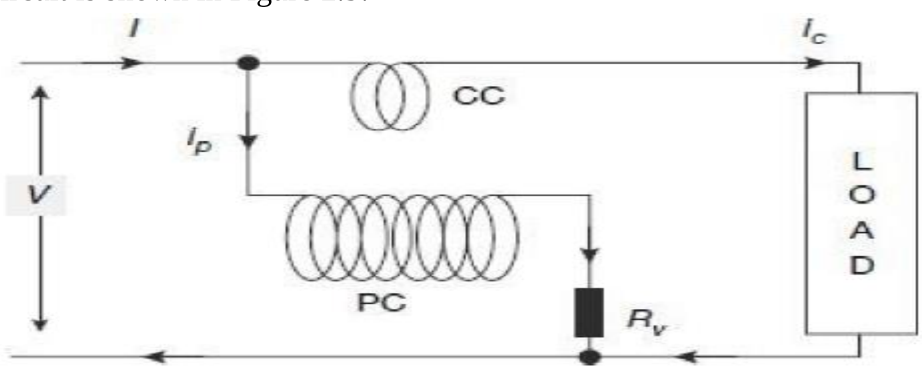


Fig. 2.9. : Operational circuit of Electrodynamometer-type Wattmeter

V = voltage to be measured (rms)
I = current to be measured (rms)
i_P = voltage (pressure) coil instantaneous current
i_C= current coil instantaneous current
R_V = external resistance connected with pressure coil
R_P = resistance of pressure coil circuit (PC resistance + RV)

M = mutual inductance between current coil and pressure coil
θ = angle of deflection of the moving system
ω = angular frequency of supply in radians per second
φ = phase-angle lag of current I with respect to voltage V

It can be proved that deflecting torque of the meter is

$$T_d = \frac{VI\cos\varphi}{R_p}\frac{dM}{d\theta}$$

Where $VI\cos\varphi$ is the power to be measured
At steady state condition Controlling torque = Deflecting torque
i.e. $T_d = T_c$

$T_c = K\theta$
Therefore

$$\theta = \left(K_1 \frac{dM}{d\theta}\right)P$$

2.3.2. Single phase induction type energy meter

Induction-type instruments are most commonly used as energy meters for measurement of energy in domestic and industrial ac circuits. Induction-type meters have lower friction and higher torque/weight ratio.

Construction & operation

There are four main parts of the operating mechanism (i) Driving system (ii) Moving system (iii) Braking system (iv) Registering system

Driving system

• The driving system of the meter consists of two electro-magnets.
• The core of these electromagnets is made up of silicon steel laminations.
• The load current excites the coil of one of the electromagnets. This coil is called the current coil.
• The coil of second electromagnet is connected across the supply and, therefore, carries a current proportional to the supply voltage. This coil is called the pressure coil.
• Consequently the two electromagnets are known as series and shunt magnets respectively.
• Copper shading bands are provided on the central limb.

• The position of these bands is adjustable.
• The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

Moving System
• This consists of an aluminium disc mounted on a light alloy shaft.
• This disc is positioned in the air gap between series and shunt magnets.
• The upper bearing of the rotor (moving system) is a steel pin located in a hole in the bearing cap fixed to the top of the shaft.
• The rotor runs on a hardened steel pivot, screwed to the foot of the shaft.
• A jewel bearing supports the pivot.
• A pinion engages the shaft with the counting or registering mechanism

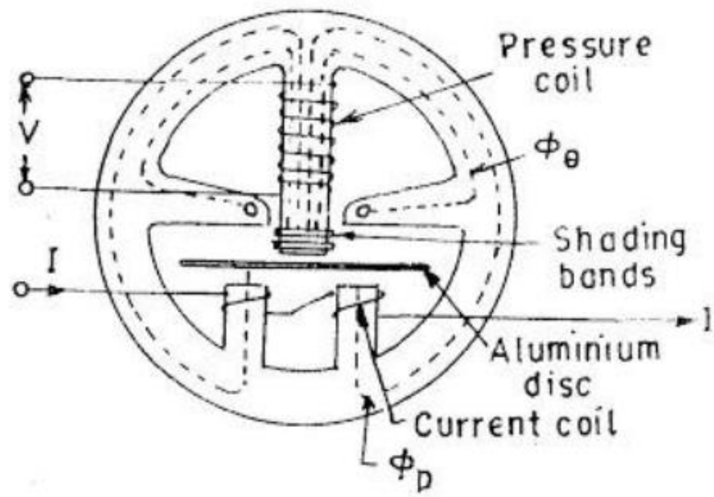


Fig. 2.10: Single phase induction type energy meter

Braking System
• A permanent magnet positioned near the edge of the aluminium disc forms the braking system.
• The aluminium disc moves in the field of this magnet and thus provides a braking torque.
• The position of the permanent magnet is adjustable, and therefore braking torque can be adjusted by shifting the permanent magnet to different radial positions

Registering (counting) Mechanism
• The function of a registering or counting mechanism is to record continuously a number, which is proportional to the revolutions made by the moving system. • By a suitable system, a train of reduction gears the pinion on the rotor shaft drives a series of five or six pointers.
• These rotate on round dials, which are marked with ten equal divisions.

Please Note: It can be shown that speed of the disc is proportional to power consumed .Also the total number of revolution of the disc is proportional to average energy consumed

Errors in the Energy Meter

The errors caused by the driving system are
(i) Incorrect magnitude of fluxes. (ii) Incorrect phase angles. (iii) Lack of Symmetry in magnetic circuit.

The errors caused by the braking system are i) Changes in strength of brake magnet ii) Changes in disc resistance iii) Abnormal friction iv) Self braking effect

Long Answer type Questions
Q2.1
i) Describe the construction and operation of PMMC instrument.

ii) Derive the torque equation of electrodynamometer type instrument.

iii) Explain the principle to measure energy by energy meter

iv) Explain the construction and working of rectifier type instrument . What are the advantages and disadvantages of rectifier type instruments ?

Module 3

Measurement of resistance and AC Bridges

3.1 Wheatstone Bridge

Definition: The device uses for the measurement of minimum resistance with the help of comparison method is known as the Wheatstone bridge. The value of unknown resistance is determined by comparing it with the known resistance. The Wheatstone bridge works on the principle of null deflection, i.e. the ratio of their resistances are equal, and no current flows through the galvanometer. The bridge is very reliable and gives an accurate result.

In normal condition, the bridge remains in the unbalanced condition, i.e. the current flow through the galvanometer. When zero current passes through the galvanometer, then the bridge is said to be in balanced condition. This can be done by adjusting the known resistance P, Q and the variable resistance S.

The working of the bridge is similar to the potentiometer. The Wheatstone bridge is only used for determining the medium resistance. For measuring the high resistance, the sensitive ammeter is used in the circuit.

Construction of Wheatstone Bridge

The basic circuit of the Wheatstone bridge is shown in the figure below. The bridge has four arms which consist two unknown resistance, one variable resistance and the one unknown resistance along with the emf source and galvanometer.

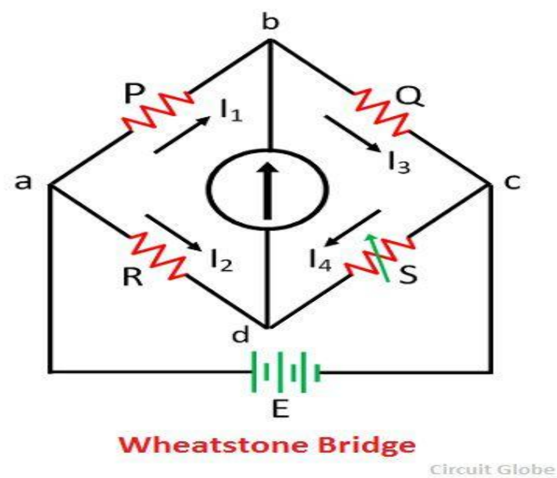


Fig. 3.1 Wheatstone Bridge

The emf supply is attached between point a and b, and the galvanometer is connected between point c and d. The current through the galvanometer depends on the potential difference across it.

Working of Galvanometer

The bridge is in balance condition when no current flows through the coil or the potential difference across the galvanometer is zero. This condition occurs when the potential difference across the a to b and a to d are equal, and the potential differences across the b to c and c to d remain same.

The current enters into the galvanometer divides into I_1 and I_2, and their magnitude remains same. The following condition exists when the current through the galvanometer is zero.

$$I_1 P = I_2 R \dots\dots\dots equ(1)$$

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$

The bridge in a balanced condition is expressed as :

Where E – emf of the battery.

By substituting the value of I_1 and 1_2 in equation (1) we get:

$$\frac{PE}{P+Q} = \frac{RE}{R+S} \quad \frac{P}{P+Q} = \frac{R}{R+S} \quad \begin{array}{c} P(R+S) = R(P+Q) \\ PR + PS = RP + RQ \end{array}$$

$$PS = RQ \ldots\ldots\ldots equ(2)$$

$$R = \frac{P}{Q} \times S \ldots\ldots\ldots equ(3)$$

The equation (2) shows the balance condition of the Wheatstone bridge.

The value of unknown resistance is determined by the help of the equation (3). The R is the unknown resistance, and the S is the standard arm of the bridge and the P and Q are the ratio arm of the bridge.

<u>Errors in Wheatstone Bridge</u>

The following are the errors in the Wheatstone bridge.

1. The difference between the true and the mark value of the three resistances can cause the error in measurement.
2. The galvanometer is less sensitive. Thus, inaccuracy occurs in the balance point.
3. The resistance of the bridge changes because of the self-heating which generates an error.
4. The thermal emf cause serious trouble in the measurement of low-value resistance.
5. The personal error occurs in the galvanometer by taking the reading or by finding the null point.

The above mention error can be reduced by using the best qualities resistor and galvanometer. The error because of self-heating of resistance can minimise by measuring the resistance within the short time. The thermal effect can also be reduced by connecting the reversing switch between the battery and the bridge.

<u>Limitation of Wheat Stone Bridge</u>

The Wheatstone bridge gives inaccurate readings if it is unbalanced. The Wheatstone bridge measures resistance from few ohms to megohms. The upper range of the bridge can be increased with the help of the applied emf, and the lower range is limited by connecting the lead at the binding post.

Sensitivity of the Wheatstone Bridge

The Wheatstone bridge is more sensitive when all their resistances are equal, or their ratio is unity. Their sensitivity decreases when their ratio is less than unity. The reduction in sensitivity reduces the accuracy of the bridge.

Kelvin Bridge Circuit | Kelvin Double Bridge

Before we introduce **Kelvin Bridge**, it is very essential to know what is the need of this bridge, though we have Wheatstone bridge which is capable of measuring electrical resistance accurately as it gives accuracy of 0.1 %. To understand the need of Kelvin bridge let us categorize the electrical resistances on the basis of view point of measurement: Electrical resistances are classified as follows:

1. **High Resistance:** under this category resistance is greater than 0.1 Mega-ohm.
2. **Medium Resistance:** under this category resistance is ranging from 1 ohm to 0.1 Mega-ohm.
3. **Low Resistance:** under this category resistance value is lower than 1 ohm.

Now the logic of doing this classification is that if we want to measure electrical resistance, we have to use different devices for different categories. It means if the device is used in measuring the high resistance gives high accuracy, it may or may not give such high accuracy in measuring the low value of resistance. So, we have to apply our brain to judge what device must be used to measure a particular value of electrical resistance. However there are other kind of methods also like ammeter-voltmeter method, substitution method etc but they give large error as compared to bridge method and are avoided in most of the industries.

Now let us again recall our classification done above, as we move from top to bottom the value of resistance decreases hence, we require more accurate and precise device to measure the low value of resistance.

One of the major drawback of the **Wheatstone bridge** is that, it can measure the resistance from few ohm to several mega ohm but to measure low resistance it gives significant error. So, we need some modification in Wheatstone bridge itself, and the modified bridge so obtained is **Kelvin bridge**, which is not only suitable for measuring low value of resistance but has wide range of applications in the industrial world. Let us discuss few terms that will be very helpful to us in studying the Kelvin Bridge.

Bridge : They are usually consists of four arms, balance detector and source. They works on the concept of null point technique. They are very useful in practical applications because there is no need of making the meter precise linear with an accurate scale. There is no requirement of measuring the voltage and current, the only need is to check the presence or absence of current or voltage. However the main concern is that during the null point meter must be able to pick up fairly small current. A bridge can be defined as the voltage dividers in parallel and the difference between the two dividers is our output. It is highly useful in measuring components like electrical resistance, capacitance, inductor and other parameter of circuit. Accuracy of any bridge is directly related to bridge components.

Null point: It can be defined as the point at which the null measurement occurs when the reading of ammeter or voltmeter is zero.

3.2 Kelvin Bridge Circuit

As we have discussed that Kelvin Bridge is a modified Wheatstone bridge and provides high accuracy especially in the measurement of low resistance. Now the question that must be arise in our mind that where do we need the modification. The answer to this question is very simple, it is the portion of leads and contacts where we must do modification because of these there is an increment in net resistance. Let us consider the modified Wheatstone bridge or **Kelvin bridge circuit** given below:

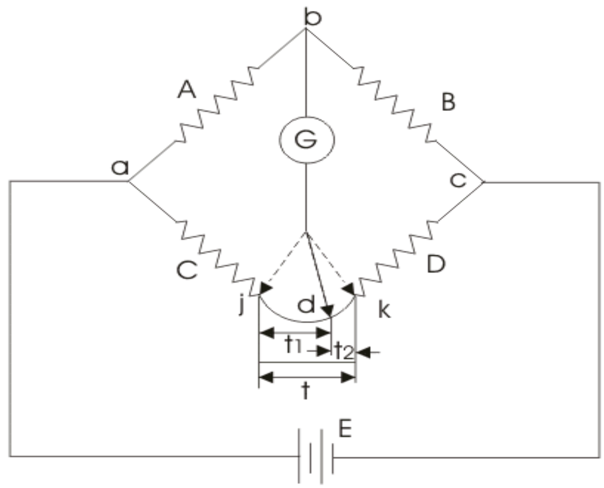


Fig. 3.2 Kelvin Bridge

Here, t is the resistance of the lead. C is the unknown resistance. D is the standard resistance (whose value is known). Let us mark the two points j and k. If the galvanometer is connected to j point the resistance t is added to D which results in too low value of C. Now we connect galvanometer to k point it would result in high value of unknown resistance C. Let us connect the galvanometer to point d which is lying in between j and k such that d divides t into ratio t_1 and t_2, now from the above figure it can be seen that

$$\boxed{\frac{t_1}{t_2} = \frac{A}{B}}$$

Then also the presence of t_1 causes no error, we can write,

$$C + t_1 = \frac{A}{B}(D + t_2)$$

$$Also\ we\ have\ \frac{t_1}{t_2} = \frac{A}{B} \cdots\cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$So,\ \frac{t_1}{t_1 + t_2} = \frac{A}{A + B} \Rightarrow t_1 = \frac{A}{A + B} \times t$$

$$As\ t_1 + t_2 = t\ and\ t_2 = \frac{B}{A + B} \times t$$

We can write equation (1) as

$$C + \frac{A}{A + B} \times t = \frac{A}{B} \times \left(D + \frac{B}{A + B} \times t\right)$$

$$It\ implies\ that\ C = \frac{A}{B} \times D$$

Thus we can conclude that there is no effect of t (i.e. resistance of leads). Practically it is impossible to have such situation however the above simple modification suggests that the galvanometer can be connected between these points j and k so as to obtain the null point.Kelvin Double Bridge

Why it is called double bridge?? it is because it incorporates the second set of ratio arms as shown Below:

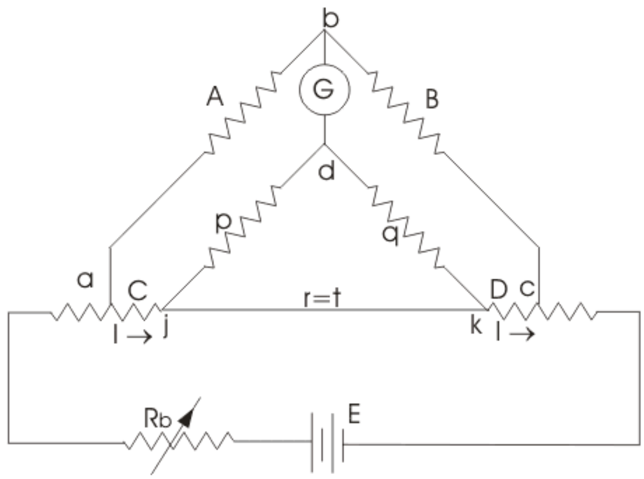


Fig. 3.2.1 Kelvin Double Bridge

In this the ratio arms p and q are used to connect the galvanometer at the correct point between j and k to remove the effect of connecting lead of electrical resistance t. Under balance condition voltage drop between a and b (i.e. E) is equal to F (voltage drop between a and c)

$$Hence,\ E = \frac{A}{A+B} \times F$$

$$\Rightarrow F = I \times \left(C + D + \frac{p+q}{p+q+t} \times t\right)$$

$$Hence,\ G\ i.e.\ (voltage\ drop\ between\ a\ and\ d) = I \times \left(C + \frac{p \times t}{p+q+t}\right)$$

For zero galvanometer deflection, E = F

$$or\ \frac{A}{A+B} \times I\left(C + D + \frac{p+q}{p+q+t} \times t\right) = I \times \left(C + \frac{p}{p+q+t} \times t\right)$$

$$\Rightarrow C = \frac{A}{B} \times D + \frac{q}{p+q+t}\left(\frac{P}{Q} - \frac{p}{q}\right) \cdots\cdots\cdots\cdots\cdots\cdots (2)$$

$$If\ \frac{A}{B} = \frac{p}{q}\ then\ C = \frac{A}{B} \times D$$

Again we reaches to the same result i.e. t has no effect. However equation (2) is useful as it gives error when, $If\ \frac{A}{B} = \frac{p}{q}$

3.3 Measurement of high resistance

High Resistance:

- Resistances of 100 kilo ohms and above are usually termed as high resistances.
- Measurement of high resistances are required for determination of insulation resistance of components and built up electrical equipment of all types volume, resistivity of a material, surface resistivity and resistance of high resistance circuit elements.

Measurement of High Resistance:

1. Three wires are required to represent a high resistance.
2. The third, guard terminal, G is utilized to reduce the errors because of leakage currents caused by insulation.
3. The methods are used for the measurement of high resistance are

- Loss of discharge method
- Direct deflection method
- Mega ohm bridge resistance method
- Megger

3.4 Earth resistance measurement

Measurement of Earth Resistance is a vital part of the maintenance of any electric installation. The function of a sound earthing system is to ensure that all electric equipment are connected to the ground potential. Hence, a well-maintained earthing system ensures the proper functioning of protection systems, absorbs electrical noise and provides safety to operating personnel. The earth resistance is measured using an earth meggar.

"Fall of Potential" Method:
The Earth resistance is measured using the "Fall of Potential" Method. The method works by injecting a constant current between two spikes which are inserted into the ground and measuring the voltage at points between them (as shown in the figure)

The "Fall of Potential" Method is a three terminal test. The electrode whose earth resistance is to be measured is disconnected from the system or earthing grid. The earth meggar has a current terminal, a

voltage terminal and a common terminal. The common terminal is connected to the electrode,

Equal lines of potential

When an electrode is inserted into the ground and current flows through it, the potential around the electrode takes the form of concentric circles of equal potential.

It is essential that the equal lines of the common terminal and the current terminal do not overlap. Therefore distance between the ground electrode to be tested and the current terminal is vital. The distance should be sufficient so that the equal lines of potential of the common terminal and the current terminal do not overlap.

Method of Measurement:
The readings are taken at points close to the ground electrode and then gradually away from it. The resistance readings in ohms are plotted against the distance in a graph. The graph should take the form as below. At around 62% of the distance between the ground electrode and the current terminal, the graph levels off. This reading is taken as the value of the earth resistance. This point should be outside the equipotential zones of both the current terminal and the ground electrode.

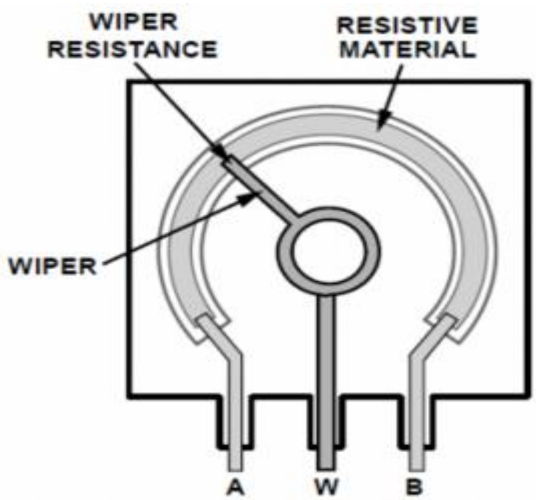
3.5 Localizing ground and short circuit fault

Impedance testing is a (generally) non-destructive way to find shorts in cables. TDR (Time Domain Reflectometry) can also be useful for finding the location of a short, and can also identify and locate open circuits or any significant impedance discontinuities in a cable or any transmission (signal or power) line.

3.6 Potentiometer

3.6.1 What is the principle of a potentiometer?

The **principle** of the **potentiometer** is that: For a wire having uniform area of cross section and uniform composition,the potential drop is directly proportional to the length of wire. The above **principle** is valid when **potentiometer** is used in comparing the EMF of two cells.



3.6.2 Why are there three terminals on a potentiometer?

A **3 terminal** pot used with **3 terminals**, is basically just a voltage divider. ... A rheostat is a variable resistor. You don't **have** to connect one the wiper to ground. So long as the wiper is connected to one leg of the **potentiometer**, it will behave a variable resistor.

3.6.3 What is the use of potentiometer?

The measuring instrument called a **potentiometer** is essentially a voltage divider **used for** measuring electric potential (voltage); the component is an implementation of the same principle, hence its name. **Potentiometers** are commonly **used to** control electrical devices such as volume controls on audio equipment.

3.6.4 What does the potentiometer measure?

A potentiometer being calibrated and then measuring an unknown **voltage**. R_1 is the resistance of the entire resistance wire. The arrow head represents the moving wiper.

3.6.5 How does a potentiometer operate?

A **potentiometer** has 3 pins. Two terminals (the blue and green) are connected to a resistive element and the third terminal (the black one) is connected to an adjustable wiper. The **potentiometer** can **work** as a rheostat (variable resistor) or as a voltage divider.

3.7 Maxwell's Bridge

Definition:

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.

Types of Maxwell's Bridge

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**

Maxwell's Inductance Bridge

In such type of bridges, the value of unknown resistance is determined by comparing it with the known value of the standard self-inductance. The connection diagram for the balance Maxwell bridge is shown in the figure below.

