UNIT- V
TRANSDUCERS

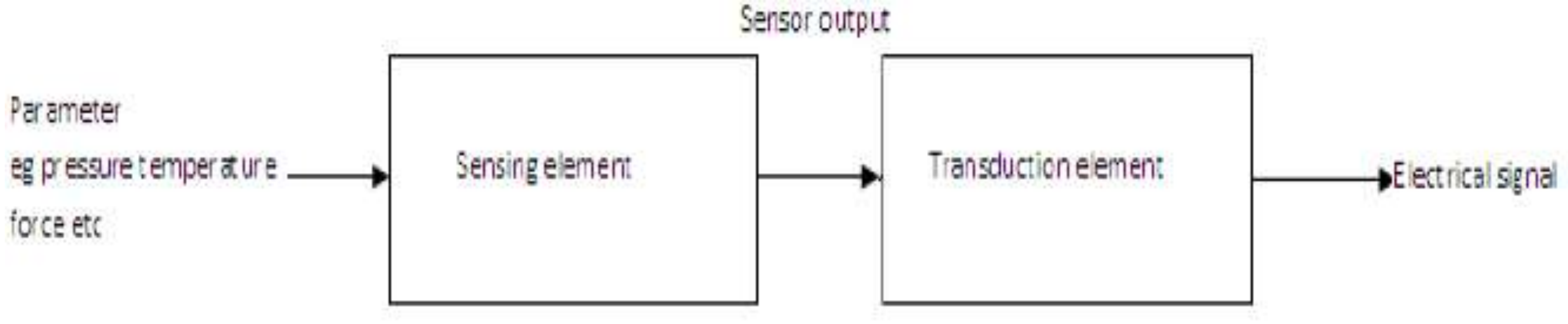
Introduction

- Basically transducer is defined as a device, which converts energy or information from one form to another. These are widely used in measurement work.

- A better measurement of a quantity can usually be made if it may be converted to another form, which is more conveniently or accurately displayed.

BLOCK DIAGRAM OF TRANSDUCERS

- Transducer contains two parts that are closely related to each other i.e. the sensing element and transduction element.
- The sensing element is called as the sensor. It is device producing measurable response to change in physical conditions.
- The transduction element convert the sensor output to suitable electrical form.



- A Transducer is a device which converts one form of energy into another form.

- Alternatively, a Transducer is defined as a device which provides usable output response to a specific input measured which may be a physical quantity.

- A Transducer can also be defined as a device when actuated by energy in one system supplies energy in the same form or in another form to a second system.

In general the **electrical transducers** are classified according to their structures, application areas, method of energy conversion, output signal nature.

The transducers can be classified as:

I. Active and passive transducers.

II. Analog and digital transducers.

III. On the basis of transduction principle used.

IV. Primary and secondary transducer

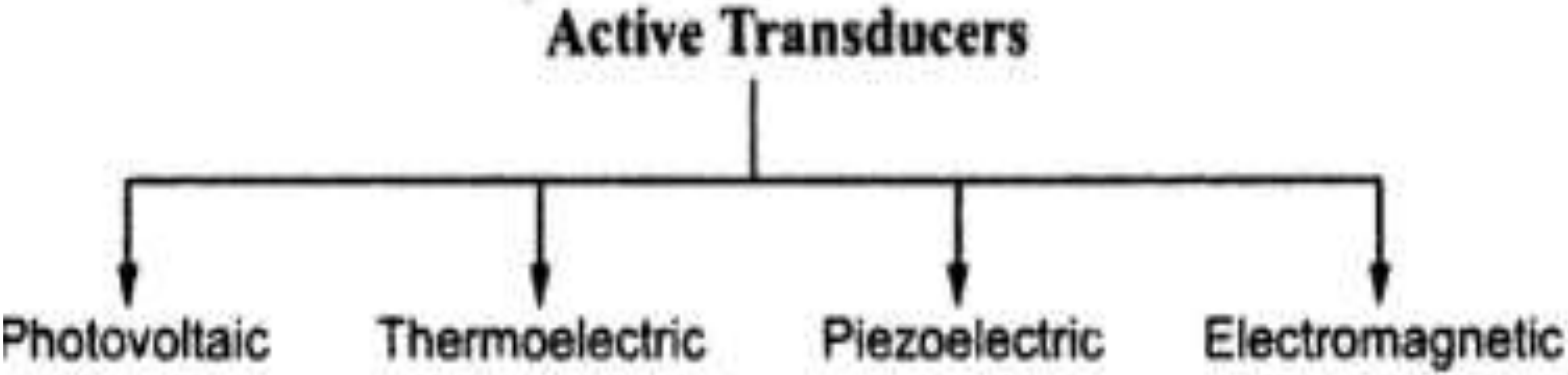
V. Transducers and inverse transducers.