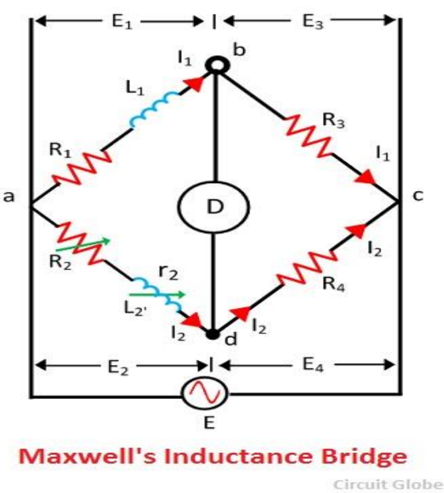


Fig. 3.7 Maxwell's Bridge

Let, L_1 – unknown inductance of resistance R_1.
L_2 – Variable inductance of fixed resistance r_1.
R_2 – variable resistance connected in series with inductor L_2.
R_3, R_4 – known non-inductance resistance

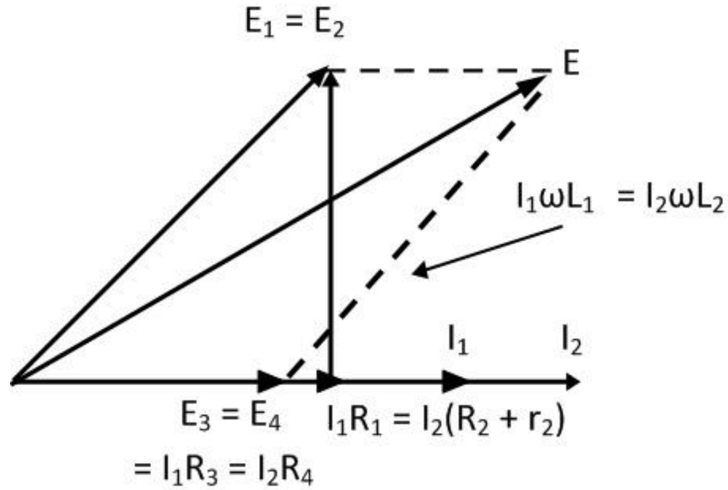
At balance,

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

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

The value of the R_3 and the R_4 resistance varies from 10 to 1000 ohms with the help of the resistance box. Sometimes for balancing the bridge, the additional resistance is also inserted into the circuit.

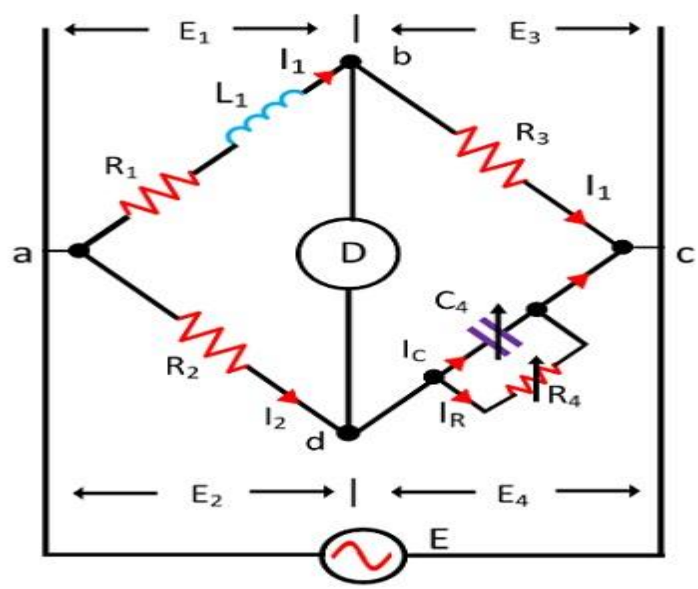
The phasor diagram of Maxwell's inductance bridge is shown in the figure below.



Phasor Diagram of Maxewell Inductance Bridge

<u>Maxwell's Inductance Capacitance Bridge</u>

In this type of bridges, the unknown resistance is measured with the help of the standard variable <u>capacitance</u>. The connection diagram of the Maxwell Bridge is shown in the figure



Maxewell's Inductance Capacitance Bridge

below.

Let, L_1 – unknown inductance of resistance R_1.
R_1 – Variable inductance of fixed resistance r_1.
R_2, R_3, R_4 – variable resistance connected in series with inductor L_2.
C_4 – known non-inductance resistance

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

$$R_1 R_4 = j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$$

For balance condition,

By separating the real and imaginary equation we get,

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

$$L_1 = R_2 R_3 C_4$$

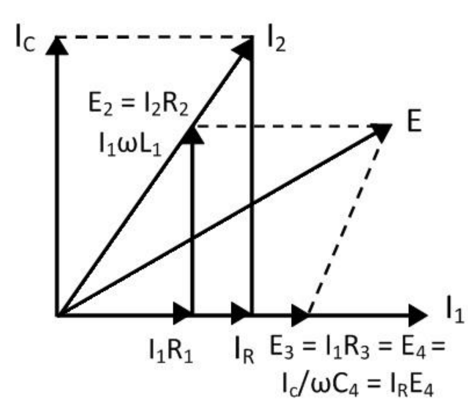
The above equation shows that the bridges have two variables R_4 and C_4which appear in one of the two equations and hence both the equations are independent.

The circuit quality factor is expressed as

$$Q = \frac{\omega L_1}{R_1} = \omega C_4 R_4$$

Phasor diagram of Maxwell’s inductance capacitance bridge is shown in the

Figure below



Phasor Diagram of Inductance Capacitance Bridge

<u>Advantages of the Maxwell’s Bridges</u>

The following are the advantages of the Maxwell 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

The main disadvantages of the bridges are

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.

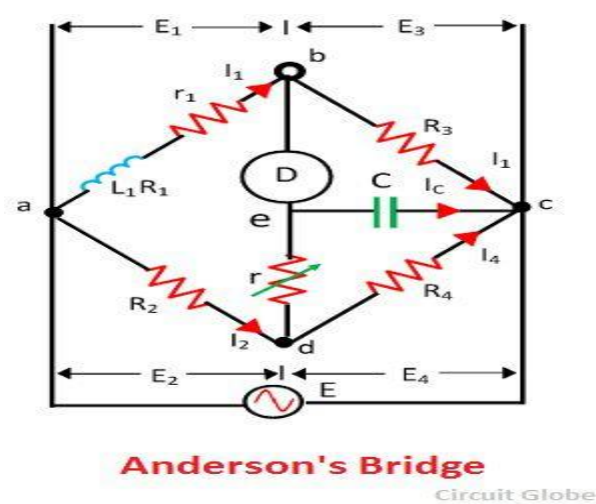
Because of the following disadvantages, the Hays bridge is used for the measurement of circuit inductance which is the advanced form of the Maxwell's Bridge.

3.8 Anderson's Bridge

Definition: The **Anderson's bridge** gives the **accurate measurement**of **self-inductance** of the circuit. The bridge is the **advanced form** of **Maxwell's inductance capacitance bridge.** In Anderson bridge, the **unknown inductance** is compared with the **standard fixed capacitance**which is connected between the two arms of the bridge.

Constructions of Anderson's Bridge

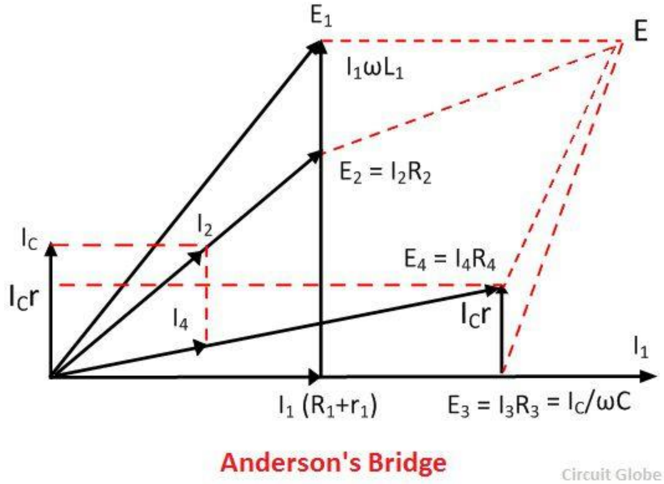
The bridge has fours arms **ab, bc, cd,** and **ad.** The arm **ab** consists unknown inductance along with the resistance. And the other three arms consist the purely resistive arms connected in series with the circuit.



The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.

Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson bridge is shown in the figure below. The current $\mathbf{I_1}$ and the $\mathbf{E_3}$ are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec**are equal.



The current enters into the bridge is divided into the two parts $\mathbf{I_1}$ and $\mathbf{I_2}$. The $\mathbf{I_1}$ is entered into the arm **ab** and causes the voltage drop $\mathbf{I_1(R_1+R)}$ which is in phase with the $\mathbf{I_1}$. As the bridge is in the balanced condition, the same current is passed through the arms bc and **ec.**

The voltage drop $\mathbf{E_4}$ is equal to the sum of the $\mathbf{I_C/\omega C}$ and the $\mathbf{I_C\, r}$. The current $\mathbf{I_4}$ and the voltage $\mathbf{E_4}$ are in the same phase and representing on the same line of the phasor diagram. The sum of the current $\mathbf{I_C}$ and $\mathbf{I_4}$ will give rise to the current $\mathbf{I_2}$ in the arm **ad.**

When the bridge is at balance condition the emf across the arm **ab** and the point **a, d** and **e** are equal. The phasor sum of the voltage across the arms **ac**and **de** will give rise the voltage drops across the arm **ab**.

The $\mathbf{V_1}$ is also obtained by adding the $\mathbf{I_1(R_1+r_1)}$ with the voltage drop $\mathbf{\omega I_1L_1}$in the arm **AB**. The phasor sum of the $\mathbf{E_1}$ and $\mathbf{E_3}$ or $\mathbf{E_2}$ and $\mathbf{E_4}$ will give the supply voltage.

Theory of Anderson Bridge

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

At balance Condition, $I_1 = I_3 \; and \; I_2 = I_C + I_4$

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

Now, $I_C = I_1 \omega C R_3$

The other balance condition equation is expressed as

$$I_1(r_1 + R_1 + j\omega L_1) = I_2R_2 + I_Cr$$

$$I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C)R_4$$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2R_2 + I_1j\omega CR_3r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega CR_3r) = I_2R_2$$

and

$$I_1(R_3 + j\omega R_3R_4 + j\omega CR_3r) = I_2R_4$$

on equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega CR_3r) = I_1(\frac{R_1R_2}{R_3} + \frac{j\omega CR_3rR_2}{R_4} + j\omega CR_3R_2)$$

Equating the real and the imaginary part, we get

$$R_1 = \frac{R_1R_3}{R_4} - r_1$$

$$L_1 = C\frac{R_3}{R_4}[4(R_4 + R_2) + R_2R_4]$$

<u>Advantages of Anderson Bridge</u>

The following are the advantages of the Anderson's Bridge.

1. The balance point is easily obtained on the Anderson bridge as compared to Maxwell's inductance capacitance bridge.
2. The bridge uses fixed capacitor because of which accurate reading is obtained.
3. The bridge measures the accurate capacitances in terms of inductances.

<u>Disadvantages of Anderson Bridge</u>

The main disadvantages of Anderson's bridge are as follow.

1. The circuit has more arms which make it more complex as compared to Maxwell's bridge. The equation of the bridge is also more complex.
2. The bridge has an additional junction which arises the difficulty in shielding the bridge.

Because of the above-mentioned disadvantages, Maxwell's inductance capacitance bridge is used in the circuit.

3.9 De Sauty Bridge

This bridge provide us the most suitable method for comparing the two values of capacitor if we neglect dielectric losses in the bridge circuit. The circuit of **De Sauty's bridge** is shown below.

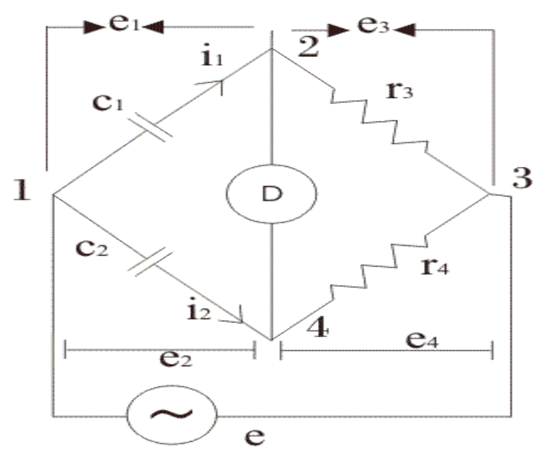


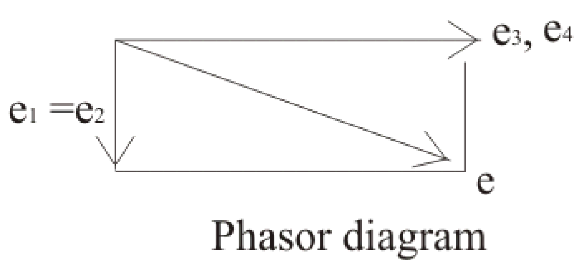
Fig 3.9 De Sauty Bridge

Battery is applied between terminals marked as 1 and 4. The arm 1-2 consists of capacitor c_1 (whose value is unknown) which carries current i_1 as shown, arm 2-4 consists of pure resistor (here pure resistor means we assuming it non inductive in nature), arm 3-4 also consists of pure resistor and arm 4-1 consists of standard capacitor whose value is already known to us. Let us derive the expression for capacitor c_1 in terms of standard capacitor and resistors. At balance condition we have,

$$\frac{1}{j\omega c_1} \times r_4 = \frac{1}{j\omega c_2} \times r_3$$

It implies that the value of capacitor is given by the expression $c_1 = c_2 \times \frac{r_4}{r_3}$ In order to obtain the balance point we must adjust the values of either r_3 or r_4 without disturbing any other element of the bridge. This is the most efficient method of comparing the two values of capacitor if all the dielectric losses are neglected from the circuit.

Now let us draw and study the phasor diagram of this bridge. Phasor diagram of **De Sauty bridge** is Shown below:



:

Let us mark the current drop across unknown capacitor as e_1, voltage drop across the resistor r_3 be e_3, voltage drop across arm 3-4 be e_4 and voltage drop across arm 4-1 be e_2. At balance condition the current flows through 2-4 path will be zero and also voltage drops e_1 and e_3 be equal to voltage drops e_2 and e_4 respectively.

3.10 Schering Bridge

c_2 is a standard capacitor. c_4 is a variable capacitor. r_3 is a pure resistor (i.e. non inductive in nature). And r_4 is a variable non inductive resistor connected in parallel with variable capacitor c_4. Now the supply is given to the bridge between the points a and c. The detector is connected between b and d. From the theory of ac bridges we have at balance condition,

Substituting the values of z_1, z_2, z_3 and z_4 in the above equation, we get

$$\left(r_1 + \frac{1}{j\omega c_1}\right)\left(\frac{r_4}{1 + j\omega c_4 r_4}\right) = \frac{r_3}{j\omega c_2}$$

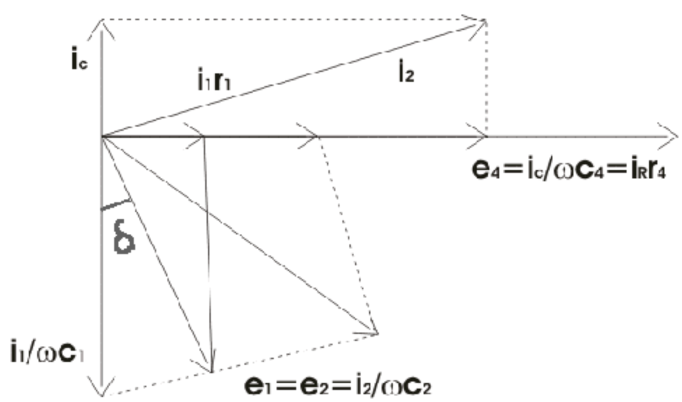
$$(r_1 + \frac{1}{j\omega c_1})r_4 = \frac{r_3}{j\omega c_2}(1 + j\omega c_4 r_4)$$

$$r_1 r_4 - \frac{j r_4}{\omega c_1} = -\frac{j r_3}{\omega c_2} + \frac{r_3 r_4 c_4}{c_2}$$

$$r_1 = \frac{r_3 c_4}{c_2}$$

$$c_1 = c_2 \frac{r_4}{r_3}$$

Equating the real and imaginary parts and the separating we get,



Let us consider the phasor diagram of the above Shering bridge circuit and mark the voltage drops across ab,bc,cd and ad as e_1, e_3,e_4 and e_2 respectively. From the above Schering bridge phasor diagram, we can calculate the value of tanδ which is also called the dissipation factor.

$$tan\delta = \omega c_1 r_1 = \omega \frac{c_2 r_4}{r3} \times \frac{r_3 c_4}{c_2} = \omega c_4 r_4$$

The equation that we have derived above is quite simple and the dissipation factor can be calculated easily. Now we are going to discuss high voltage Schering Bridge in detail. As we have discussed that simple schering bridge (which uses low voltages) is used for measuring dissipation factor, capacitance and measurement of other properties of insulating materials like insulating oil etc.

What is the need of high voltage schering bridge?

The answer to this question is very simple, for the measurement of small capacitance we need to apply high voltage and high frequency as compare to low voltage which suffers many disadvantages. Let us discuss more features of this high voltage Schering Bridge:

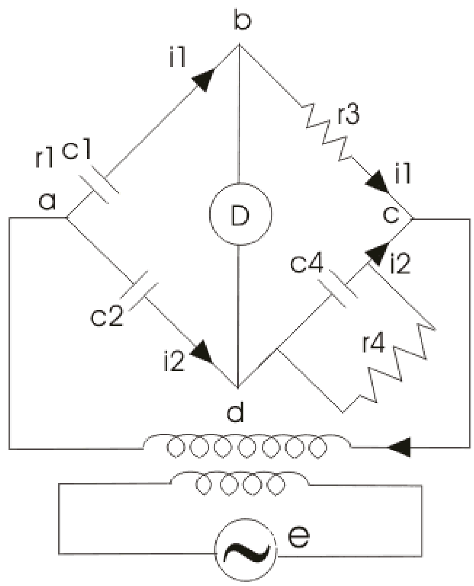
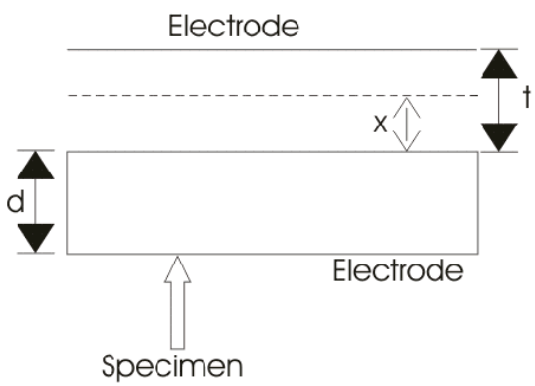


Fig 3.10 Schering Bridge

1. The bridge arms ab and ad consists of only capacitors as shown the bridge given below and impedances of these two arms are quite large as compared to the impedances of bc and cd. The arms bc and cd contains resistor r_3 and parallel combination of capacitor c_4 and resistor r_4 respectively. As impedances of bc and cd are quite small therefore drop across bc and cd is small. The point c is earthed, so that the voltage across bc and dc are few volts above the point c.
2. The high voltage supply is obtained from a transformer 50 Hz and the detector in this bridge is a vibration galvanometer.
3. The impedances of arms ab and ad very are large therefore this circuit draws low current hence power loss is low but due to this low current we need a very sensitive detector to detect this low current.
4. The fixed standard capacitor c_2 has compressed gas which works as dielectric therefore dissipation factor can be taken as zero for compressed air. Earthed screens are placed between high and low arms of the bridge to prevent errors caused due to inter capacitance.

Let us study how Schering bridge measures relative permittivity: In order measure the relative permittivity, we need to first measure capacitance of a small capacitor with specimen as dielectric. And from this measured value of capacitance relative permittivity can calculated easily by using the very simple relation: $r = \frac{cd}{\epsilon A}$

Where, r is relative permeability. c is the capacitance with specimen as dielectric. d is the spacing between the electrodes. A is the net area of electrodes. and ε is permittivity of free space. There is another way to calculate relative permittivity of the specimen by changing electrode spacing. Let us consider diagram shown below:



Here A is the area of electrode. d is the thickness of the specimen. t is the gap between the electrode and specimen (here this gap is filled by compressed gas or air). c_s is the capacitance of specimen. c_o is capacitance due to spacing between electrode and specimen. c is the effective combination of c_s and c_o.

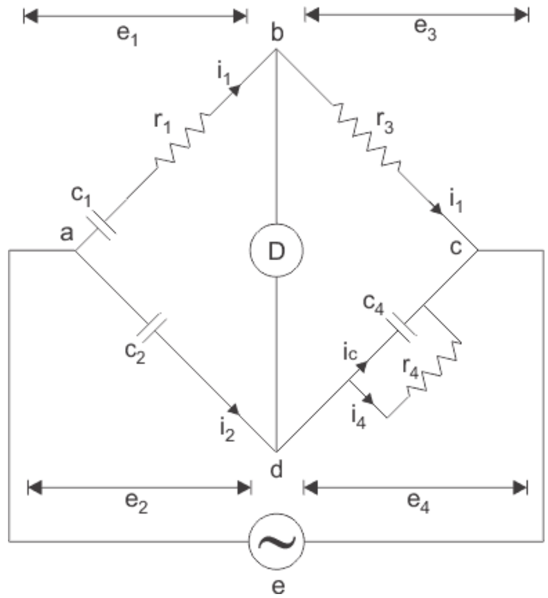
$Now,\ c = \frac{c_s c_o}{c_s + c_o}$ From figure above, as two capacitors are connected in series,

$c = \frac{\epsilon_r \epsilon_o A}{\epsilon_r t + d} \cdots\cdots\cdots(1)$ ϵ_o is permittivity of free space, ϵ_r is relative permittivity, when we remove specimen and the spacing readjusted to have same value of capacitance, the expression for capacitance reduces to $c = \frac{\epsilon_o A}{t + d - x} \cdots\cdots\cdots(2)$

On equating (1) and (2), we will get the final expression for of ϵ_r as: $\epsilon_r = \frac{d}{d - x}$

Schering Bridge Theory

This bridge is used to measure to the capacitance of the capacitor, dissipation factor and measurement of relative permittivity. Let us consider the circuit of Schering bridge as shown below:

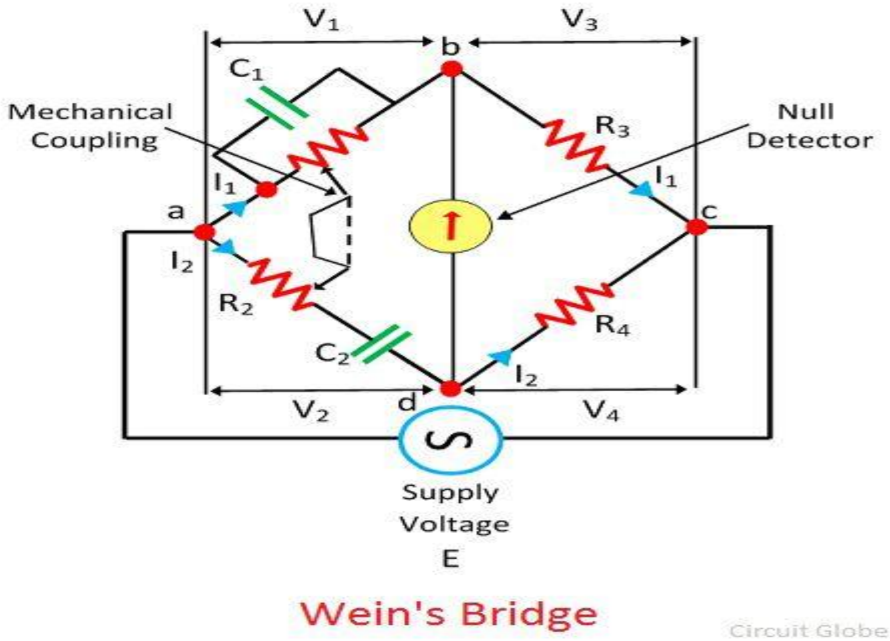


Here, c_1 is the unknown capacitance whose value is to be determined with series electrical resistance r_1.

3.11 Wien's Bridge

The Wien's bridge use in AC circuits for determining the value of unknown frequency**.** The bridge measures the frequencies from 100Hz to 100kHz. The accuracy of the bridges lies between 0.1 to 0.5 percent. The bridge is used for various other applications like capacitance measurement, harmonic distortion analyser and in the HF frequency oscillator.

The Wien's bridge is frequency sensitive. Thereby, it is difficult to obtain the balance point in it. The input supply voltage is not purely sinusoidal, and they have some harmonics. The harmonics of the supply voltage disturbs the balance condition of the bridge. To overcome this problem the filter is used in the bridge. The filter connects in series with the null detector.



When the bridge is in the balanced condition, the potential of the node B and C are equal, i.e., the $V_1 = V_2$ and $V_3 = V_4$ The phase and the magnitude of $V_3 = I_1R_3$ and $V_4 = I_2R_4$ are equal, and they are overlapping each other. The current I_1 flowing through the arm BD and the current I_2 flowing through R_4 is also in phase along with the I_1R_3 and I_2R_4.

The total voltage drop across the arm AC is equal to the sum of the voltage drop I_2R_2 across the resistance R_2 and the capacitive drop I_2/wC_2 across the capacitance C_2. When the bridge is in a balanced condition, the voltage V_1 and V_2 both are equals in magnitude and phase.

The phase of the voltage V_1 and the voltage drop I_RR_1 across the arms R_1 is also same. The resistance R_1 is in the same phase as that of the voltage V_1. The phasor sum of V_1 and V_3 or V_2 and V_4 will give the resultant supply voltage.

$$\left(\frac{R_1}{1+j\omega C_1 R_1}\right)R_4 = \left(R_2 - \frac{j}{\omega C_2}\right)R_3$$

At balance condition,

On equating the real part,

$$R_1R_4C_2 = R_2C_2R_3 + R_3C_1R_1$$

$$\frac{R_1R_4C_2}{R_1R_3C_2} = \frac{R_2C_2R_3}{R_1R_3C_2} + \frac{R_3C_1R_1}{R_1R_3C_2}$$

$$\frac{R_4}{R_3} = \frac{R_2}{R_1} + \frac{C_1}{C_2}$$

On comparing the imaginary part,

$$R_3R_2\omega^2C_2C_1R_1 = R_3$$

$$R_2\omega^2C_2C_1R_1 = 1$$

$$\omega = \frac{1}{\sqrt{R_1R_2C_1C_2}}$$

By substituting the value of $\omega = 2\pi f$,

$$f = \frac{1}{2\pi\sqrt{R_1R_2C_1C_2}}$$

The slider of the resistance R_1 and R_2 mechanically connect to each other. So that, the $R_1 = R_2$ obtains.

A. Multiple choice questions:

1. In the simplest form, an AC bridge consists of ____________
a) arms, source and a detector
b) arms and source
c) source and detector
d) arms and detector
2. Source is ________
a) dc supply
b) ac supply
c) mixed mode supply
d) high voltage supply
3. At high frequency, source consists of ________
a) amplifiers
b) regulators
c) oscillators
d) op amps
4. Commonly used balance detectors for AC bridges are headphones, tuned amplifiers and vibration galvanometers.
a) True
b) False
5. What is the frequency range for a headphone as a detector?
a) 20 Hz to 20 kHz
b) 10 kHz to 1 MHz
c) 10 MHz to 1 GHz
d) 250 Hz to 4 kHz

6. For single frequency value, the most sensitive detector is ________
a) tuned detector
b) vibration galvanometer
c) headphone
d) oscillator
7. Tuned detectors are used in the frequency range of ________
a) 1 Hz to 100 Hz
b) 10 Hz to 100 Hz
c) 1 kHz to 100 kHz
d) 1 MHz to 100 MHz
8. Vibration galvanometers are used for ________
a) very high frequency
b) very low frequency
c) low audio frequency
d) high audio frequency
9. AC bridge is an outcome of ________
a) Kelvin bridge
b) Megger
c) De Sauty bridge
d) Wheatstone bridge
10. Maxwell-Wien bridge is used for measuring

(a) capacitance
(b) dielectric loss
(c) inductance
(d) phase angle
11. Maxwell's L/C bridge is so called because
(a) it employs L and C in two arms
(b) ratio L/C remains constant
(c) for balance, it uses two opposite impedances in opposite arms
(d) balance is obtained when L = C
12. .... bridge is used for measuring an unknown inductance in terms of a known capacitance and resistance.
(a) Maxwell's L/C
(b) Hay's
(c) Owen
(d) Anderson

13. Anderson bridge is a modification of .... bridge.
(a) Owen
(b) Hay's
(c) De Sauty
(d) Maxwell-Wien

14. Hay's bridge is particularly useful for measuring
(a) inductive impedance with large phase angle

(b) mutual inductance
(c) self inductance
(d) capacitance and dielectric loss

15. The most useful ac bridge for comparing capacitances of two air capacitors is .... bridge.
(a) Schering
(b) De Sauty
(c) Wien series
(d) Wien parallel

16. Heaviside-Campbell Equal Ratio bridge is used for measuring
(a) self-inductance in terms of mutual inductance
(b) capacitance in terms of inductance
(c) dielectric loss of an imperfect capacitor
(d) phase angle of a coil

Long answer type questions

1.Explain any one bridge circuit for measurement of inductance.

2.Explain the method of measuring the insulating property of a capacitor by relevant bridge circuit.

3.Describe the circuit of Kelvin’s double bridge used for measurement of low resistance. Derive the conditions for balance

Module 4

Electronic Instrument

4.1 Construction and operation of DMM

A **Digital multimeter** or **DMM** is a test equipment used for resistance, voltage, current measurement and other electrical parameters as per requirement and displaying the results in the mathematical digits form on an LCD or LED readout. It is a type of multimeter which functions digitally. Digital multimeters are widely accepted worldwide as they have better accuracy levels and ranging from simple 3 ½ to 4 ½ digit handheld DMM to very special system DMM.

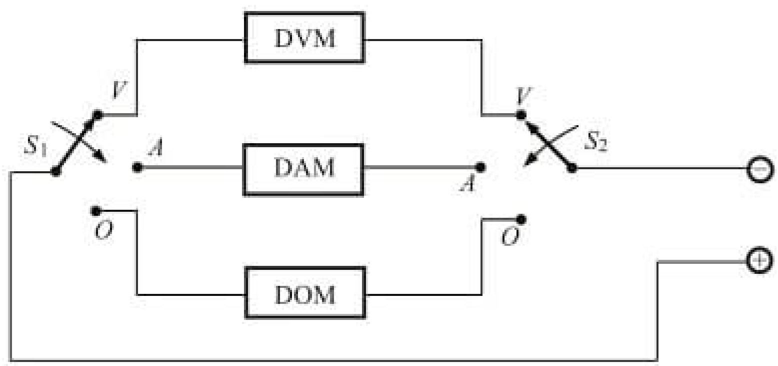
Features of Digital Multimeter

Digital multimeter is most advanced instruments that make use of modern Integrated circuits for making electrical measurements. Some of its features which make it famous in the eyes of professional technicians are:

1. It is light in weight.
2. Capable of giving more accurate readings.
3. It measures lots of physical quantities like voltage, current, resistance, frequency etc.
4. It is less costly.
5. It measures different electrical parameters at high frequencies with the help of special probes.

Block diagram of Digital multimeter

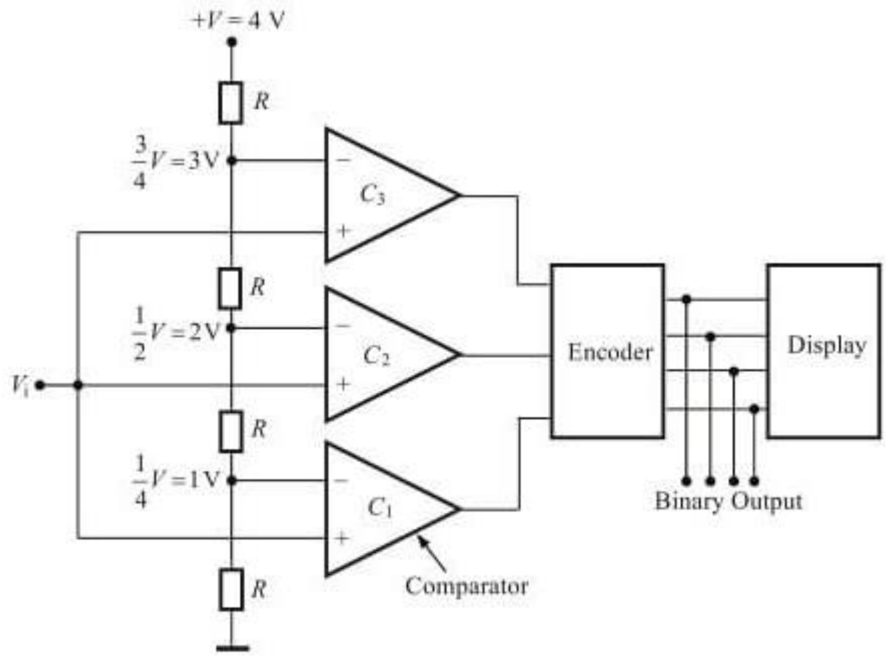
In digital multimeter, we can incorporate many types of meters like ohmmeter, ammeter, a voltmeter for the measurement of electrical parameters. Its block diagram is shown below in the figure. Let us have a look at its working and specification one by one.



(i) Digital voltmeter (DVM):

Digital voltmeter is the basic instrument used for measurement of voltage through the use of Analog to Digital converter. The basic principle behind the digital multimeters is the Analog to digital converter because without this we are not able to convert the analog output into digital form. There are several ADC available in the market, but we mainly use Flash type ADC due to its simplicity and fastest speed. Let's have a look at its basic operation.

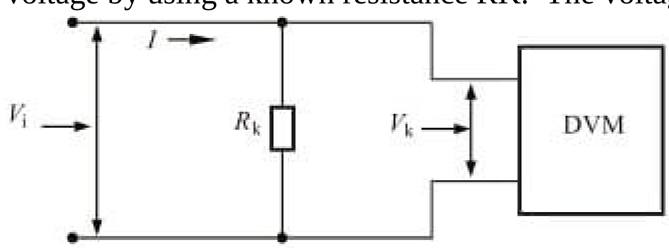
(a) Flash AD converter: It comprises of comparators, encoder, and digital display. Comparators are driven by resistor divider network, the encoder converts its inputs to corresponding outputs which drive the digital display.



As shown above, three resistors of value R drives the comparators C1, C2, C3. Let the input voltage Vi = 1v, +V= 4V and comparators i.e. C1 , C2, C3 voltages equal to 1V, 2V and 3V respectively. If the output of the C1 = +1 and C2=C3= 0, then we fed 001 as the input to the encoder which further converts it into 0001. This binary output drives the seven segment display to read 1V on it. With the help of this method, we read the voltages of magnitude 1V, 2V, 3V and we also add more comparators for more accurate readings as per our requirement.

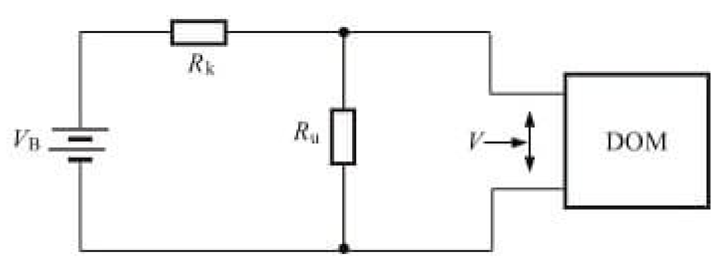
(ii) Digital Ammeter (DAM):

Digital ammeter uses a shunt resistor to produce a calibrated voltage proportional to the current flowing. As shown in the diagram, to read the current we must first convert the current to be measured into a voltage by using a known resistance RK. The voltage so developed is calibrated to read the input current.



(iii) Digital Ohm meter (DOM):

A digital ohmmeter is used to measure electrical resistance which obstructs the path to the flow of current.



As shown in the diagram, resistance network comprising a known resistance R_k and unknown resistance Ru used to develop a voltage across the unknown resisttance. The voltage is given by

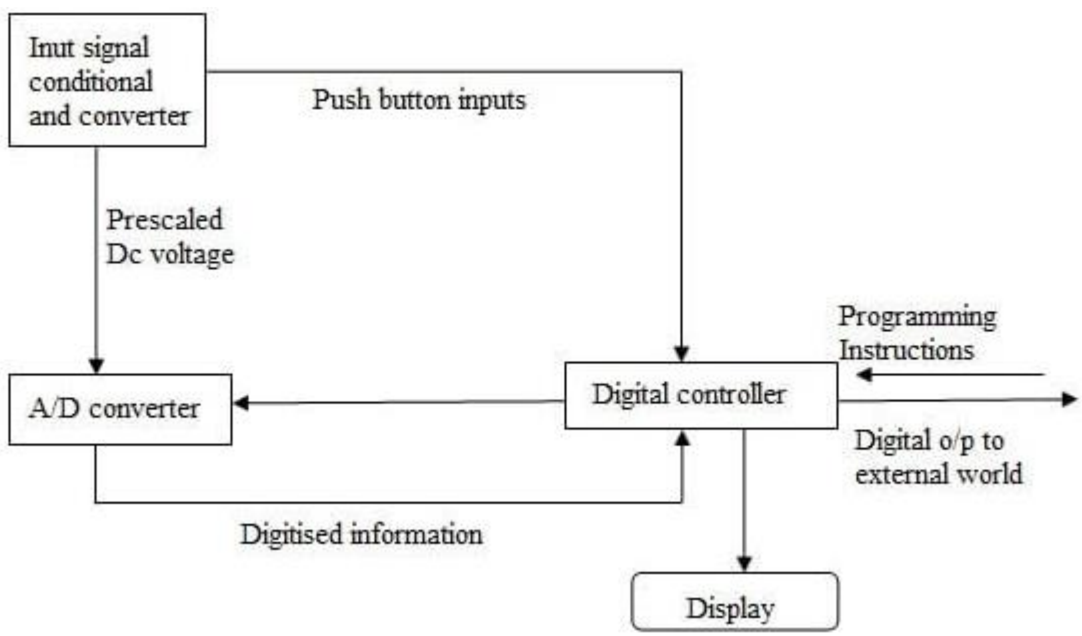
V = VB Ru / RK + Ru

where VB = Voltage of the built-in battery

After calibrating voltage, the meter can be calibrated in terms of ohms.

Working Principle of Digital Multimeter

As shown in block diagram, in a typical Digital multimeter the input signal i.e ac or dc voltage, current, resistance, temperature or any other parameter is converted to dc voltage within the range of the ADC. The analog to digital converter then converts the pre-scaled dc voltage into its equivalent digital numbers which will be displayed on the display unit. Sometimes, digital controller block is implemented with a microcontroller or a microprocessor manages the flow of information within the instrument. This block will coordinate all the internal functions as well as transferring information to external devices such as printers or personal computer. In the case of some hand held multimeter, some of or all of these blocks may be implemented in a VLSI circuit while A/D converter and display driver can be in the same IC.



4.2 Function Generator

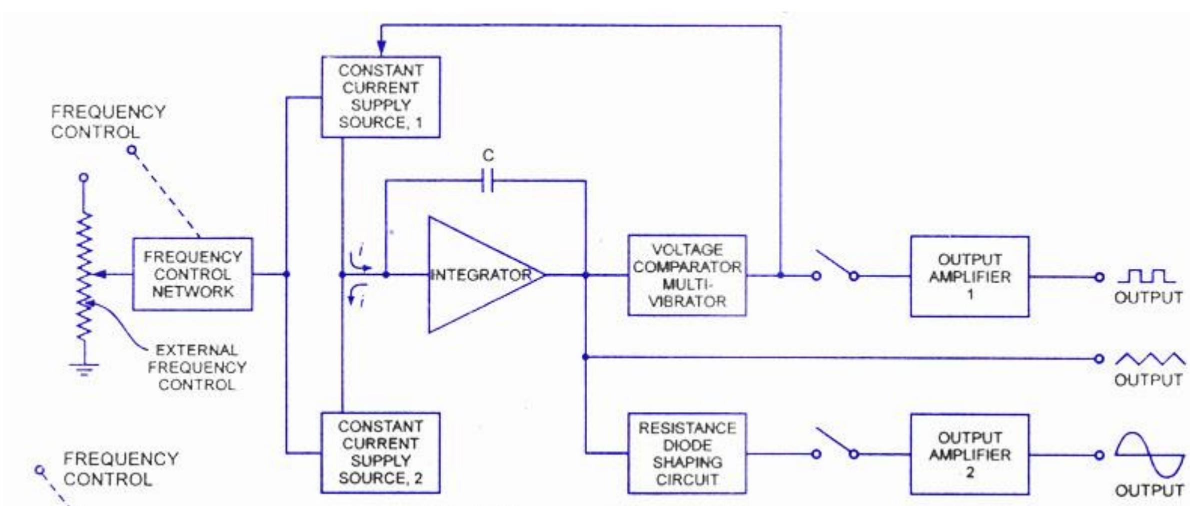
A function generator is a signal source that has the capability of producing different types of waveforms as its output signal. The most common output waveforms are sine-waves, **triangular waves**,**square waves**, and **sawtooth waves**. The frequencies of such waveforms may be adjusted from a fraction of a hertz to several hundred kHz.

Actually, the function generators are very versatile instruments as they are capable of producing a wide variety of waveforms and frequencies. In fact, each of the waveforms they generate is particularly suitable for a different group of applications. The uses of sinusoidal outputs and square-wave outputs have already been described in the earlier Arts. The triangular-wave and sawtooth wave outputs of function generators are commonly used for those applications which need a signal that increases (or reduces) at a specific linear rate. They are also used in driving sweep oscillators in oscilloscopes and the X-axis of X-Y recorders.

Many function generators are also capable of generating two different waveforms simultaneously (from different output terminals, of course). This can be a useful feature when two generated signals are required for a particular application. For instance, by providing a square wave for linearity measurements in an audio-system, a simultaneous sawtooth output may be used to drive the horizontal deflection amplifier of an oscilloscope, providing a visual display of the measurement result. For another example, a triangular-wave and a sine-wave of equal frequencies can be produced simultaneously. If the**zero crossings** of both the waves are made to occur at the same time, a linearly varying waveform is available which can be started at the point of zero phase of a sine-wave.

Another important feature of some function generators is their capability of phase-locking to an external signal source. One function generator may be used to phase lock a second function generator, and the two output signals can be displaced in phase by an adjustable amount. In addition, one function generator may be phase locked to a harmonic of the sine-wave of another function generator. By adjustment of the phase and the amplitude of the harmonics, almost any waveform may be produced by the summation of the fundamental frequency generated by one function generator and the harmonic generated by the other function generator. The function generator can also be phase locked to an accurate frequency standard, and all its output waveforms will have the same frequency, stability, and accuracy as the standard.

Function Generator Working & Block Diagram



Block Diagram of Function Generator

DSO, Frequency Counter, L-C-R and Q-Meter, Distortion Meter, Spectrum Analyzer, resolution, sensitivity and accuracy specification of digital meters.

The block diagram of a function generator is given in the figure. In this instrument, the frequency is controlled by varying the magnitude of the current that drives the integrator. This instrument provides different types of waveforms (such as sinusoidal, triangular and square waves) as its output signal with a frequency range of 0.01 Hz to 100 kHz.

The frequency controlled voltage regulates two current supply sources. Current supply source 1 supplies a constant current to the integrator whose output voltage rises linearly with time. An increase or decrease in the current increases or reduces the slope of the output voltage and thus controls the frequency.

The voltage comparator multivibrator changes state at a predetermined maximum level, of the integrator output voltage. This change cuts-off the current supply from supply source 1 and switches to the supply source 2. The current supply source 2 supplies a reverse current to the integrator so that its output drops linearly with time. When the output attains a predetermined level, the voltage comparator again changes state and switches on to the current supply source. The output of the integrator is a triangular wave whose frequency depends on the current supplied by the constant current supply sources. The comparator output provides a square wave of the same frequency as output. The resistance diode network changes the slope of the triangular wave as its amplitude changes and produces a sinusoidal wave with less than 1% distortion.

4.3 Digital oscilloscope vs digital storage oscilloscope

A **digital oscilloscope** is an instrument which stores a digital copy of the waveform in the digital memory which it analyses further using digital signal processing techniques rather than using analogue techniques. It captures the non-repetitive signals and displays it consciously until the device gets reset. In **digital storage oscilloscope**, signals are received, stored and then displayed. The maximum frequency measured by digital oscilloscope depends upon two things: one is sampling rate of the scope, and the other is the nature of the converter. Converter is either analogue or digital. The traces in digital oscilloscope are bright, highly defined, and displayed within seconds as they are non-stored traces. The main advantage of the digital oscilloscope is that it can display visual as well as numerical values by analyzing the stored traces.
The name digital storage oscilloscope dates back to the days when digital technology was entering the scope arena. Analogue storage scopes were not particularly effective, and therefore there was a need for effective storage technologies.

The original digital storage scopes had analogue input stages, and then converted the signals into a digital format to enable them to be stored in digital memory. They could then be processed before being converted back into an analogue format for display on a cathode ray tube.

As technology progressed, the storage facility was retained, but the whole scope became digital.

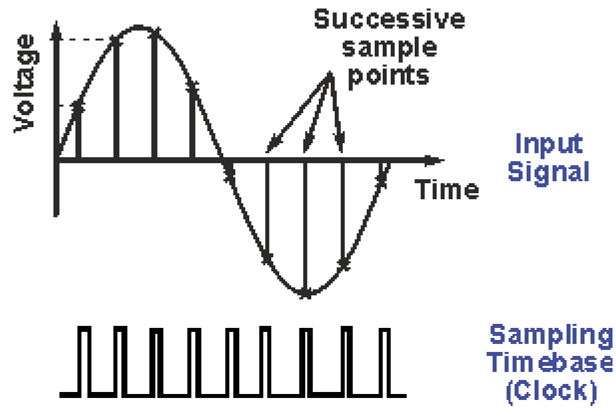
For a while, there was a difference between standard digital scopes and those with a storage capability, but this difference was eroded as the facility became incorporated on all digital oscilloscopes. Accordingly the two types are effectively the same, and the names are often used interchangeably to describe the same type of test instrument.

Digital oscilloscope technology

The basic concept behind digital oscilloscopes / DSOs is the conversion of the incoming analogue signal into a digital format where it can be processed using digital signal processing techniques.

When the signal enters the scope it is first pre-conditioned by some analogue circuits to ensure that the optimum signal is presented to the next stage.

This next stage involves the acquisition of the digital samples. To achieve this, an analog-to-digital converter, ADC, takes samples are discrete regular time intervals.



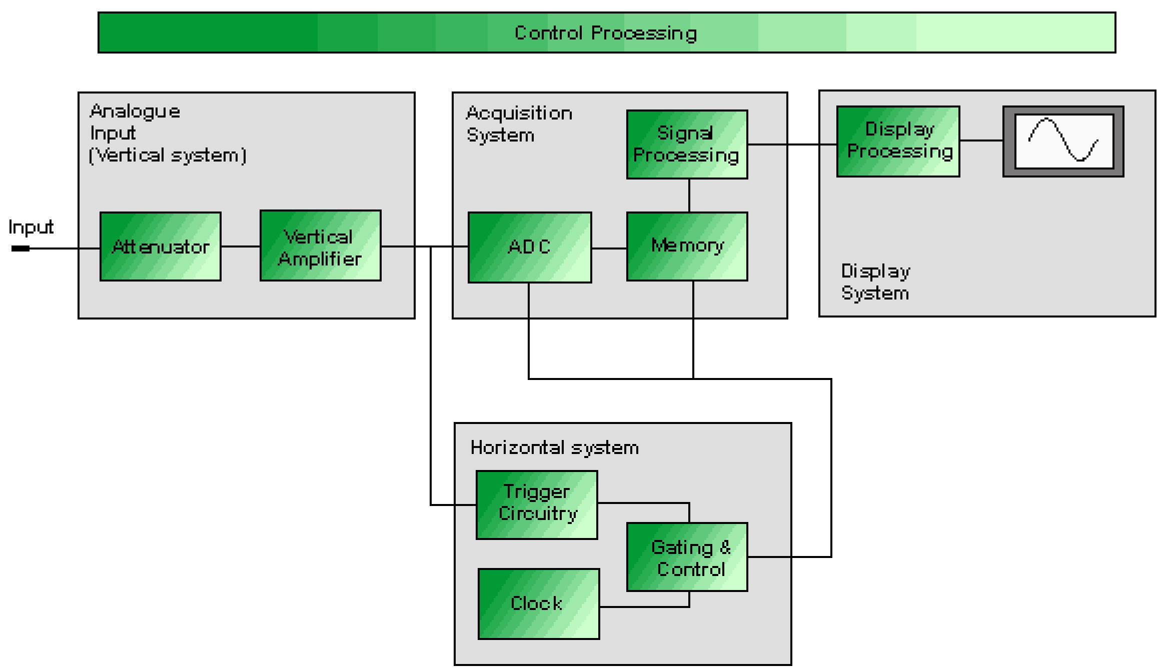
Digital oscilloscope sampling

The times and rate at which samples are taken is determined by the system clock. The rate at which samples are taken is often defined as part of the specification of the scope. This is measured in samples per second, and often quoted in Mega samples per second M samples per second.

The samples from the ADC are stored in memory and referred to as waveform points and together these points make up the overall waveform record. The number of waveform points within the record is referred to as the waveform length.

The waveform record is initiated by the trigger and again stopped by the timebase circuit after the given amount of time.

The waveform record is then processed by the processing circuitry and presented to the display for visual inspection by the user.



Digital oscilloscope basic block diagram

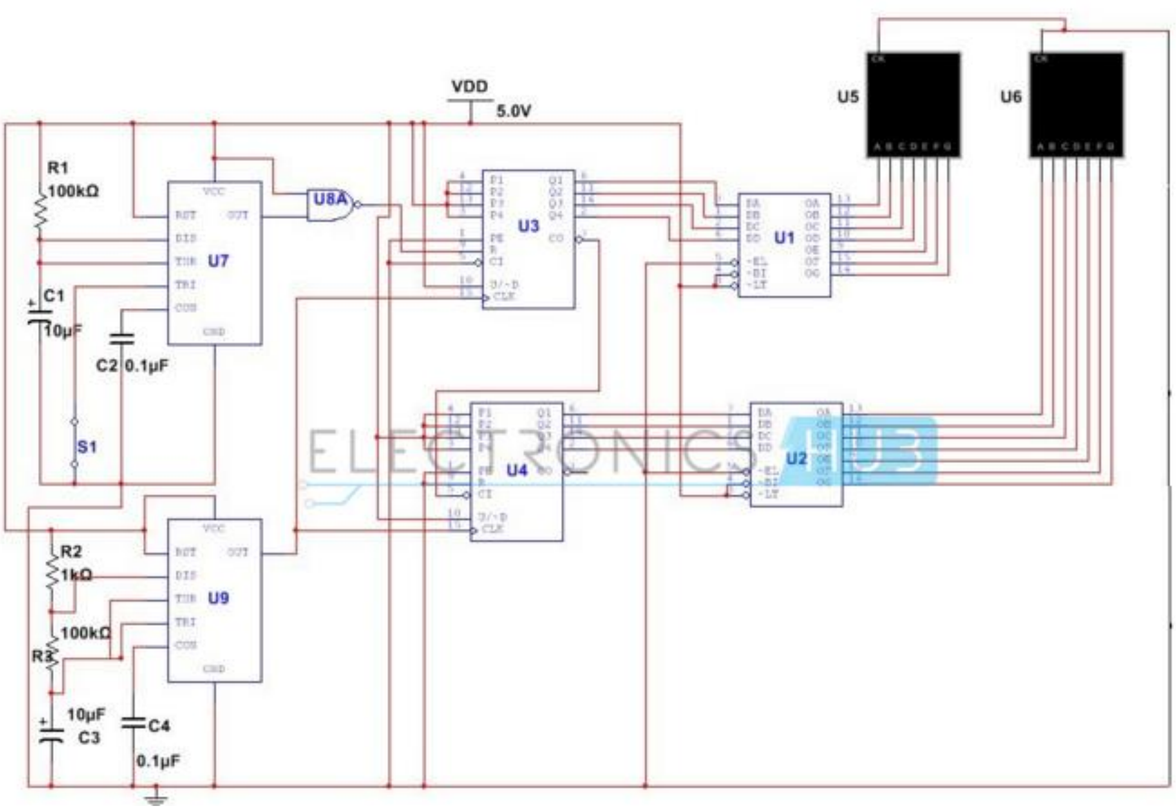
4.4 <u>Frequency Counter</u>

A frequency counter is an instrument used to measure the frequency. In scientific terms, frequency is the number of cycles per second in the signal. In terms of a layman, frequency of a signal denotes the rate of occurrence of the signal in certain time. Frequency Counters are basically simple counter systems with a limited time period for counting.

Frequency Counter Circuit Operating Principle

This circuit is based on the simple definition of frequency, which is the number of cycles per second. An astable multivibrator is used to generate oscillating pulses which are fed as clock pulses to a counter. Another monostable multivibrator is used to generate a timing signal for 1 second used to control the counter. The counter thus counts the number of pulses for 1 second and the resultant value displayed on the 7-segment display is the value of frequency in hertz.

Frequency Counter Circuit Diagram:



Circuit Diagram of Frequency Counter

4.5 L-C-R and Q-Meter

An LCR meter is used to measure the impedance of a circuit or a device. This section explains the uses, types, and some parameters related to LCR meters.
The LCR meter also measures D or Q. D stands for the dissipation factor. It is given by dividing the real part of the impedance by the imaginary part of the impedance (which is the reactance). Q stands for the quality factor. It is the inverse of D.

An LCR meter is used to measure the inductance, capacitance and resistance of a circuit. Hence, the name LCR meter.

When there is a change in the current flowing through a conductor, a corresponding change is induced in the voltage in it and in conductors surrounding it. This property is known as inductance. The ability of a body or a conductor to store electrical charge is known as capacitance. The opposition that a conductor offers to the passage of electric current through it is called resistance.

Working Principle

We pass an AC voltage through a DUT (Device Under Test). Now the LCR meter is used to measure the voltage and the current across the DUT. The magnitude of the impedance can be calculated from the ratio of these two quantities.

Uses of an LCR Meter

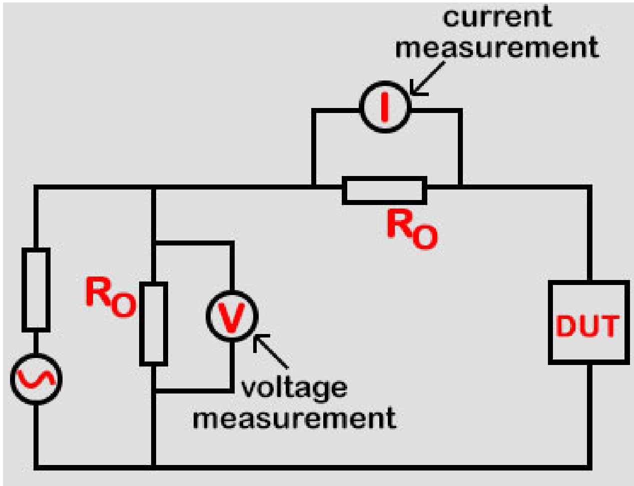
A digital LCR meter is used to measure the impedance flowing through a Device Under Test (DUT). It measures the voltage (V) across it, the current (I) flowing through it, and the phase angle between current and voltage. Subsequently, we can determine all the impedance parameters from these three factors.

Thus, an LCR meter measures the following parameters related to a circuit:

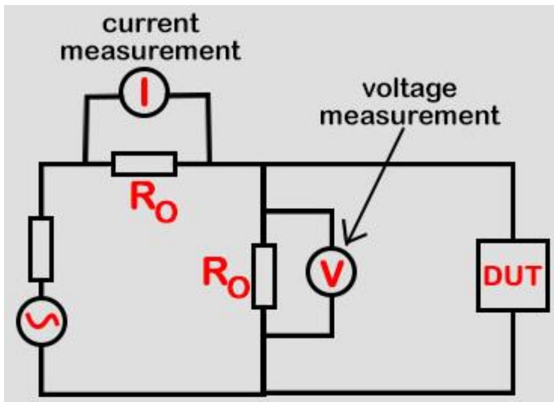
- inductance
- capacitance
- resistance
- dissipation factor
- quality factor
- current
- voltage
- phase angle between the current and voltage
- conductance
- susceptance

- **LCR Measurement by Current-Voltage Technique**
- In this technique, the LCR measurement of a component is done by measuring the current and voltage. Then the impedance values are found out from these two quantities.
- There are different arrangements for low impedance and high impedance circuits, which are as follows:

LCR measurement by current and voltage technique for high impedance current



LCR measurement by current and voltage technique for low impedance current



Both analog and digital LCR meters are available. While analog testers are cheaper, the digital variety scores on quality as it is more accurate.

4.6 Distortion Meter

What is distortion meter?

Harmonic distortion is the distortion in our signal that is produced by the additional frequencies generated in the signal. These frequencies are nothing but multiples of the original frequency of our signal. Harmonic distortion occurs not only in sound waves, as that is the most commonly used example.

It also occurs in electrical signals, that is, when a current is passing through a circuit, it can induce vibrations in the circuit and the vibrations produced would obviously be some multiple of the current signal frequency. Hence these vibrations can cause distortion in our original signal. This distortion in current can lead to many problems like voltage fluctuation etc.

The thing that needs to be noted here is that harmonic potential is not always an undesirable phenomenon. Often in techniques of artificial reverberations we utilize it to create useful effects.

How to use a distortion meter?

Now that we are familiar with the basics of harmonic distortion, and also the fact that a distortion meter is used for the detection and measurement of such frequencies, what lies next?

So once the frequencies are detected, the distortion meter now acts such that it works to eliminate the effect of such frequencies. For this purpose it has the option to set certain predefined parameters, so that any frequencies which lie outside these set of parameters are eliminated and not allowed to pass along with the original signal. The original signal can then be produced at the output in whatever way it is required.

So in short a distortion meter not only detects and measures the distortion in our signal frequencies but also works to overcome or eliminate them.

Application of distortion meter

1. **Distortion meters** are being widely used now a days especially in music industry. To make the sound more pleasing and musical, many frequencies are eliminated and some are enhanced as well. For eliminating the unwanted frequencies we use a distortion meter.
2. Distortion meters also find extensive uses in electrical circuits now a days. As mentioned earlier they are used to eliminate the distortions in the currents and voltages which can also prove fatal in some cases.
3. Many advance electrical machines use distortion meters to compensate for the current distortions so that the expensive appliance can be saved from damage due to these distortions.

4.7 Spectrum Analyser

Spectrum analyzers are widely used within the electronics industry for analysing the frequency spectrum of radio frequency, RF and audio signals. Looking at the spectrum of a signal they are able to reveal elements of the signal, and the performance of the circuit producing them that would not be possible using other means.

Spectrum analysers are able to make a large variety of measurements and this means that they are an invaluable tool for the RF design development and test laboratories, as well as having many applications for specialist field service.

Why spectrum analysis?

The most natural way to look at waveforms is in the time domain - looking at how a signal varies in amplitude as time progresses, i.e. in the time domain. This is what an oscilloscope is used for, and it is quite natural to look at waveforms on an oscilloscope display. However this is not the only way in which signals can be displayed.

A French mathematician and physicist, named Jean Baptiste Joseph Fourier, who lived from 1768 to 1830 also started to look at how signals are seen in another format, in the frequency domain where signals are viewed as a function of their frequency rather than time. He discovered that any waveform seen in the time domain, there is an equivalent representation in the frequency domain. Expressed differently, any signal is made up from a variety of components of different frequencies. One common example is a square waveform. This is made up from signal comprising the fundamental as well as third, fifth, seventh, ... harmonics in the correct proportions.

In exact terms it is necessary that the signal must be evaluated over an infinite time for the transformation to hold exactly. However in reality it is sufficient to know that the waveform is continuous over a period of at least a few seconds, or understand the effects of changing the signal.

It is also worth noting that the mathematical Fourier transformation also accommodates the phase of the signal. However for many testing applications the phase information is not needed and considerably complicates the measurements and test equipment. Also the information is normally not needed, and only the amplitude is important.

By being able to look at signals in the time domain provides many advantages and in particular for RF applications, although audio spectrum analyzers are also widely used. Looking at signals in the frequency domain with a spectrum analyzer enables aspects such as the harmonic and spurious content of a signal to analyzed. Also the width of signals when modulation has been applied is important. These aspects are of particular importance for developing RF signal sources, and especially any form of transmitter including those in cellular, Wi-Fi, and other radio or wireless applications. The radiation of unwanted signals will cause interference to other users of the radio spectrum, and it is therefore very important to ensure any unwanted signals are kept below an acceptable level, and this can be monitored with a spectrum analyzer.

Spectrum analyzer basics

There are many different types of RF test equipment that can be used for measuring a variety of different aspects of an RF signal. It is therefore essential to choose the right type of RF test equipment to meet the measurement requirements for the particular job in hand.

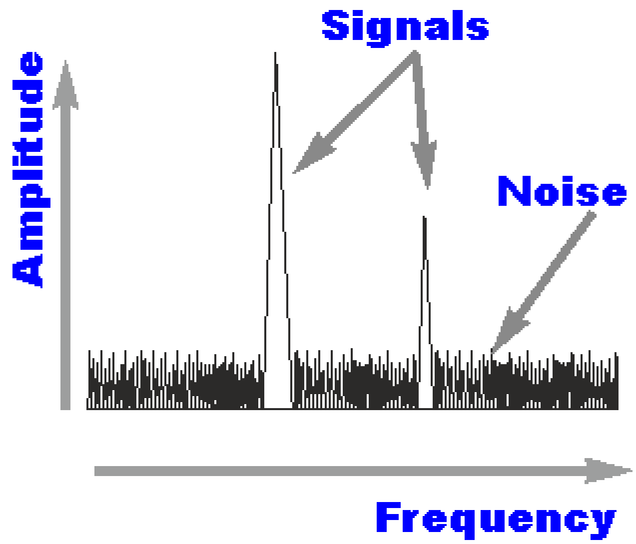
TEST INSTRUMENT TYPE	FREQUENCY MEASUREMENT	INTENSITY / AMPLITUDE MEASUREMENT	APPLICATION
Power meter	N	Y	Use for accurate total power measurements
Frequency counter	Y	N	Used to provide very accurate measurements of the dominant frequency within a signal
Spectrum analyser	Y	Y	Used primarily to display the spectrum of a radio frequency signal. Can also be used to make power and frequency measurements, although not as accurately as dedicated instruments
RF network analyser	Y	Y	Used to measure the properties of RF devices

Properties of RF measuring instruments in common use

The spectrum analyzer is able to offer a different measurement capability to other instruments. Its key factor is that it is able to look at signals in the frequency domain, i.e. showing the spectrum, it is possible to see many new aspects of the signal.

An analyser display, like that of an oscilloscope has two axes. For the spectrum analyser the vertical axis displays level or amplitude, whereas the horizontal axis displays frequency. Therefore as the scan moves along the horizontal axis, the display shows the level of any signals at that particular frequency.

This means that the spectrum analyser, as the name indicates analyses the spectrum of a signal. It shows the relative levels of signals on different frequencies within the range of the particular sweep or scan.



General format of the display on a spectrum analyzer

In view of the very large variations in signal level that are experienced, the vertical or amplitude axis is normally on a logarithmic scale and is calibrated in dB in line with many other measurements that are made for signal amplitudes. The horizontal scale conversely is normally linear. This can be adjusted to cover the required range. The term span is used to give the complete calibrated range across the screen. Terms like scan width per division may also be used and refer to the coverage between the two major divisions on the screen.

Multiple choice questions

Q1. To increase the current sensitivity below 10 mV, electronic instrument uses

A. Amplifiers
B. Modulator
C. Transducer
D. Oscillator

Q2. Electronic voltmeters can be designed to measure

A. Only very small voltages
B. Only very high voltages

C. Both very small and very high voltages
D. None of these

Q3. An rms reading voltmeter can accurately measure voltages of

A. Sine waveforms
B. Square waveforms
C. Saw tooth waveforms
D. All of these

Q4. In electronic voltmeter, the range of input voltages can be extended by using

A. Functional switch
B. Input attenuator
C. Rectifier
D. Balanced bridge dc amplifier

Q5. The measurement range of digital voltmeter is

A. 1V to 1MV
B. 1V to 1kV
C. 1kV to 1MV
D. 100 kV to 100MV

Q6. Which among the following is not the type of digital voltmeters?
A. Ramp type
B. Integrating
C. Potentiometric type
D. None of these
Q7. In a ramp type DVM, the multivibrator determines the rate at which the

A. Clock pulses are generated
B. Measurement cycles are initiated
C. It oscillates
D. Its amplitude varies

Q8. In potentiometric type DVM, the adjustment of sliding contact is done by
A. A single phase servomotor
B. Two phase servomotor
C. Three phase servomotor
D. All of these
Q9. In the beginning, all the outputs of the successive approximation type register is at
A. Logic zero
B. Logic one
C. Toggling
D. None of these

Q10. Q meter is used to measure the properties of
A. Inductive coils
B. Non inductive coils
C. Capacitive coils
D. Both (a) and (c)

Long answer type questions

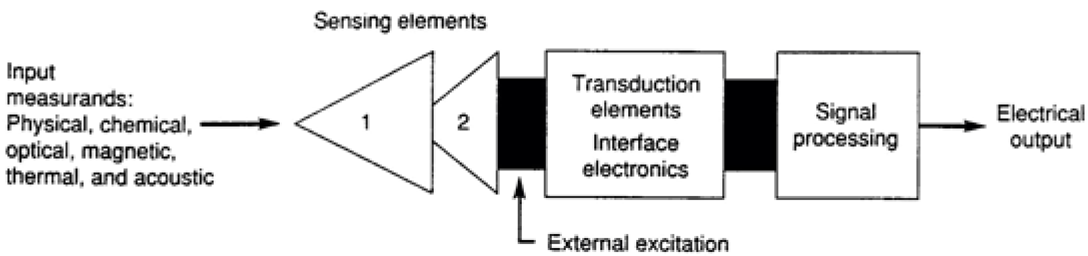
1. Describe the working of a spectrum analyzer with it's basic circuit.
2. Discuss any one –Wave analyzer in detail.
3. Explain the functional block diagram of Function generator and mention it's features.
4. Explain with the help of block diagram, fundamental suppression distortion analyzer. Discuss it's two modes of operation.
5. With a block diagram explain operation of a heterodyne wave analyzer.
6. Explain various applications of the spectrum analyzer.
7. With the help of neat block explain the operation of a sweep frequency generator.
8. How a spectrum analyzer can be used to operate and measure VHF? Draw the waveforms and Block diagram.
9. Explain how the Q-meter can be used for the measurement of Q-factor and effective Resistance and discuss the source of error
10. With a neat block diagram explain the function of a general purpose oscilloscope
11. Write Brief notes on: A. Storage oscilloscope. B.Sampling oscilloscope
12. Briefly explain the operations of different types of storage oscilloscopes.
13. Sketch the basic block diagram for a digital storage oscilloscope and explain the operation.
14. What is meant by gating error in a frequency counter ?How does it arise? can it be eliminated?

Module 5

Sensing Element and Transducer

5.1 TRANSDUCER:

A **transducer** is a device that converts energy from one form to another. Usually a transducer converts a signal in one form of energy to a signal in another.
Transducers are often employed at the boundaries of automation, measurement, and control systems, where electrical signals are converted to and from other physical quantities (energy, force, torque, light, motion, position, etc.). The process of converting one form of energy to another is known as transduction.



A transducer model showing multiple sensing elements, often found in some chemical and biochemical transducers. The output of the transduction element is interfaced with suitable electronic circuits to provide usable analog or digital signal output.

Sensing Element and Transducer:

Components of Transducer

In general terms, the transduction process involves the transformation of one form of energy into another form. This process consists of sensing with specificity the input energy from the *measurand* by means of a "*sensing element*" and then transforming it into another form by a "*transduction element*." The sensor-transduction element combination shown in figure below will henceforth be referred to as the "**transducer**". Measurand relates to the quantity, property, or state that the transducer seeks to translate into an electrical output.

- **TRANSDUCTION MECHANISMS**

  Capacitive
  Thermoelectric effects (Seebeck and Peltier)
  Inductive and electromagnetic Resistive
  Ionization effects
  Resistive and thermoresistive
  Photoelectric effect
  Piezoresistive effect
  Photoresistive effect
  Hall effect
  Photovoltaic effect
  Lateral effect
  Acoustooptic effect
  Magnetoresistive effect

Doppler effect
Tunneling effect

II. MEASURANDS

Displacement
Position
Velocity
Acceleration
Force and load
Strain
Rotation and encoding
Vibrations
Flow
Temperature
Pressure
Vacuum

Atomic and surface profiles
Gas concentration and pH
pH and partial pressure of O2 and CO2 in blood
Infrared radiation
Torque
Magnetic field
Acoustic fields
Medical imaging
Non-destructive testing
Audio fields and noise
Rotation and guidance

III. SELECTION OF TRANSDUCERS

When selecting a transducer, in addition to the question of cost, careful attention must be given to the following

- Sensitivity
- Range
- Physical properties
- Frequency response
- Electrical output format
- Output impedance
- Power requirements
- Noise
- Calibration
- Environment

Transducers may be classified as self-generating or externally powered. Self-generating transducers develop their own voltage or current and in the process absorb all the energy needed from the measurand. Externally powered transducers, as the name implies, must have power supplied from an external source, though they may absorb some energy from the measurand.

TRANSDUCER TYPES:

Mechanical and electrical transducers.

Transducers that convert physical quantities into mechanical ones are called mechanical transducers; Transducers that convert physical quantities into electrical are called electrical transducers. Examples are a thermocouple that changes temperature differences into a small voltage, or a Linear variable differential transformer (LVDT) used to measure displacement.

Sensors and actuators

Transducers can be categorized by which direction information passes through them:

- A sensor is a transducer that receives and responds to a signal or stimulus from a physical system. It produces a signal, which represents information about the system, which is used by some type of telemetry, information or control system.
- An actuator is a device that is responsible for moving or controlling a mechanism or system. It is controlled by a signal from a control system or manual control. It is operated by a source of energy, which can be mechanical force, electrical current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple (a fixed mechanical or electronic system), software-based (e.g. a printer driver, robot control system), a human, or any other input.
- Bidirectional transducers convert physical phenomena to electrical signals and also convert electrical signals into physical phenomena. An example of an inherently bidirectional transducer is an antenna, which can convert radio waves (electromagnetic waves) into an electrical signal to be processed by a radio receiver, or translate an electrical signal from a transmitter into radio waves. Another example is voice coils, which are used in loudspeakers to translate an electrical audio signal into sound and in dynamic microphonesto translate sound waves into an audio signal.

Passive vs active sensors

- *Passive* sensors require an external power source to operate, which is called an excitation signal. The signal is modulated by the sensor to produce an output signal. For example, a thermistor does not generate any electrical signal, but by passing an electric current through it, its resistance can be measured by detecting variations in the current or voltage across the thermistor.
- *Active* sensors, in contrast, generate an electric current in response to an external stimulus which serves as the output signal without the need of an additional energy source. Such examples are a photodiode, and a piezoelectric sensor, thermocouple.

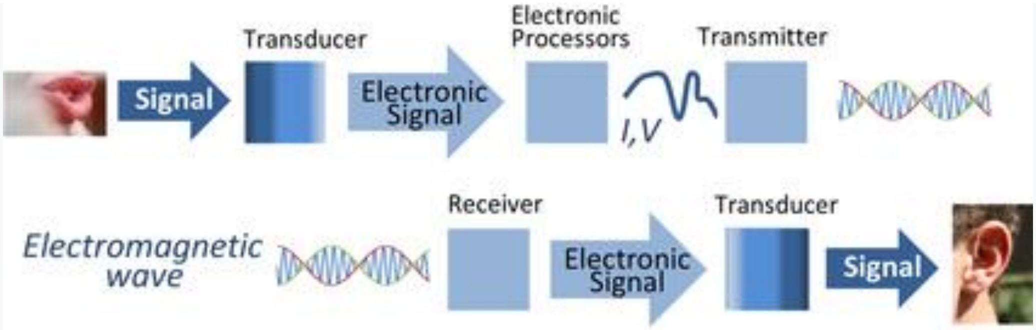
CHARACTERISTICS OF TRANSDUCER:

Some specifications that are used to rate transducers

- Dynamic range: This is the ratio between the largest amplitude signal and the smallest amplitude signal the transducer can effectively translate.[2] Transducers with larger dynamic range are more "sensitive" and precise.

- Repeatability: This is the ability of the transducer to produce an identical output when stimulated by the same input.
- Noise: All transducers add some random noise to their output. In electrical transducers this may be electrical noise due to thermal motion of charges in circuits. Noise corrupts small signals more than large ones.
- Hysteresis: This is a property in which the output of the transducer depends on not only its current input but also its past input. For example, an actuator which uses a gear trainmay have some backlash, which means that if the direction of motion of the actuator reverses, there will be a dead zone before the output of the actuator reverses, caused by play between the gear teeth.

<u>APPLICATION OF TRANSDUCER</u>:



Transducers are used in electronic communications systems to convert signals of various physical forms to electronic signals, and *vice versa*. In this example, the first transducer could be a microphone, and the second transducer could be a speaker.

- Electromagnetic:
- Antennae – converts propagating electromagnetic waves to and from conducted electrical signals
- magnetic cartridges – converts relative physical motion to and from electrical signals
- Tape head, disk read-and-write heads – converts magnetic fields on a magnetic medium to and from electrical signals
- Hall effect sensors – converts a magnetic field level into an electrical signal
- Electrochemical:

pH probes

- Electro-galvanic oxygen sensors
- Hydrogen sensors
- Electromechanical (electromechanical output devices are generically called actuators):
- Accelerometers
- Air flow sensors
- Electroactive polymers
- Rotary motors, linear motors
- Galvanometers
- Linear variable differential transformers or rotary variably differential transformers

- Load cells – converts force to mV/V electrical signal using strain gauges
- Microelectromechanical systems
- Potentiometers (when used for measuring position)
- Pressure sensors
- String potentiometers
- Tactile sensors
- Vibration powered generators
- Electroacoustic:

Loudspeakers, earphones – converts electrical signals into sound (amplified signal → magnetic field → motion → air pressure)
- Microphones – converts sound into an electrical signal (air pressure → motion of conductor/coil → magnetic field → electrical signal)
- Pickup (music technology) – converts motion of metal strings into an electrical signal (magnetism → electrical signal)
- Tactile transducers – converts electrical signal into vibration (electrical signal → vibration)
- Piezoelectric crystals – converts deformations of solid-state crystals (vibrations) to and from electrical signals
- Geophones – converts a ground movement (displacement) into voltage (vibrations → motion of conductor/coil → magnetic field → signal)
- Gramophone pickups – (air pressure → motion → magnetic field → electrical signal)
- Hydrophones – converts changes in water pressure into an electrical signal
- Sonar transponders (water pressure → motion of conductor/coil → magnetic field → electrical signal)
- Ultrasonic transceivers, transmitting ultrasound (transduced from electricity) as well as receiving it after sound reflection from target objects, availing for imaging of those objects.
- Electro-optical (Photoelectric):
- Fluorescent lamps – converts electrical power into incoherent light
- Incandescent lamps – converts electrical power into incoherent light
- Light-emitting diodes – converts electrical power into incoherent light
- Laser diodes – converts electrical power into coherent light
- Photodiodes, photoresistors, phototransistors, photomultipliers – converts changing light levels into electrical signals
- Photodetector or photoresistor or light dependent resistor (LDR) – converts changes in light levels into changes in electrical resistance
- Cathode-ray tubes (CRT) – converts electrical signals into visual signals
- Electrostatic:
- Electrometers
- Thermoelectric:
- Resistance temperature detectors (RTD) – converts temperature into an electrical resistance signal

- Thermocouples – converts relative temperatures of metallic junctions to electrical voltage
- Thermistors (includes PTC resistor and NTC resistor)
- Radioacoustic:
- Geiger-Müller tubes – converts incident ionizing radiation to an electrical impulse signal
- Radio receiver converts electromagnetic transmissions to electrical signals.
- Radio transmitter converts electrical signals to electromagnetic transmissions.
  -

Electrical Transducer: Basics, Types, Requirements:

What is meant by electrical transducer?

The transducer that gives electrical energy a output is known as electrical transducers.
In other words, The Electrical transducers are the devices that convert energy in the form of sound, light, heat, etc., into an equivalent electrical signal, or vice versa.
The output electrical signal may be voltage, current,or frequency. Production of these electrical signals is based upon resistive, inductive, capacitive effects.
For measuring non electrical quantities, a detector is used which usually converts the physical quantity into a displacement, that activates the electrical transducers.

Classification of Electrical Transducer:

A sharp distinction among the types of transducers is difficult. The transducers may be classified according to their application, method of energy conversion, nature of the output signal and so on. All these classifications generally result in overlapping areas.
In one way, the electrical transducers are classified as;
(1) Active Transducers
(2) Passive Transducers

Active Transducers:

It is also known as self-generating type transducers. They develop their own voltage or current as the output signal. The energy required for production fo this output signal is obtained from the physical phenomenon being measured.
Examples of active transducers: Thermocouple, Piezoelectric transducers, Photovoltaic cell, Moving coil generator, Photoelectric cell.

Passive Transducers:

It is also called as externally powered transducers. They derive the power required for energy conversion from an external power source.
The passive transducers are further classified into Resistive type, Inductive type and capacitive type.

- Resistance: Thermistor, Photoconductive cell, Resistance strain gauge
- Inductance: LVDT- Linear Variable Differential Transformer
- Capacitance: Photoemissive cell, Hall effect based devices.

Apart from these classifications, some kind of transducers are known as opto-electronic transducers. They use the principle of converting light energy into electrical energy. Some of the examples of opto-electronic transducers are photoconductive cell, photovoltaic cell, solar cell, photomultiplier tube and photomultiplier.

Basic requirements of the Electrical transducer:

Some of the basic requirements of the transducers are given below:

1. **Repeatability**

When the same input signal is applied to the transducer at different times under the same environmental conditions, it should give identical output signals.

2. **Linearity**

The transducers should have linear input-output characteristics.

3. **Ruggedness**

The transducer circuit should have overload protection so that it will withstand overloads.

4. **High stability and reliability**

The transducers output signal should not get affected by environmental variations(disturbances) like temperature, vibration etc. It should give minimum error in measurements.

5. **Good dynamic response**

In real-time applications, the input signal will vary with time (ie, the input signal is dynamic in nature). The transducer should respond as quick as possible for any change in the input signal.

6. **Convenient instrumentation**

The transducers output signal should be measured either directly or after suitable amplification.

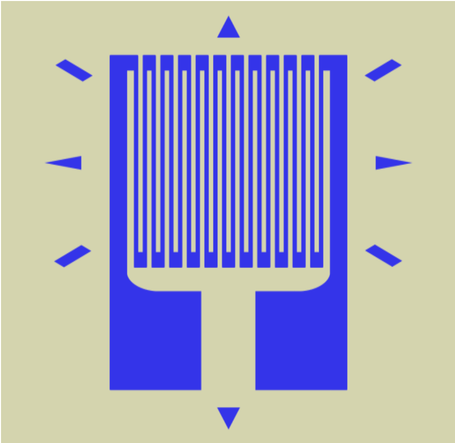
7. **Mechanical characteristics**

When the transducer is subjected to various mechanical strains during working conditions, its performance should not degrade. It should withstand the mechanical strains.

5.2 STRAIN GAUGE:

A **strain gauge** is a device used to measure strain on an object. Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheatstone bridge, is related to the strain by the quantity known as the *gauge factor*.

PHYSICAL OPERATION:



A strain gauge takes advantage of the physical property of electrical conductance and its dependence on the conductor's geometry. When an electrical conductor is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end. Conversely, when a conductor is compressed such that it does not buckle, it will broaden and shorten, changes that decrease its electrical resistance end-to-end. From the measured electrical resistance of the strain gauge, the amount of induced stress may be inferred.

A typical strain gauge arranges a long, thin conductive strip in a zig-zag pattern of parallel lines. This does not increase the sensitivity, since the percentage change in resistance for a given strain for the entire zig-zag is the same as for any single trace. However, a single linear trace would have to be extremely thin and hence liable to overheating (which would both change its resistance and cause it to expand), or would have to be operated at a much lower voltage, making it harder to measure resistance changes accurately**.**

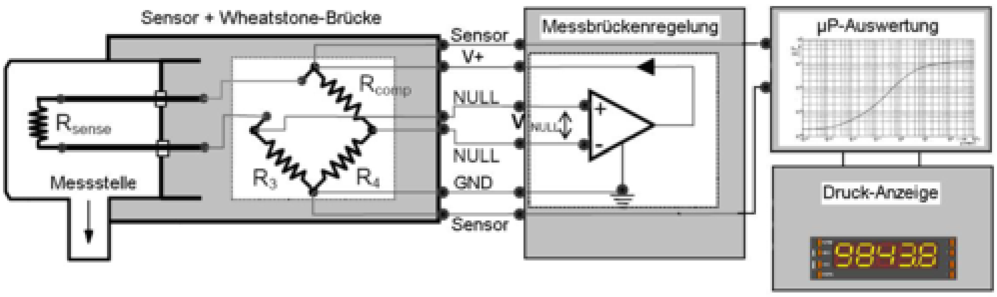
Pirani Gauges:

The **Pirani gauge** is a robust thermal conductivity gauge used for the measurement of the pressures in vacuum systems. It was invented in 1906 by Marcello Pirani.

Structure:

The Pirani gauge consists of a metal filament (usually platinum) suspended in a tube which is connected to the system whose vacuum is to be measured. Connection is usually made either by a ground glass joint or a flanged metal connector, sealed with an o-ring. The filament is connected to an electrical circuit from which, after calibration, a pressure reading may be taken.

Mode of Operation:



A **heated metal wire** (also called a filament) suspended in a gas will lose heat to the gas as its molecules collide with the wire and remove heat. If the gas pressure is reduced the number of molecules present will fall proportionately and the wire will lose heat more slowly. Measuring the heat loss is an indirect indication of pressure.

The electrical resistance of a wire varies with its temperature, so the resistance indicates the temperature of wire. In many systems, the wire is maintained at a constant resistance R by controlling the current I through the wire. The resistance can be set using a bridge circuit. The power delivered to the wire is I^2R, and the same power is transferred to the gas. The current required to achieve this balance is therefore a measure of the vacuum.

The gauge may be used for pressures between 0.5 Torr to 10^{-4} Torr. The thermal conductivity and heat capacity of the gas may affect the readout from the meter, and therefore the apparatus may need calibrating before accurate readings are obtainable. For lower pressure measurement, the thermal conductivity of the gas becomes increasingly smaller and more difficult to measure accurately, and other instruments such as a Penning gauge are used instead.

Advantages and disadvantages:

Advantages

- Significantly better resolution in the range above 75 Torr.
- The power consumption is drastically reduced compared to continuously operated Pirani gauges.
- The gauge's thermal influence on the real measurement is lowered considerably due to the low temperature threshold of 80 °C and the ramp heating in pulsed mode.

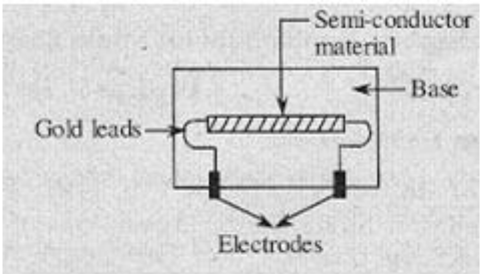
- The pulsed mode can be efficiently implemented using modern microprocessor technology.

Disadvantages

- Increased calibration effort
- Longer heat-up phase

Semiconductor strain gauges:

A typical semiconductor strain gauge is formed by the semiconductor technology i.e., the semiconducting wafers or filaments of length varying from 2 mm to 10 mm and thickness of 0.05 mm are bonded on suitable insulating substrates (for example Teflon). The gold leads are usually employed for making electrical contacts. The electrodes are formed by vapour deposition. The assembly is placed in a protective box as shown in the figure below.



Semiconductor Strain gauge

The strain sensitive, elements used by the semiconductor strain gauge are the semiconductor materials such as, silicon and germanium. When the strain is applied to the semiconductor element a large of change in resistance occur which can be measured with the help of a wheatstone bridge. The strain can be measured with high degree of accuracy due to relatively high change in resistance.

A temperature compensated semiconductor strain gauge can be used to measure small strains of the order of 10-6 i.e., micro-strain. This type of gauge will have a gauge factor of 130 ± 10% for a semiconductor material of dimension 1 x 0.5 x 0.005 inch having the resistance of 350 Ω.

Advantages of Semiconductor Strain Gauge:

1. The gauge factor of semiconductor strain gauge is very high, about ±130.

2. Semiconductor strain gauge exhibits very low hysteresis i.e., less than 0.05%.

3. They are useful in measurement of very small strains of the order of 0.01 micro-strains due to their high gauge factor.

4. The semiconductor strain gauge has much higher output, but it is as stable as a metallic strain gauge.

5. It has a large fatigue life i.e., 10 x 106 operations can be performed.

6. It possesses a high frequency response of 1012 Hz.

8. They can be manufactured in very small sizes, their lengths ranging from 0.7 to 7.0 mm.

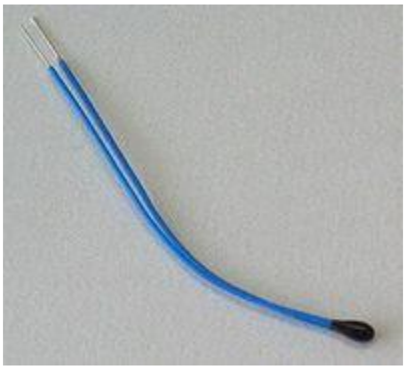
5.3 Thermistors

A thermistor is a type of resistor whose resistance is dependent on temperature, more so than in standard resistors. The word is a portmanteau of thermal and resistor. Thermistors are widely used as inrush current limiters, temperature sensors (negative temperature coefficient or NTC type typically), self-resetting over current protectors, and self-regulating heating elements (positive temperature coefficient or PTC type typically).

Thermistors are of two opposite fundamental types:

- With NTC thermistors, resistance *decreases* as temperature rises. An NTC is commonly used as a temperature sensor, or in series with a circuit as an inrush current limiter.
- With PTC thermistors, resistance *increases* as temperature rises. PTC thermistors are commonly installed in series with a circuit, and used to protect against overcurrent conditions, as resettable fuses.

Thermistors differ from resistance temperature detectors (RTDs) in that the material used in a thermistor is generally a ceramic or polymer, while RTDs use pure metals. The thermistors are in the form of beads, rods and discs but RTDs are in different shapes and sizes. The temperature response is also different; RTDs are useful over larger temperature ranges, while thermistors typically achieve a greater precision within a limited temperature range, typically −90 °C to 130 °C.



NTC (negative temperature coefficient)

A failed (blown) NTC thermistor works as an inrush current limiter in a switched-mode power supply. The most likely cause of failure was overload caused by engineering failure (the part was constantly subjected to a higher load than what it was designed for)

Many NTC thermistors are made from a pressed disc, rod, plate, bead or cast chip of semiconducting material such as sintered metal oxides. They work because raising the temperature of a semiconductor increases the number of active charge carriers - it promotes them into the *conduction band*. The more charge carriers that are available, the more current a material can conduct. In certain materials like ferric oxide (Fe_2O_3) with titanium (Ti) doping an *n-type* semiconductor is formed and the charge carriers are electrons. In materials such as nickel oxide (NiO) with lithium (Li) doping a *p-type* semiconductor is created where holes are the charge carriers.
This is described in the formula:

$$I=n*A*v*e$$

I= electric current (amperes)

n= density of charge carriers (count/m³)

A = cross-sectional area of the material (m²)

v= drift velocity of electrons (m/s)

e = charge of an electron (e=1.602*10^-19 coulomb)

Over large changes in temperature, calibration is necessary. Over small changes in temperature, if the right semiconductor is used, the resistance of the material is linearly proportional to the temperature. There are many different semiconducting thermistors with a range from about 0.01 kelvin to 2,000 kelvins (−273.14 °C to 1,700 °C).
The IEC standard symbol for a NTC thermistor includes a "-t°" under the rectangle.

PTC (positive temperature coefficient)

Most PTC thermistors are made from doped polycry stalline ceramic (containing barium titanate ($BaTiO_3$) and other compounds) which have the property that their resistance rises suddenly at a certain critical temperature. Barium titanate is ferroelectric and its dielectric constant varies with temperature. Below the Curie point temperature, the high dielectric constant prevents the formation of potential barriers between the crystal grains, leading to a low resistance. In this region the device has a small negative temperature coefficient. At the Curie point temperature, the dielectric constant drops sufficiently to allow the formation of potential barriers at the grain boundaries, and the resistance increases sharply with temperature. At even higher temperatures, the material reverts to NTC behaviour.

Another type of thermistor is a **silistor**, a thermally sensitive silicon resistor. Silistors employ silicon as the semiconductive component material. Unlike ceramic PTC thermistors, silistors have an almost linear resistance-temperature characteristic.

Barium titanate thermistors can be used as self-controlled heaters; for a given voltage, the ceramic will heat to a certain temperature, but the power used will depend on the heat loss from the ceramic.

The dynamics of PTC thermistors being powered also is extremely useful. When first connected to a voltage source, a large current corresponding to the low, cold, resistance flows, but as the thermistor self-heats, the current is reduced until a limiting current (and corresponding peak device temperature) is reached. The current-limiting effect can replace fuses. They are also used in the degaussing circuits of many CRT monitors and televisions where the degaussing coil only has to be connected in series with an appropriately chosen thermistor; a particular advantage is that the current decrease is smooth, producing optimum degausing effect. Improved degaussing circuits have auxiliary heating elements to heat the thermistor further (and reduce the final current) or timed relays to disconnect the degaussing circuit entirely after it has operated.

Another type of PTC thermistor is the polymer PTC, which is sold under brand names such as "Polyswitch" "Semifuse", and "Multifuse". This consists of plastic with carbon grains embedded in it. When the plastic is cool, the carbon grains are all in contact with each other, forming a conductive path through the device. When the plastic heats up, it expands, forcing the carbon grains apart, and causing the resistance of the device to rise, which then causes increased heating and rapid resistance increase. Like the $BaTiO_3$ thermistor, this device has a highly nonlinear resistance/temperature response useful for thermal or circuit control, not for temperature measurement. Besides circuit elements used to limit current, self-limiting heaters can be made in the form of wires or strips, useful for heat tracing. PTC thermistors 'latch' into a hot / high resistance state: once hot, they stay in that high resistance state, until cooled. In fact, Neil A Downie showed how you can use the effect as a simple latch/memory circuit, the effect being enhanced by using two PTC thermistors in series, with thermistor A cool, thermistor B hot, or vice versa.

The IEC standard symbol for a PTC thermistor includes a "+t°" under the rectangle.

5.4 Thermocouple:

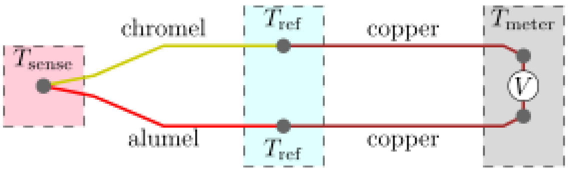
A **thermocouple** is an electrical device consisting of two dissimilar electrical conductors forming electrical junctions at differing temperatures. A thermocouple produces a temperature-dependent voltage as a result of the thermoelectric effect, and this voltage can be interpreted to measure temperature. Thermocouples are a widely used type of temperature sensor.

Commercial thermocouples are inexpensive, interchangeable, are supplied with standard connectors, and can measure a wide range of temperatures. In contrast to most other methods of temperature measurement, thermocouples are self powered and require no external form of excitation. The main limitation with thermocouples is accuracy; system errors of less than one degree Celsius (°C) can be difficult to achieve.

Thermocouples are widely used in science and industry. Applications include temperature measurement for kilns, gas turbine exhaust, diesel engines, and other industrial processes. Thermocouples are also used in homes, offices and businesses as the temperature sensors in thermostats, and also as flame sensors in safety devices for gas-powered appliances.

Principle of operation:

In 1821, the German physicist Thomas Johann Seebeck discovered that when different metals are joined at the ends and there is a temperature difference between the joints, a magnetic field is observed. At the time, Seebeck referred to this consequence as thermo-magnetism. The magnetic field he observed was later shown to be due to thermo-electric current. In practical use, the voltage generated at a single junction of two different types of wire is what is of interest as this can be used to measure temperature at very high and low temperatures. The magnitude of the voltage depends on the types of wire being used. Generally, the voltage is in the microvolt range and care must be taken to obtain a usable measurement. Although very little current flows, power can be generated by a single thermocouple junction. Power generation using multiple thermocouples, as in a thermopile, is common.



K-type thermocouple (chromel–alumel) is having the standard thermocouple measurement configuration. The measured voltage (V) can be used to calculate temperature T, provided that temperature Tref is known.

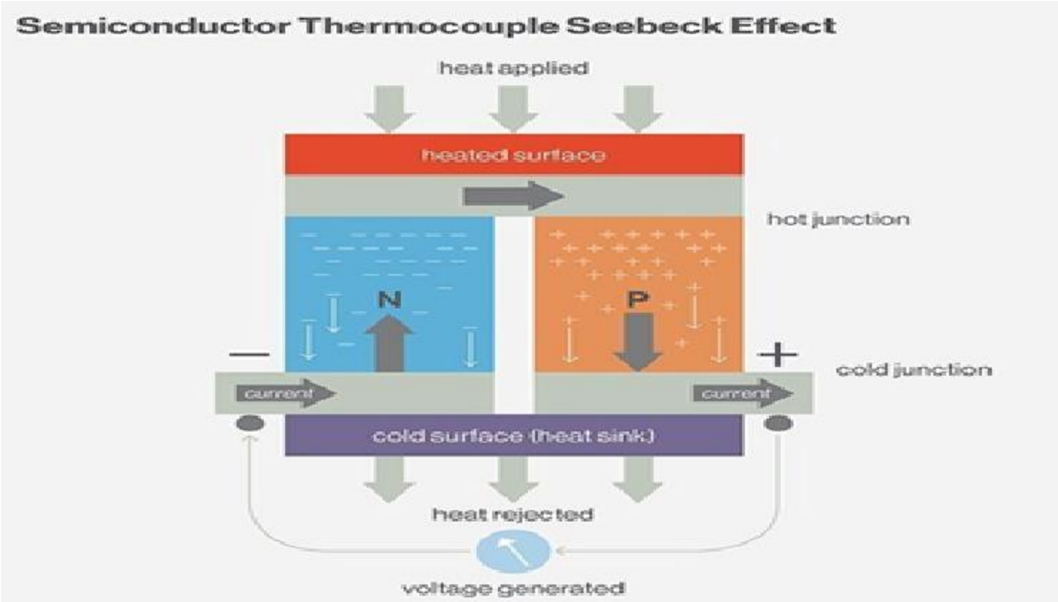
The standard configuration for thermocouple usage is shown in the figure. Briefly, the desired temperature T_{sense} is obtained using three inputs—the characteristic function $E(T)$ of the thermocouple, the measured voltage V, and the reference junctions' temperature T_{ref}. The solution to the equation $E(T_{sense}) = V + E(T_{ref})$ yields T_{sense}. These details are often hidden from the user since the reference junction block (with T_{ref} thermometer), voltmeter, and equation solver are combined into a single product.

Physical principle: Seebeck effect

The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances.

When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit.

The voltages produced by Seebeck effect are small, usually only a few microvolts (millionths of a volt) per kelvin of temperature difference at the junction. If the temperature difference is large enough, some Seebeck-effect devices can produce a few millivolts (thousandths of a volt). Numerous such devices can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current. Large arrays of Seebeck-effect devices can provide useful, small-scale electrical power if a large temperature difference is maintained across the junctions.



The Seebeck effect is responsible for the behavior of thermocouples, which are used to approximately measure temperature differences or to actuate electronic switches that can turn large systems on and off. This capability is employed in thermoelectric coolingtechnology. Commonly used thermocouple metal combinations include constantan/copper, constantan/iron, constantan/chromel and constantan/alumel.

5.5 IC temperature sensor:

Semiconductor temperature sensors are produced in the form of ICs. Their fundamental design results from the fact that semiconductor diodes have temperature-sensitive voltage vs. current characteristics.

The use of IC temperature sensors is limited to applications where the temperature is within a –55° to 150°C range. The measurement range of IC temperature sensors may be small compared to that of thermocouples and RTDs, but they have several advantages: they are small, accurate, and inexpensive, and are easy to interface with other devices such as amplifiers, regulators, DSPs, and microcontrollers.

IC temperature sensors continue to evolve, providing a varied array of functions, features, and interfaces. With the higher level of integration now feasible, digital IC temperature sensors can report both local and remote temperatures, monitor other system parameters, control fans, or warn when a specific temperature is exceeded.

There are two main types of IC temperature sensorsï¿½analog and digitalï¿½and several variations of each type. Analog sensors can produce a voltage or current proportional to temperature. Digital sensors may monitor local and/or remote temperatures, and can also include features such as voltage monitoring, fan control, and over- or under-limit alarms.

The earliest type of IC temperature sensor improved on the existing thermistor solutions whose resistance varied with temperature in a nonlinear fashion. Analog temperature sensors eliminated the need for additional linearization circuitry to correct for thermistor nonlinearity. While newer digital output temperature sensors have supplanted analog output temperature sensors in many applications, analog temperature sensors continue to find a home in applications that do not require a digitized output. For example, the AD590 sensor is still a viable product in many applications more than 25 years after its release. Often used in remote applications as its high-impedance current makes it insensitive to voltage drops over long lines, it can be used in a wide variety of temperature-sensing applications not only because it operates up to 150°C, but also because of its wide +4 to +30V operating voltage range.
Many applications require temperature data ultimately in a digital format, which can be achieved by feeding the output of an analog output temperature sensor into an A/D converter. With advances in IC production technology, however, it has become cost effective to integrate the A/D conversionï¿½and indeed many other functionsï¿½onto the temperature sensor die, leading to cost, space, and power savings while simplifying the system designer's task.

Digital temperature sensors are similar to analog temperature sensors, but instead of outputting the data in current or voltage, it is converted into a digital format of 1's and 0's. Digital-output temperature sensors are therefore particularly useful when interfacing to a microcontroller. Such interfaces include single-wire PWM, two-wire IC and SMBus, and three-/four-wire SPI protocols.

Inductive transducer:

Inductive transducers work on the principle of inductance change due to any appreciable change in the quantity to be measured i.e. measured. For example, LVDT, a kind of inductive transducers, measures displacement in terms of voltage difference between its two secondary voltages. Secondary voltages are nothing but the result of induction due to the flux change in the secondary coil with the displacement of the iron bar. Anyway LVDT is discussed here briefly to explain the principle of inductive transducer. LVDT will be explained in other article in more detail. For the time being let’s focus on basic introduction of inductive transducers.So first our motive is to find how the inductive transducers can be made to work. This can be done by changing the flux with the help of measured and this changing flux obviously changes the inductance and this inductance change can be calibrated in terms of measured. Hence inductive transducers use one of the following principles for its working.

5.6 LVDT:

LVDT is an acronym for Linear Variable Differential Transformer. It is a common type of electromechanical transducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal. LVDT linear position sensors are readily available that can measure movements as small as a few millionths of an inch up to several inches, but are also capable of measuring positions up to

±30 inches (±0.762 meter). Figure 1 shows the components of a typical LVDT. The transformer's internal structure consists of a primary winding centered between a pair of identically wound secondary windings, symmetrically spaced about the primary. The coils are wound on a one-piece hollow form of thermally stable glass reinforced polymer, encapsulated against moisture, wrapped in a high permeability magnetic shield, and then secured in cylindrical stainless steel housing. This coil assembly is usually the stationary element of the position sensor.

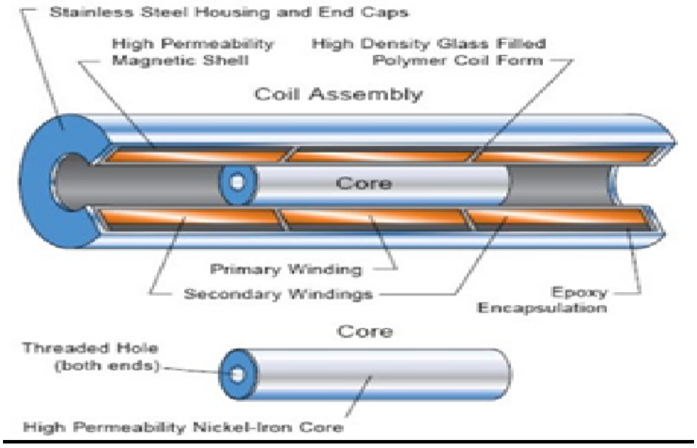


Fig:The primary winding is illustrated in the center of the LVDT. Two secondary coils are wound symmetrically on each side of the primary coil as shown for “short stroke” LVDTs or on top of the primary coil for “long stroke” LVDTs. The two secondary windings are typically connected in “series opposing” (Differential).

The moving element of an LVDT is a separate tubular armature of magnetically permeable material. This is called the core, which is free to move axially within the coil's hollow bore, and mechanically coupled to the object whose position is being measured. This bore is typically large enough to provide substantial radial clearance between the core and bore, with no physical contact between it and the coil. In operation, the LVDT's primary winding is energized by alternating current of appropriate amplitude and frequency, known as the primary excitation. The LVDT's electrical output signal is the differential AC voltage between the two secondary windings, which varies with the axial position of the core within the LVDT coil. Usually this AC output voltage is converted by suitable electronic circuitry to high level DC voltage or current that is more convenient to use.

How does a LVDT work?

Figure 2 illustrates what happens when the LVDT's core is in different axial positions**.** The LVDT's primary winding, P, is energized by a constant amplitude AC source. The magnetic flux thus developed is coupled by the core to the adjacent secondary windings, S1 and S2. If the core is located midway between S1 and S2, equal flux is coupled to each secondary so the voltages, E1 and E2, induced in windings S1 and S2 respectively, are equal. At this reference midway core position, known as the null point, the differential voltage output, (E1 - E2), is essentially zero. As shown in Figure 2, if the core is moved closer to S1 than to S2, more flux is coupled to S1 and less to S2, so the induced voltage E1 is increased while E2 is decreased, resulting in the differential voltage (E1 - E2). Conversely, if the core is moved closer to S2, more flux is coupled to S2 and less to S1, so E2 is increased as E1 is decreased, resulting in the differential voltage (E2 - E1).

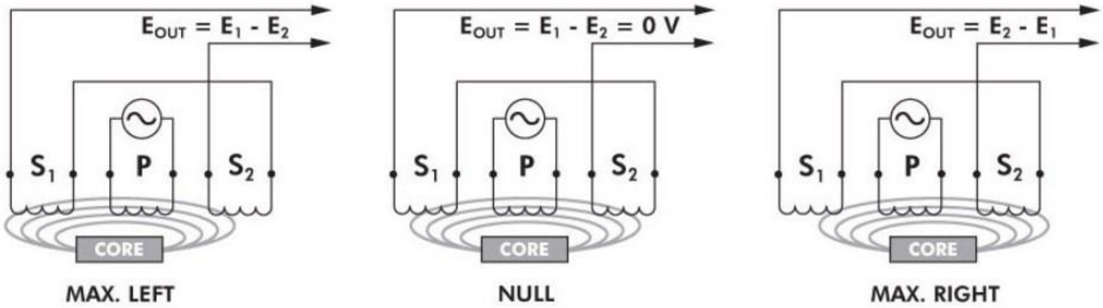


FIGURE 2: Illustrates what happens when the LVDT's core is in different axial positions.

Figure 3A shows how the magnitude of the differential output voltage, EOUT, varies with core position. The value of EOUT at maximum core displacement from null depends upon the amplitude of the primary excitation voltage and the sensitivity factor of the particular LVDT, but is typically several volts RMS. The phase angle of this AC output voltage, EOUT, referenced to the primary excitation voltage, stays constant until the center of the core passes the null point, where the phase angle changes abruptly by 180 degrees, as shown graphically in Figure 3B. This 180 degree phase shift can be used to determine the direction of the core from the null point by means of appropriate circuitry. This is shown in Figure 3C, where the polarity of the output signal represents the core's positional relationship to the null point. The figure shows also that the output of an LVDT is very linear over its specified range of core motion, but that the sensor can be used over an extended range with some reduction in output linearity.

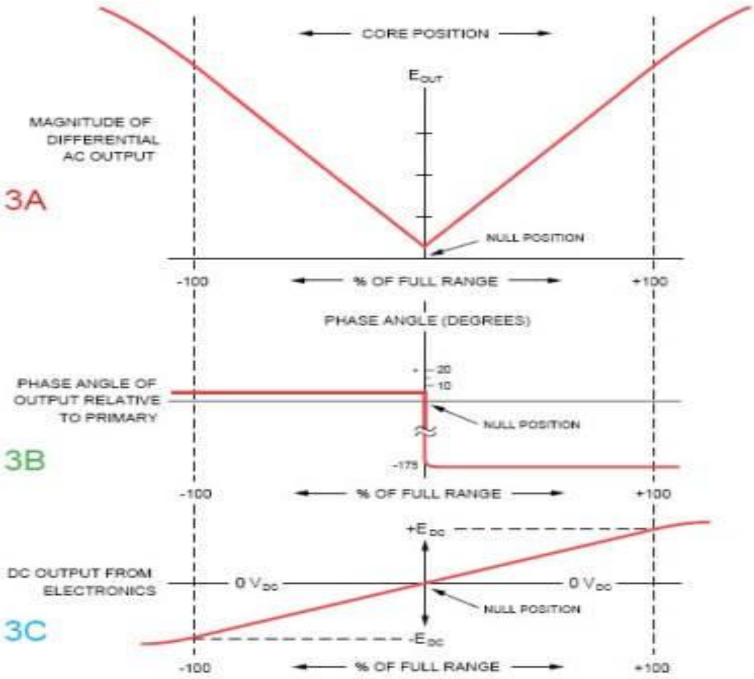


FIGURE 3: The output characteristics of an LVDT vary with different positions of the core. Full range output is a large signal, typically a volt or more, and often requires no amplification. Note that an LVDT continues to operate beyond 100% of full range, but with degraded linearity.

5.7 Capacitive transducer:

To learn about a capacitive transducer, it is important to know the basics of a parallel plate capacitor. Being the simplest form of a capacitor, it has two parallel conducting plates that are separated to each other by a dielectric or insulator with a permittivity of E (for air). Other than paper, vacuum, and semi-conductor depletion region, the most commonly used dielectric is air.

Due to a potential difference across the conductors, an electric field develops across the insulator. This causes the positive charges to accumulate on one plate and the negative charges to accumulate on the other. The capacitor value is usually denoted by its capacitance, which is measured in Farads. It can be defined as the ratio of the electric charge on each conductor to the voltage difference between them.

The capacitance is denoted by C. In a parallel plate capacitor,

$$C = [A*Er*9.85*10^{12}\ F/M]/d$$

A – Area of each plate (m)

d – Distance between both the plates (m)

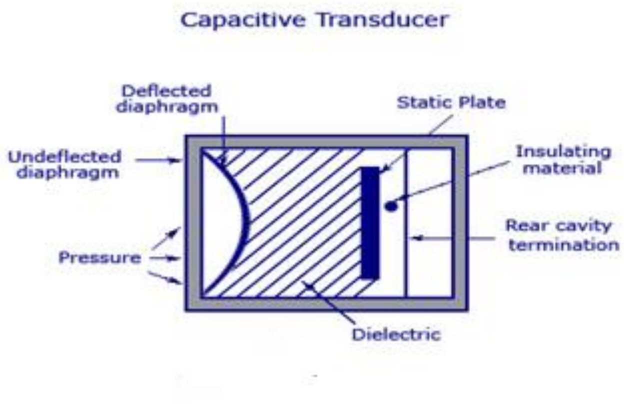
Er – Relative Dielectric Constant

The value 9.85*1012 F/M is a constant denoted by Eo and is called the dielectric constant of free-space.

From the equation it is clear that the value of capacitance C and the distance between the parallel plates,d are inversely proportional to each other. An increase of distance between the parallel plates will decrease the capacitance value correspondingly. The same theory is used in a capacitive transducer. This **transducer** is used to convert the value of displacement or change in pressure in terms of frequency.

Capacitance Transducer

As shown in the figure below, a capacitive transducer has a static plate and a deflected flexible diaphragm with a dielectric in between. When a force is exerted to the outer side of the diaphragm the distance between the diaphragm and the static plate changes. This produces a capacitance which is measured using an alternating current bridge or a tank circuit.



Capacitive Transducer

A tank circuit is more preferred because it produces a change in frequency according to the change in capacitance. This value of frequency will be corresponding to the displacement or force given to the input.

Advantages

- It produces an accurate frequency response to both static and dynamic measurements.

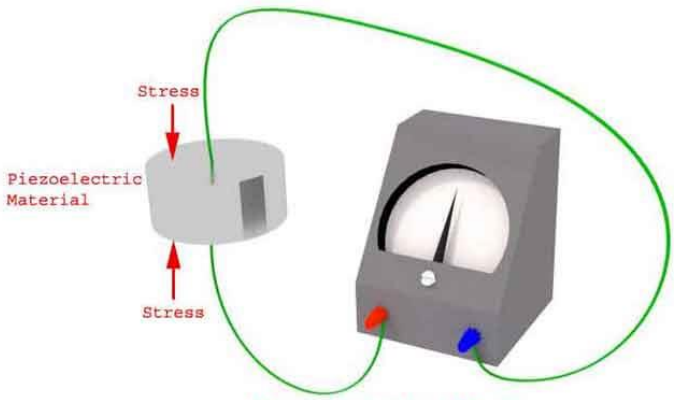
Disadvantages

- An increase or decrease in temperature to a high level will change the accuracy of the device.
- As the lead is lengthy it can cause errors or distortion in signals.

5.8 Piezo-electric transducer:

A transducer can be anything which converts one form of energy to another. **Piezoelectric material** is one kind of transducers. We squeeze this material or we apply force or pressure on this material it converts it into electric voltage and this voltage is function of the force or pressure applied to it. The material which behaves in such a way is also known as **piezoelectric sensor**.

The electric voltage produced by **piezoelectric transducer** can be easily measured by voltage measuring instruments, which can be used to measure stresses or forces. The physical quantity like mechanical stress or force cannot be measured directly. Therefore, piezoelectric transducer can be used.

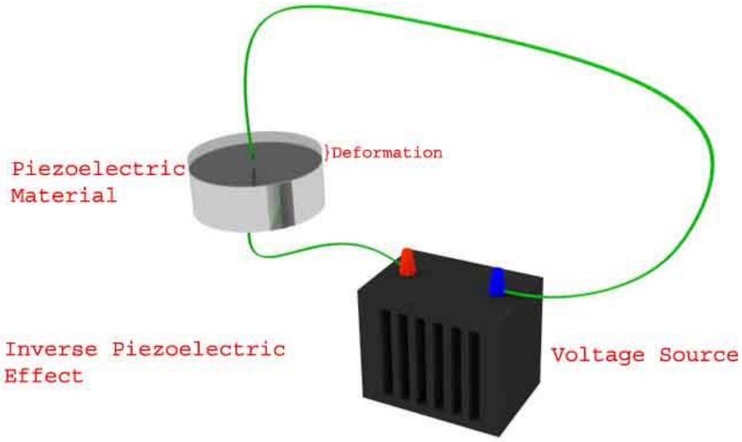


Piezoelectric Effect

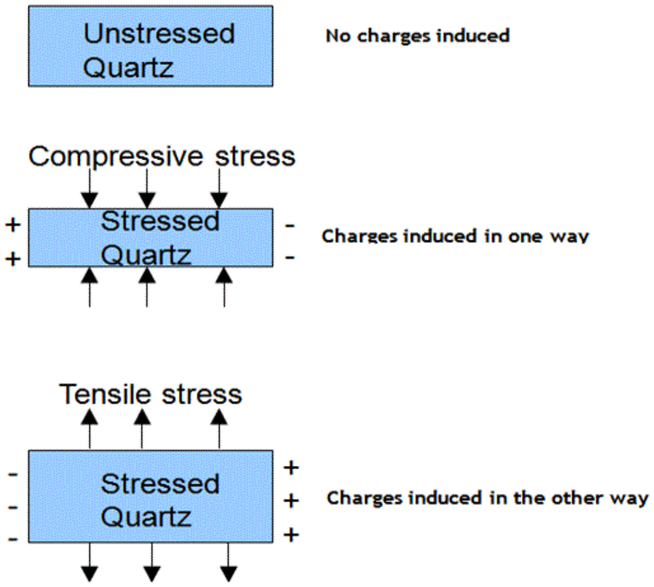
Piezoelectric Actuator

Piezoelectric actuator behaves in reverse manner of **piezoelectric sensor**. It is the one in which the electric effect will cause the material to deform i.e. stretch or bend.

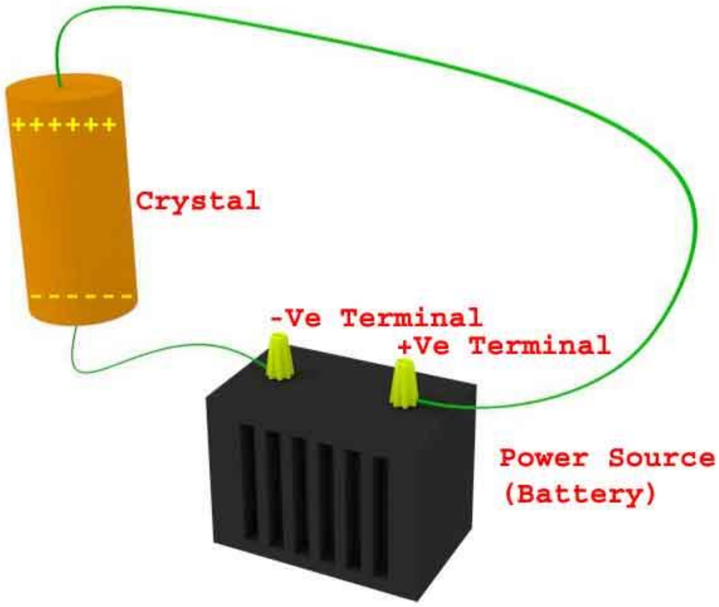
That means in piezoelectric sensor, when force is applied to stretch or bend it, an electric potential is generated and in opposite when on a **piezoelectric actuator**, an electric potential is applied it is deformed i.e. stretched or bend.

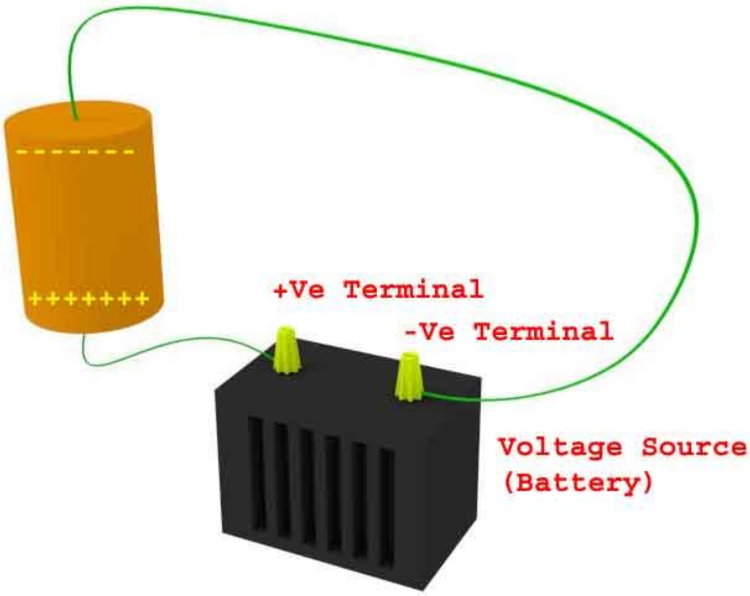


Piezoelectric transducer consists of quartz crystal which is made from silicon and oxygen arranged in crystalline structure (SiO_2). Generally, unit cell (basic repeating unit) of all crystal is symmetrical but in piezoelectric quartz crystal it is not. Piezoelectric crystals are electrically neutral. The atoms inside them may not be symmetrically arranged but their electrical charges are balanced means positive charges cancel out negative charge. The quartz crystal has unique property of generating electrical polarity when mechanical stress applied on it along certain plane. Basically, There are two types of stress. One is compressive stress and other is tensile stress.



When there is unstressed quartz no charges induce on it. In case of compressive stress, positive charges are induced in one side and negative charges are induced in opposite side. The crystal size gets thinner and longer due to compressive stress. In case of tensile stress, charges are induced in reverse as compare to compressive stress and quartz crystal gets shorter and fatter. **Piezoelectric transducer** is based on principle of piezoelectric effect. The word piezoelectric is derived from Greek word piezen, which means to squeeze or press. Piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, produce electrical charges on quartz crystal surface. The piezoelectric effect is discovered by Pierre and Jacques curie. The rate of charge produced will be proportional to rate of change of mechanical stress applied on it. Higher will be stress higher will be voltage. One of the unique characteristics of piezoelectric effect is that it is reversible means when voltage is applied to them ,they tends to change dimension along certain plane i.e quartz crystal structure is placed into electric field, it will deform quartz crystal by amount proportional to strength of electric field. If same structure is placed into an electric field with direction of field reversed, the deformation will be opposite.





Quartz crystal becomes shorter due to electric field applied in reversed direction. It is self-generating transducer. It does not require electric voltage source for operation. The electric voltage produced by piezoelectric transduce is linearly varies to applied stress or force. **Piezoelectric transducer** has high sensitivity. So, it acts as sensor and used in accelero meter due to its excellent frequency of response. The piezoelectric effect is used in many application that involve production and detection of sound, electronic frequency generation. It acts as ignition source for cigarette lighter and used in sonar, microphone, force, pressure and displacement measurement

Application of Piezoelectric Materials

1. In microphones, the sound pressure is converted into electric signal and this signal is ultimately amplified to produce louder sound.
2. Automobile seat belts lock in response to a rapid deceleration is also done by piezoelectric material.
3. It is also used in medical diagnostics.
4. It is used in electric lighter used in kitchens. Pressure made on piezoelectric sensor creates an electric signal which ultimately causes flash to fire up.
5. They are used for studying high speed shock waves and blast waves.
6. Used in fertility treatment.
7. Used in Inkjet printers
8. It is also used in restaurants or airports where when a person steps near the door and the door opens automatically. In this the concept used is when person is near the door a pressure is exerted persons weight on the sensors due to which the electric effect is produced and the door opens automatically.

Examples of Piezoelectric Material

The materials are :

1. Barium Titanate.
2. Lead zirconate titanate (PZT).
3. Rochelle salt.

The Piezoelectric Ultrasonic Transducer

It produces frequencies which are far above than that which can be hear by human ear. It expands and contracts rapidly when subjected to any voltage. It is typically used in vaccum cleaner.

Piezo Buzzer

Buzzer is anything which produces sound. They are driven by oscillating electronic circuit.

Advantages of Piezoelectric Transducer

1. No need of external force.
2. Easy to handle and use as it has small dimensions.
3. High frequency response it means the parameters change very rapidly.

Disadvantages of Piezoelectric Transducer

1. It is not suitable for measurement in static condition.
2. It is affected by temperatures.
3. Output is low so some external circuit is attached to it.
4. It is very difficult to give desired shape to this material and also desired strength.

5.9 LDR:

Light dependent resistors, LDRs or photoresistors are often used in circuits where it is necessary to detect the presence or the level of light.

They can be described by a variety of names from light dependent resistor, LDR, photoresistor, or even photo cell, photocell or photoconductor.

Although other devices such as photodiodes or photo-transistor can also be used, LDRs or photoresistors are a particularly convenient electronics component to use. They provide large change in resistance for changes in light level.

In view of their low cost, ease of manufacture, and ease of use LDRs have been used in a variety of different applications. At one time LDRs were used in photographic light meters, and even now they are still used in a variety of applications where it is necessary to detect light levels.

What is light dependent resistor, LDR or photoresistor

A photoresistor or light dependent resistor is a component that is sensitive to light. When light falls upon it then the resistance changes. Values of the resistance of the LDR may change over many orders of magnitude the value of the resistance falling as the level of light increases.

It is not uncommon for the values of resistance of an LDR or photoresistor to be several megohms in darkness and then to fall to a few hundred ohms in bright light. With such a wide variation in resistance, LDRs are easy to use and there are many LDR circuits available. The sensitivity of light dependent resistors or photoresistors also varies with the wavelength of the incident light.
LDRs are made from semiconductor materials to enable them to have their light sensitive properties. Many materials can be used, but one popular material for these photoresistors is cadmium sulphide, CdS.

How an LDR works

It is relatively easy to understand the basics of how a LDR works without delving into complicated explanations. It is first necessary to understand that an electrical current consists of the movement of electrons within a material. Good conductors have a large number of free electrons that can drift in a given direction under the action of a potential difference. Insulators with a high resistance have very few free electrons, and therefore it is hard to make the them move and hence a current to flow.

A LDR or photo resistor is made any semiconductor material with a high resistance. It has a high resistance because there are very few electrons that are free and able to move - the vast majority of the electrons are locked into the crystal lattice and unable to move. Therefore in this state there is a high LDR resistance.

As light falls on the semiconductor, the light photons are absorbed by the semiconductor lattice and some of their energy is transferred to the electrons. This gives some of them sufficient energy to break free from the crystal lattice so that they can then conduct electricity. This results in a lowering of the resistance of the semiconductor and hence the overall LDR resistance.

The process is progressive, and as more light shines on the LDR semiconductor, so more electrons are released to conduct electricity and the resistance falls further.

Multiple-choice Questions

Which of the following is not a characteristic of ideal transducer?
a) High dynamic range
b) Low linearity
c) High repeatability
d) Low noise

2. A transducer converting ground movement or velocity to voltage is known as
a) Geophone
b) Pickup
c) Hydrophone
d) Sonar transponder

3. Which of following represent active transducer?
a) Strain gauge
b) Thermistor
c) LVDT
d) Thermocouple

4. Which transducer is known as ‘self-generating transducer’?
a) Active transducer
b) Passive transducer
c) Secondary transducer
d) Analog transducer

5. What is the relation between scale factor and sensitivity of a transducer?
a) Scale factor is double of sensitivity
b) Scale factor is inverse of sensitivity
c) Sensitivity is inverse of scale factor

d) Sensitivity is equal to scale factor

6. Which of the following is an analog transducer?
a) Encoders
b) Strain gauge
c) Digital tachometers
d) Limit switches

7. What is the principle of operation of LVDT?
a) Mutual inductance
b) Self-inductance
c) Permanence
d) Reluctance

8. Which of the following can be measured using Piezo-electric transducer?
a) Velocity
b) Displacement
c) Force
d) Sound

9. Capacitive transducer are used for?
a) Static measurement
b) Dynamic measurement
c) Transient measurement
d) Both static and dynamic

10. Which of the following is used in photo conductive cell?
a) Selenium
b) Quartz
c) Rochelle salt
d) Lithium sulphate

Review Question

1.Define transducer and state their classification.(5 marks)
2. Explain working of Bimetallic thermometer.(5 marks)
3 .Define metrology and write its significance.(5 marks)
4. Justify- L VDT can be used as primary as well as secondary transducer.(5 marks)

5. Thermistor has a resistance of 3980 Ω at the ice point (0° and 794 Ω at 50°C. The resistance-temperature relationship is given by R_T= a R_0 exp (b/T).
(i) calculate the constants a and b
(ii) Calculate the range of resistance to be measured in case the temperature varies from 40°C and 100°C.

6. Explain different types Temperature transducers.

Write short notes:

7. Lead wire compensation in RTD
8.Strain gauge
9.Thermistor
10.Capacitive transducer.
11.Piezo-electric transducer.
12.Thermocouple.

MODULE 6

6.1 Telemetry System:

Telemetry is an automated communications process by which measurements and other data are collected at remote or inaccessible points and transmitted to receiving equipment for monitoring. The word is derived from Greek roots: *tele* = remote, and *metron* = measure. Systems that need external instructions and data to operate require the counterpart of telemetry, telecommand.

Although the term commonly refers to wireless data transfer mechanisms (e.g., using radio, ultrasonic, or infrared systems), it also encompasses data transferred over other media such as a telephone or computer network, optical link or other wired communications like power line carriers. Many modern telemetry systems take advantage of the low cost and ubiquity of GSMnetworks by using SMS to receive and transmit telemetry data.

A telemeter is a device used to remotely measure any quantity. It consists of a sensor, a transmission path, and a display, recording, or control device. Telemeters are the physical devices used in telemetry. Electronic devices are widely used in telemetry and can be wireless or hard-wired, analog or digital. Other technologies are also possible, such as mechanical, hydraulic and optical.

Telemetry may be commutated to allow the transmission of multiple data streams in a fixed frame.

APPLICATION:

- **Meteorology**

Telemetry has been used by weather balloons for transmitting meteorological data since 1920.

- **Oil and gas industry**

Telemetry is used to transmit drilling mechanics and formation evaluation information uphole, in real time, as a well is drilled. These services are known as Measurement while drillingand Logging while drilling. Information acquired thousands of feet below ground, while drilling, is sent through the drilling hole to the surface sensors and the demodulation software. The pressure wave (sana) is translated into useful information after DSP and noise filters. This information is used for Formation evaluation, Drilling Optimization, and Geosteering.

- **Motor racing**

Telemetry is a key factor in modern motor racing, allowing race engineers to interpret data collected during a test or race and use it to properly tune the car for optimum performance. Systems used in series such as Formula One have become advanced to the point where the potential lap time of the car can be calculated, and this time is what the driver is expected to meet. Examples of measurements on a race car include accelerations (G forces) in three axes, temperature readings, wheel speed, and suspension displacement. In Formula One, driver input is also recorded so the team can assess driver performance and (in case of an accident) the FIA can determine or rule out driver error as a possible cause.

Later developments include two-way telemetry which allows engineers to update calibrations on the car in real time (even while it is out on the track). In Formula One, two-way telemetry surfaced in the early 1990s and consisted of a message display on the dashboard which the team could update. Its development continued until May 2001, when it was first allowed on the cars. By 2002, teams were able to change engine mapping and deactivate engine sensors from the pit while the car was on the track. For the 2003 season, the FIA banned two-way telemetry from Formula One however; the technology may be used in other types of racing or on road cars.

Telemetry has also been applied in yacht racing on Oracle Racing's USA 76.

One way telemetry system has also been applied in R/C racing car to get information by car's sensors like: engine RPM, voltage, temperatures, and throttle.

- **Transportation**

In the transportation industry, telemetry provides meaningful information about a vehicle or driver's performance by collecting data from sensors within the vehicle. This is undertaken for various reasons ranging from staff compliance monitoring, insurance rating to predictive maintenance.

- **Agriculture**

Most activities related to healthy crops and good yields depend on timely availability of weather and soil data. Therefore, wireless weather stations play a major role in disease prevention and precision irrigation. These stations transmit parameters necessary for decision-making to a base station: air temperature and relative humidity, precipitation and leaf wetness (for disease prediction models), solar radiation and wind speed (to calculate evapo-transpiration), water deficit stress (WDS) leaf sensors and soil moisture (crucial to irrigation decisions).

Because local micro-climates can vary significantly, such data needs to come from within the crop. Monitoring stations usually transmit data back by terrestrial radio, although occasionally satellite systems are used. Solar power is often employed to make the station independent of the power grid.

- **Water management**

Telemetry is important in water management, including water quality and stream gauging functions. Major applications include AMR (automatic meter reading), groundwatermonitoring, leak detection in distribution pipelines and equipment surveillance. Having data available in almost real time allows quick reactions to events in the field. Telemetry control allows engineers to intervene with assets such as pumps and by remotely switching pumps on or off depending on the circumstances. Watershed telemetry is an excellent strategy of how to implement a water management system.

- **Defense, space and resource exploration**

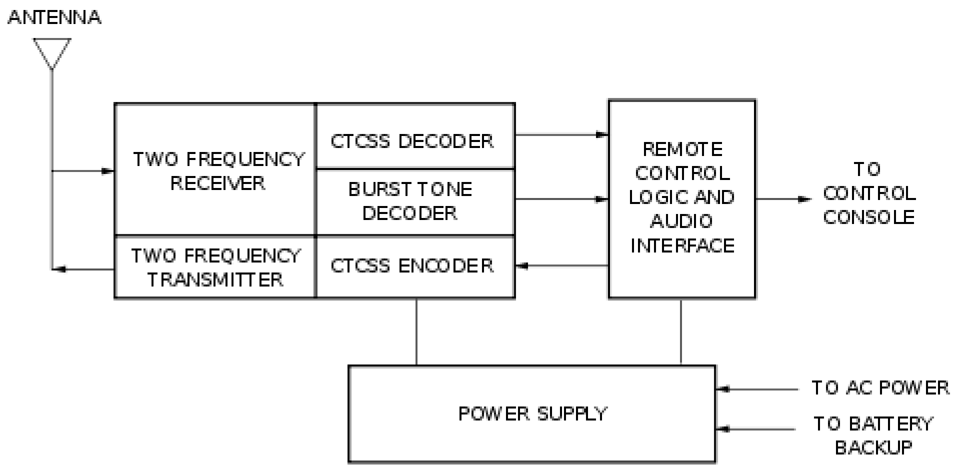
Telemetry is used in complex systems such as missiles, RPVs, spacecraft, oil rigs, and chemical plants since it allows the automatic monitoring, alerting, and record-keeping necessary for efficient and safe operation. Space agencies such as ISRO, NASA, the European Space Agency (ESA), and other agencies use telemetry and/or telecommand systems to collect data from spacecraft and satellites.

Telemetry is vital in the development of missiles, satellites and aircraft because the system might be destroyed during or after the test. Engineers need critical system parameters to analyze (and improve) the performance of the system. In the absence of telemetry, this data would often be unavailable.

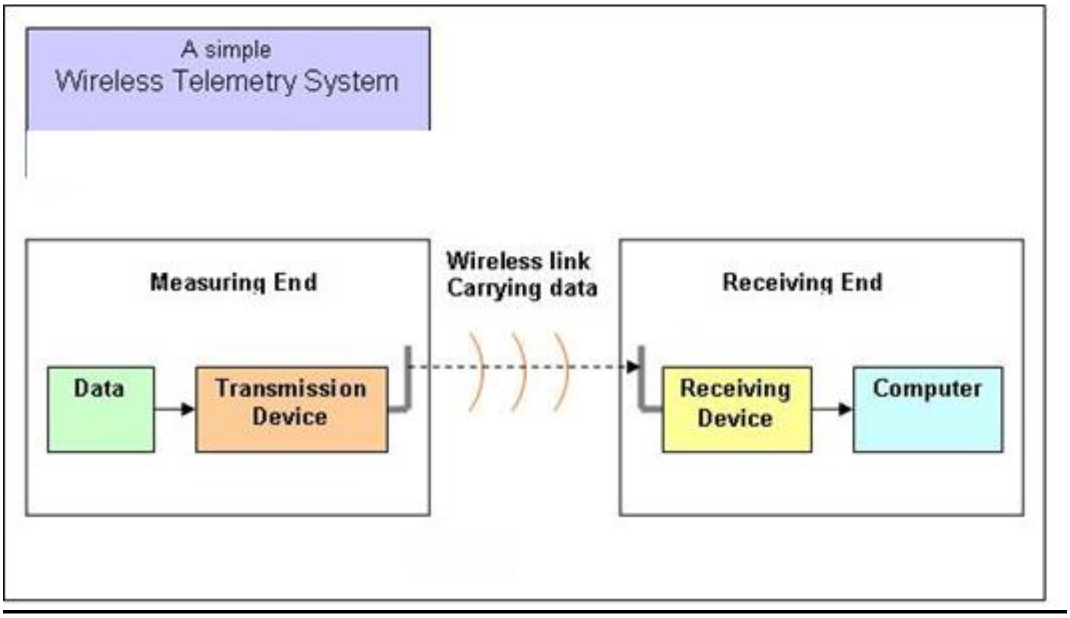
- **Space science**

Telemetry is used by manned or unmanned spacecraft for data transmission. Distances of more than 10 billion kilometres have been covered, e.g., by Voyager 1.

Interface Standard: block diagram –land :



R.F telemetry:



Introduction

A telemetry system consists of a remote site and a control site. The remote site wireless telemetry device contains systems and processes whose parameters are to be monitored. It would ideally consist of instruments that measure flow, pressure, temperature, etc. of a process. A wireless telemetry device at a control site is equipped with monitoring systems, which supervise conditions of power failure, water level, battery voltage, intrusion, etc. Chart recorders, alarm control panels, and data loggers are used for this supervision

Operation of a telemetry system

When a telemetry device at the remote site detects any abrupt behaviour in the digital/analog inputs, it triggers a signal. This signal is carried to the control site. The control site telemetry device then decides the action to be taken depending on the received signal. It then sends a signal back to the remote site with necessary control actions. The communication between the control site and the remote site is, many times, done by wireless medium.

Wireless Telemetry

Wireless telemetry systems were implemented to eliminate the use of dedicated wires and circuits to transfer data between a remote site and a control site. A radio system operating on RF (radio frequency) provides single point and/or multi-point communication. This is often called RF telemetry.

Advancements and massive developments in wireless technology have scaled up the performance of RF telemetry systems. Wireless telemetry provides a cost-effective way to monitor remote sites without any delay or risk of broken circuits. Also, changing a wired system to a wireless system is done at minimal cost.

Applications of Wireless Telemetry

Wireless Telemetry is used in almost every activity of process engineering, chemical plants, irrigation projects, military, etc.

6.2 Display Devices :

Cathode Ray Tube (CRT) Display

Electron gun shoots beam of electrons toward the back of monitor screen.It is coated with chemical dots called phosphors glow when electrons strike them.Beam of electrons scans the monitor from left to right, and top to bottom in a raster pattern to create the image.

Trio of dot phosphors is grouped in triangle for each hardware picture element. Electron beam returns regular to each phosphor to sustain the glow. More dots better quality is achieved.

Dot pitch (Measurement between the same spot in two vertically adjacent dot trios) expressed in millimetres or dots per inch. Dot pitch tells “sharpness”.Software-pixel placement is limited to hardware’s transistor placement.

Resolution

- Number of pixels used to draw the screen.
- Higher resolutions = more information in the same screen area.
- Indicates rows and columns of pixels on screen

Liquid Crystal Display (LCD)

- Crystals align themselves with the current when passed through a semi-crystalline liquid.
- Combining transistors with liquid crystals, a pattern is formed.
- Patterns combined to represent numbers or letters.
- First used in watches, now in monitor, even TV.
- Available in analog (like VGA)
- PCs digital signals are converted to analog by video card digital interface
- No analog modulation required, generally sharper
- Backlight makes easier to view

ACTIVE MATRIX:

Transistor at each pixel, switches to different level changing alignment and produces 1000s of shades crisp, wide viewing angles and pixels hold value thus, no refreshing is needed.But large power needed

PASSIVE MATRIX:

- Pixels in x-y matrix and transistors on the axis circuits controlling the columns that are synchronized to fire when that row's transistor is active.
- Refreshment is required
- Can be muddy

DUAL SCAN:

- Passive matrix split in half and each half refreshed separately.
- Quality is improved in this case
- Slower response leading to submarining.
- Lesser viewing angle
- Antiglare filters brighten, clarifying displays

6.2.1 LED Displays:

- LCD displays with LED as light sources.
- Each LED can be intelligently controlled for better quality
- Work on DC power

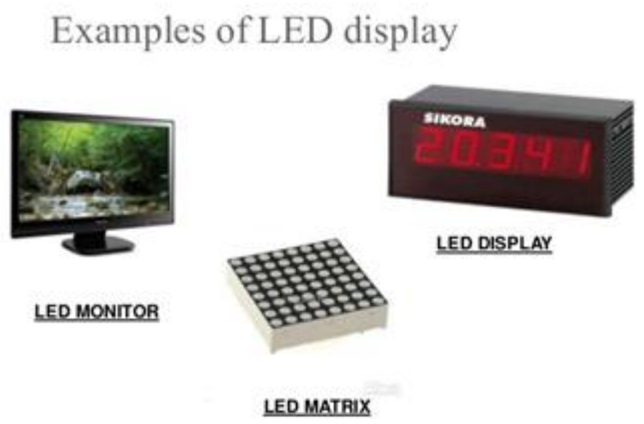
Plasma Displays

Plasma: Cloud of ionized particles.These produce light when electrons change the energy level. Electrodes are placed in front and back of sealed chambers with neon gas and mercury vapours. Not suitable in high altitude.No backlight, produce deeper black 600Hz is refresh rate.

Organic Light Emitting Diode (OLED)

- Organic light emitting compound placed b/w anode-cathode. It emits light when excited by current.
- No backlight is needed.
- Thin, light weight, flexible layer.
- Better contrast ratio
- Reflective thus filters required
- Active matrix (AMOLED) LED is available
- Passive matrix (PMOLED) LEDis available
- Lesser power than LCDs
- Super AMOLED plus has subpixels for clearer display

Application of LED in display system:



- **Digital Factory & Production Signage**

A programmable LED electronic sign is a great way of conveying information to large groups of employees at the same time. These information display systems help employees monitor their own progress, which, in turn, helps improve morale and motivation. It also helps keeps management focused on results.

Here are some things you can do with a LED display:

Show output, for example:

Up to the minute production information.

Actual production figures.

Comparisons against a target or a previous period.

Results for the business as a whole.

Units produced per minute, hour, day, machine, team or person at regular intervals.

- **LED Financial Displays & Stock Tickers**

We have an extensive range LED ticker, LED marquee and electronic sign displays that are all suitable for use in the banking and financial service sectors. The very nature of electronic signs means they are a perfect way of conveying financial information.

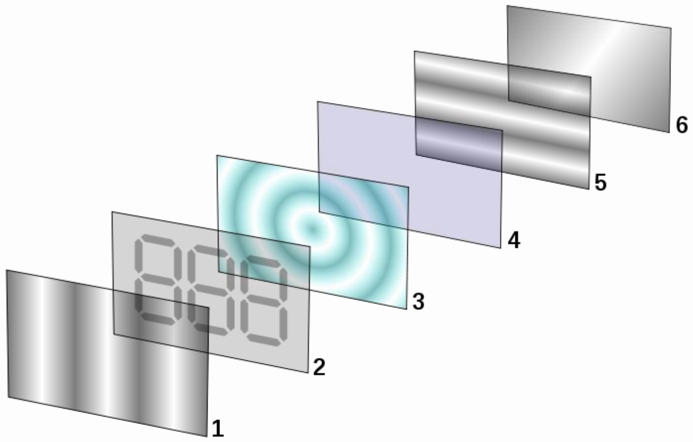
LED ticker displays are great at displaying the latest stocks and share prices and LED electronic sign boards are often used in dealing rooms. LED electronic signs can also be linked to specific financial 'Newswire' services, showing the latest developments and prices. In dealing rooms and on market floors, it's crucial that the financial ticker displays are fast and accurate. A lot of money can be made or lost on the strength of the information on these displays.

- **Indoor & Outdoor LED Scoreboards**

We supply a vast range of different types of sports LED scoreboards. From small. Simple scoreboards that just use digits, to more complex video electronic scoreboards for stadiums. The benefit of the larger scoreboards is that during a break in the action, you can use the scoreboard screen to run advertisements to get some return on investment**.**

6.2.2 Application LCD in display system:

LCDs are used in a wide range of applications including LCD televisions, computer monitors, instrument panels, aircraft cockpit displays, and indoor and outdoor signage. Small LCD screens are common in portable consumer devices such as digital cameras, watches, calculators, and mobile telephones, including smartphones. LCD screens are also used on consumer electronics products such as DVD players, video game devices and clocks. LCD screens have replaced heavy, bulky cathode ray tube (CRT) displays in nearly all applications. LCD screens are available in a wider range of screen sizes than CRT and plasma displays, with LCD screens available in sizes ranging from tiny digital watches to very large television receivers.



6.2.3 Fourteen Segment Display:

A **fourteen-segment display** (**FSD**) (sometimes referred to as a **starburst display** or **Union Jack display)** is a type of display based on 14 segments that can be turned on or off to produce letters and numerals. It is an expansion of the more common seven-segment display, having an additional four diagonal and two vertical segments with the middle horizontal segment broken in half. A seven-segment display suffices for numerals and certain letters, but unambiguously rendering the ISO basic Latin alphabet requires more detail. A slight variation is the sixteen-segment display which allows additional legibility in displaying letters or other symbols.

A decimal point or comma may be present as an additional segment, or pair of segments; the comma (used for triple-digit groupings or as a decimal separator in many regions) is commonly formed by combining the decimal point with a closely 'attached' leftwards-descending arc-shaped segment.

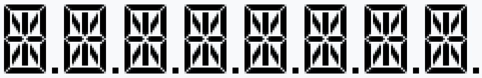


Diagram of 14-segment display

Note unbroken top and bottom segments in comparison with a sixteen-segment display.

Electronic alphanumeric displays may use LEDs, LCDs, or vacuum fluorescent display devices. The LED variant is typically manufactured in single or dual character packages, allowing the system designer to choose the number of characters suiting the application.

Often a character generator is used to translate 7-bit ASCII character codes to the 14 bits that indicate which of the 14 segments to turn on or off.

Applications:

Multiple-segment display devices use fewer elements than a full dot-matrix display, and may produce a better character appearance where the segments are shaped appropriately. This can reduce the number of driver components and power consumption.

Fourteen-segment gas-plasma displays were used in pinball machines from 1986 through 1991 with an additional comma and period part making for a total of 16 segments.

Fourteen and sixteen-segment displays were used to produce alphanumeric characters on calculators and other embedded systems. Applications today include displays fitted to telephone Caller ID units, gymnasium equipment, VCRs, car stereos, microwave ovens, slot machines, and DVD players.

Such displays were very common on pinball machines for displaying the score and other information, before the widespread use of dot-matrix display panels.

6.2.4 Dot Matrix Display-3×5 dot ,27 dot ,5×7 dot:

A **dot-matrix display** is a display device used to display information on machines, clocks, railway departure indicators and many other devices requiring a simple display device of limited resolution.

The display consists of a dot matrix of lights or mechanical indicators arranged in a rectangular configuration (other shapes are also possible, although not common) such that by switching on or off selected lights, text or graphics can be displayed. A dot matrix controller converts instructions from a processor into signals which turns on or off lights in the matrix so that the required display is produced.

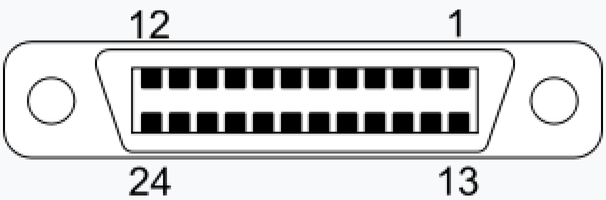
6.5 Bus interface standard –GPIB interface bus(IEEE488):

IEEE 488 is a short-range digital communications 8-bit parallel multi-master interface bus specification. IEEE 488 was created as **HP-IB** (**Hewlett-Packard Interface Bus**) and is commonly called **GPIB** (**General Purpose Interface Bus**). It has been the subject of several standards.

Although originally created in the late 1960s to connect together automated test equipment, it also had some success during the 1970s and 1980s as a peripheral bus for early microcomputers, notably the Commodore PET. Newer standards have largely replaced IEEE 488 for computer use, but it still sees some use in the test equipment field.

Connectors:

IEEE 488		
Pin out		



Female IEEE 488 connector

Pin 1	DIO1	Data input/output bit.
Pin 2	DIO2	Data input/output bit.
Pin 3	DIO3	Data input/output bit.
Pin 4	DIO4	Data input/output bit.
Pin 5	EOI	End-or-identify.

Pin 6	DAV	Data valid.
Pin 7	NRFD	Not ready for data.
Pin 8	NDAC	Not data accepted.
Pin 9	IFC	Interface clear.
Pin 10	SRQ	Service request.
Pin 11	ATN	Attention.
Pin 12	SHIELD	
Pin 13	DIO5	Data input/output bit.
Pin 14	DIO6	Data input/output bit.
Pin 15	DIO7	Data input/output bit.
Pin 16	DIO8	Data input/output bit.
Pin 17	REN	Remote enable.
Pin 18	GND	(wire twisted with DAV)
Pin 19	GND	(wire twisted with NRFD)
Pin 20	GND	(wire twisted with NDAC)
Pin 21	GND	(wire twisted with IFC)
Pin 22	GND	(wire twisted with SRQ)
Pin 23	GND	(wire twisted with ATN)
Pin 24	Logic ground	

IEEE 488 specifies a 24-pin Amphenol-designed micro ribbon connector. Micro ribbon connectors have a D-shaped metal shell, but are larger than D-subminiature connectors. They are sometimes called "Centronics connectors" after the 36-pin micro ribbonconnector Centronics used for their printers.

One unusual feature of IEEE 488 connectors is they commonly use a "double-headed" design, with male on one side, and female on the other. This allows stacking connectors for easy daisy-chaining. Mechanical considerations limit the number of stacked connectors to four or fewer, although a workaround involving physically supporting the connectors may be able to get around this.

They are held in place by screws, either UTS (now largely obsolete) or metric M3.5×0.6 threads. Early versions of the standard suggested that metric screws should be blackened to avoid confusion with the incompatible UTS threads. However, by the 1987 revision this was no longer considered necessary because of the prevalence of metric threads.[19]

The IEC 60625 standard prescribes the use of 25-pin D-subminiature connectors (the same as used for the parallel port on IBM-PCs). This connector did not gain significant market acceptance against the established 24-pin connector.

Multiple Choice Questions

1. The full form of LCD is
a) LIquid Crystal Display
b) Liquid Crystalline Display
c) Logical Crystal Display
d) Logical Crystalline Display

2. The optical properties of liquid crystals depend on the direction of
a) Air
b) Solid
c) Light
d) Water

3. By which properties, the orientation of molecules in a layer of liquid crystals can be changed?
a) Magnetic field
b) Electric field
c) Electromagnetic field
d) None of the Mentioned

4. Electro-optical effect is produced in
a) LED
b) LCD
c) OFC
d) None of the Mentioned

5. The direction of electric field in a LCD is determined by
a) the molecule’s chemical structure
b) Crystalline surface structure
c) Molecular Orbital Theory
d) None of the Mentioned

6. The first LCDs became commercially available in
a) 1950s
b) 1980s
c) 1960s
d) None of the Mentioned

7. LCDs operate from a voltage ranges from
a) 3 to 15V

b) 10 to 15V
c) 10V
d) 5V

8. LCDs operate from a frequency ranges from
a) 10Hz to 60Hz
b) 50Hz to 70Hz
c) 30Hz to 60Hz
d) None of the Mentioned

9. In 7 segment display, how many LEDs are used?
a) 8
b) 7
c) 10
d) 9

10. What is backplane in LCD?
a) The ac voltage applied between segment and a common element
b) The dc voltage applied between segment and a common element
c) The amount of power consumed
d) None of the Mentioned

Review Questions

1. What are the difference between LED and LCD?
2. Write short note on:
    - Display Devices
    - Application of LED in display system
    - Fourteen Segment Display,
    - Dot Matrix Display
    - Application LCD in display system,
    - IEEE488
3. What is telemetry? Explain with a block diagram.
4. Explain fourteen segment displays.

Module 7

Data Acquisition and Advanced Instruments

7.1 Components of modern digital data acquisition system

7.1.1 Introduction

Data acquisition systems (DAS) interface between the real world of physical parameters, which are analog, and the artificial world of digital computation and control. With current emphasis on digital systems, the interfacing function has become an important one; digital systems are used widely because complex circuits are low cost, accurate, and relatively simple to implement. In addition, there is rapid growth in the use of microcomputers to perform difficult digital control and measurement functions. Computerized feedback control systems are used in many different industries today in order to achieve greater productivity in our modern industrial societies. Industries that presently employ such automatic systems include steel making, food processing, paper production, oil refining, chemical manufacturing, textile production, cement manufacturing, and others. The devices that perform the interfacing function between analog and digital worlds are analog-to-digital (A/D) and digital-to-analog (D/A) converters, which together are known as data converters. Some of the specific applications in which data converters are used include data telemetry systems, pulse code modulated communications, automatic test systems, computer display systems, video signal processing systems, data logging systems, and sampled data control systems. In addition, every laboratory digital multimeter or digital panel meter contains an A/D converter.

7.2 BASIC DATA ACQUISITION SYSTEM

Besides A/D and D/A converters, data acquisition and distribution systems may employ one or more of the following circuit functions:

• transducers,

• amplifiers,

• filters,

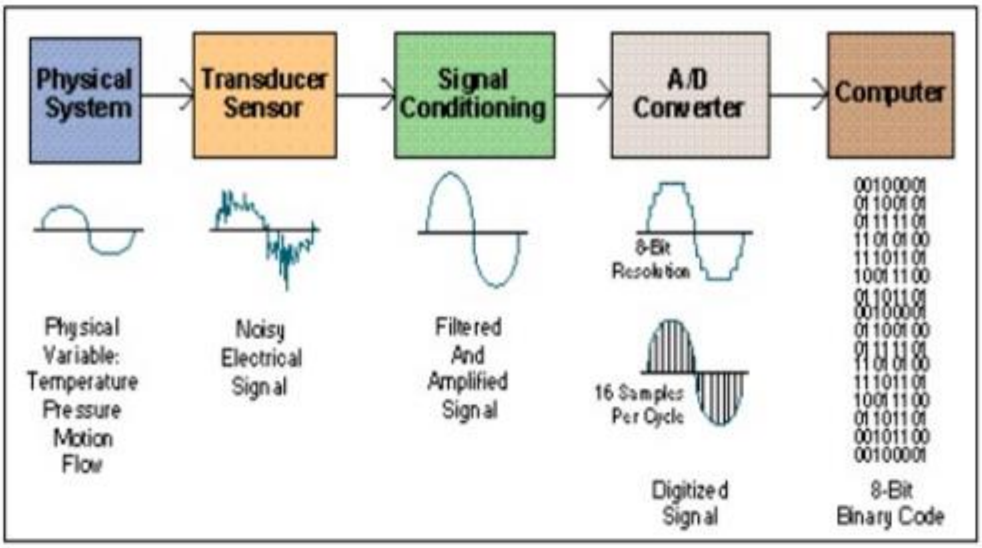
• nonlinear analog functions,

• analog multiplexers,

• sample-holds.

The interconnection of these components is shown in the diagram of the data acquisition portion of a computerized feedback control system in Figure 1.

DAS
BLOCK DIAGRAM



1. **Transducer:-**
A transducer is used to convert the physical parameters corning from the field into electrical 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) signals which cannot be used for further processing. In order to make the signals strong enough to drive the other elements signal conditioners are used such as amplifiers, modifiers, filters etc.

3. **Multiplexer:-**
The function of the multiplexer is to accept multiple analog inputs (after signal conditioning) 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 analog data 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 various purposes like for control operation and display etc.

The transmission of data in digital form is possible over short distances as well as long distances of and has advantages over transmission in analog form. The data can be stored permanently or temporarily and can be displayed on a CRT or digital panel.

5. **Recorders and Display Devices:-**
In display devices the data is displayed in a suitable form in order to monitor 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 and analog data can be recorded either graphically or on a magnetic tape. Optical recorders, ultraviolet recorders, styles-and-ink recorders are some of its examples.
The digital data can be recorded through digital recorders. The digital data is first converted into a suitable form for recording by means of a coupling unit and then recorded on a magnetic tape, punched cards or a perforated paper tape.

3 BASIC DATA DISTRIBUTION SYSTEM

The data distribution portion of a feedback control system, illustrated in Figure 2, is the reverse of the data acquisition system. The computer, based on the inputs of the data acquisition system, must close the loop on a process and control it by means of output control functions. These control outputs are in digital form and must, therefore, be converted into analog form in order to drive the process. The conversion is accomplished by a series of D/A converters as shown (also often called DAC's). Each D/A converter is coupled to the computer data bus by means of a register, which stores the digital word until the next update. The registers are activated sequentially by a decoder and control circuit, which is under computer control. The D/A converter outputs then drive actuators that directly control the various process parameters such as temperature, pressure, and flow. Thus, the loop is closed on the process and the result is a complete automatic process control system under computer control.

7.2 Basic concept of PLC & Virtual Instrument

The Basics of Programmable Logic Controllers

What do amusement park rides, factory assembly lines, and light fixtures have in common? They are all controlled by a Programmable Logic Controller (PLC), a digital computer used to control machinery by constantly monitoring input and output devices.
PLCs are designed for multiple input and output arrangements, and can withstand various temperature ranges, electrical noises, vibrations, and impacts. Integrating a PLC into any production line or mechanical process is highly beneficial. PLCs enable operation processes to be changed or replicated, while simultaneously collecting and communicating important information.

How do PLCs work?

There are four basic operational steps for every PLC:

1. Input Scan: Identifies the status of all input devices that are connected to the PLC.
2. Program Scan: Implements the user-created program logic.
3. Output Scan: Either energizes or de-energizes all connected output devices.
4. Housekeeping: This includes communications with programming terminals and internal diagnostics.

What are input/output devices?

Input Device: An input device is a piece of computer hardware equipment used to provide data, and control signals to an information processing system (IPS).
Some examples of input devices include:

- Switches and push buttons
- Sensing devices
- Limit switches
- Proximity sensors
- Photoelectric Sensors
- Condition sensors
- Vacuum switches
- Temperature switches
- Level switches
- Pressure switches

Output Devices: An output device is any piece of hardware used to communicate the results of data processing carried out by an IPS, and translate the information into an understandable form.

- Valves
- Motor starters
- Horns and alarms
- Stack lights
- Control relays
- Pumps
- Printers
- Fans

What are the fundamentals of a PLC system?

CPU or processor: The Central Processing Unit, or main processor, is a microprocessor-based system. It executes the control program after reading field input status, then sends out commands to field outputs.
I/O section: I/O modules act as the Real Data Interface between field and CPU. A PLC knows the real status of field devices and controls them with relevant I/O cards.
Programming device: CPU cards can be connected with programming devices through a communication link via a programming port on the CPU.
Operating station: An operating station is used to provide an “operating window” to the PLC process. It is generally a separate device, like a PC, that is loaded with Human Machine Interface Software.

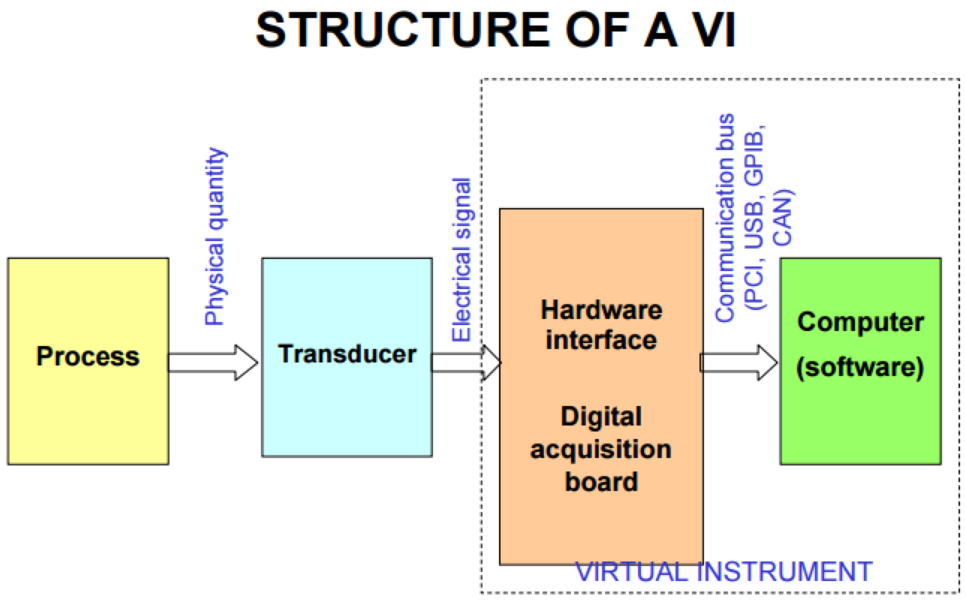
Why should I use a PLC?

- PLCs eliminate the need for rewiring and adding additional hardware for each new logical configuration.

- These devices increase the functionality of controls and do not take up much physical space.
- Since PLCs are sectional, they can be mixed and matched, so you can choose the best combination of input and output devices for your specific operation.
- PLCs can perform relay-switching tasks, as well as count, calculate, and compare analog process values.
- A PLC’s flexibility makes it easy to modify control logic at any time.
- PLCs are cost-effective for controlling complex systems.
- PLCs provide easy trouble-shooting capabilities.
- PLCs can work seamlessly with Human-Machine Interface computers.

7.3 Virtual instrumentation

is the use of customizable software and modular measurement hardware to create user-defined measurement systems, called **virtual** instruments. The primary difference between hardware **instrumentation** and **virtual instrumentation** is that software is used to replace a large amount of hardware.



ADVANTAGES OF A VI

• Possibility of measuring on a large number of points and places
• Complex processing of data and of measurement information
• Local or remote data storing
Remote transmission of data through wired or wireless communication
• Statistics and forecasts accomplishment
• Flexibility: possibility of extension or adding of new functions to the instrument by simple modifications of software
Improving measurement accuracy by statistical processing and compensation of influence factors

• Possibility of adding of new functions for process testing, monitoring and control Fibre Optic Measurement –Splicing, OTDR, end to end loss measurement.

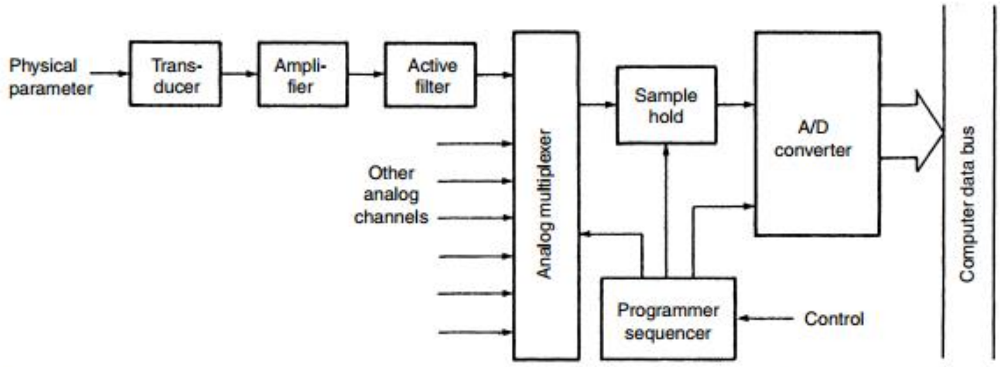


Figure 1. Data acquisition system. (*Source*: reproduced by permission of Sydenham, P.H. (1983) *Handbook of Measurement Science*, Volume 1, Theoretical Fundamentals. John Wiley & Sons Ltd., Chichester.)

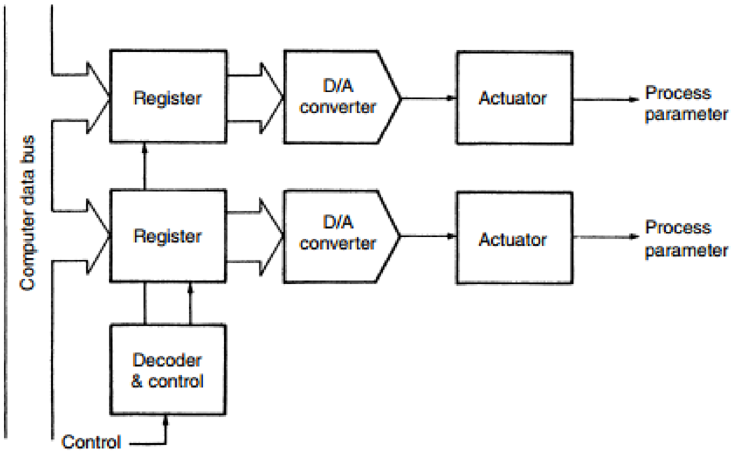


Figure 2. Data distribution system. (*Source*: reproduced by permission of Sydenham, P.H. (1983) *Handbook of Measurement Science*, Volume 1, Theoretical Fundamentals. John Wiley & Sons Ltd., Chichester.)

Multiple choice questions:

1. What led to development of PC based transducers?

a) low cost

b) medium cost

c) high cost

d) zero cost

View Answer

2. ADD ON card is used for _______

a) to reduce noise

b) communication

c) to boost the magnitude

d) to measure voltage

View Answer

3. PC based data acquisition system displays system parameters
a) once in a while
b) intermittently
c) continuously
d) only at specific intervals
View Answer

4. What are MIMIC displays?
a) man-material interface
b) man-made interface
c) man-machine interface
d) man-machine interface
View Answer

5. System parameters are distinguished by physical attributes.
a) True
b) False
View Answer

6. Personal computer does not contain additional hardware in a PC based data acquisition system.
a) True
b) False
View Answer

7. Data analysis hardware is used for ________
a) making the process independent
b) slowing the process
c) fastening the process
d) making the process constant
View Answer

8. Input signal range in a PC based data acquisition system is ________
a) 0.10 mV to 1 V
b) 1 mV to 100 V
c) 5 mV to 5 V
d) 10 mV to 10 V
View Answer

9. Amplified input signal is digitised through _________
a) A/D converters
b) D/A converters

c) Rectifiers

d) Sigma delta modulators

View Answer

Long answer type questions

1. Write any two instruments used in computer controlled instrumentation.

2. What are the various instrument used in computer controlled instrumentation?

3. Explain the generalized block schematic of a Digital Data Acquisition system and list out it's advantages over analog data acquisition system.

4. Explain the optical time domain reflectometer