Active and Passive Transducers

- **Active transducers :**
- These transducers do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

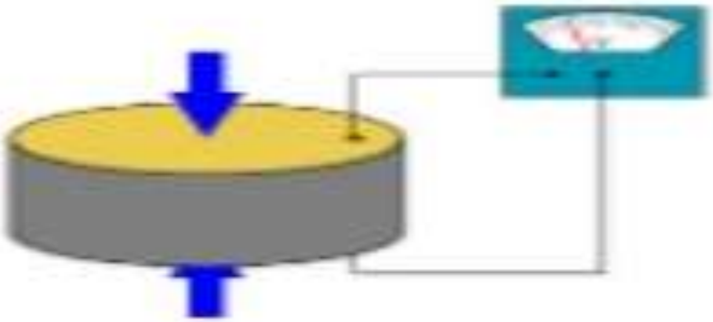
I. The active transducer are self generating devices which operate under the energy conversion principle.

II. As the output of active transducers we get an equivalent electrical output signal e.g. temperature or strain to electric potential, without any external source of energy being used


Active Transducers
Photovoltaic
Thermoelectric
Piezoelectric
Electromagnetic

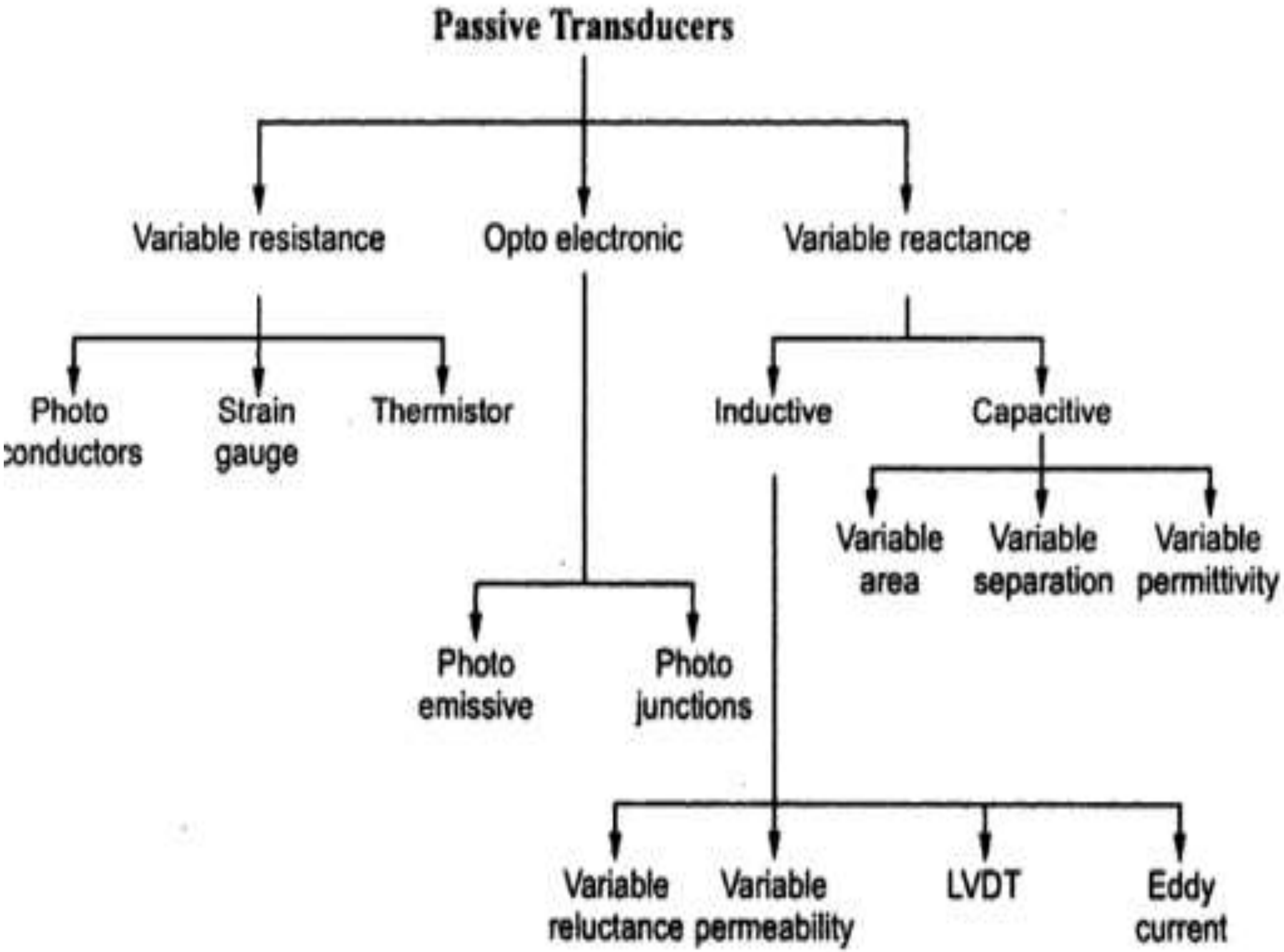
Example of active transducers

- **Piezoelectric Transducer-** When an external force is applied on to a quartz crystal, there will be a change in the voltage generated across the surface. This change is measured by its corresponding value of sound or vibration.

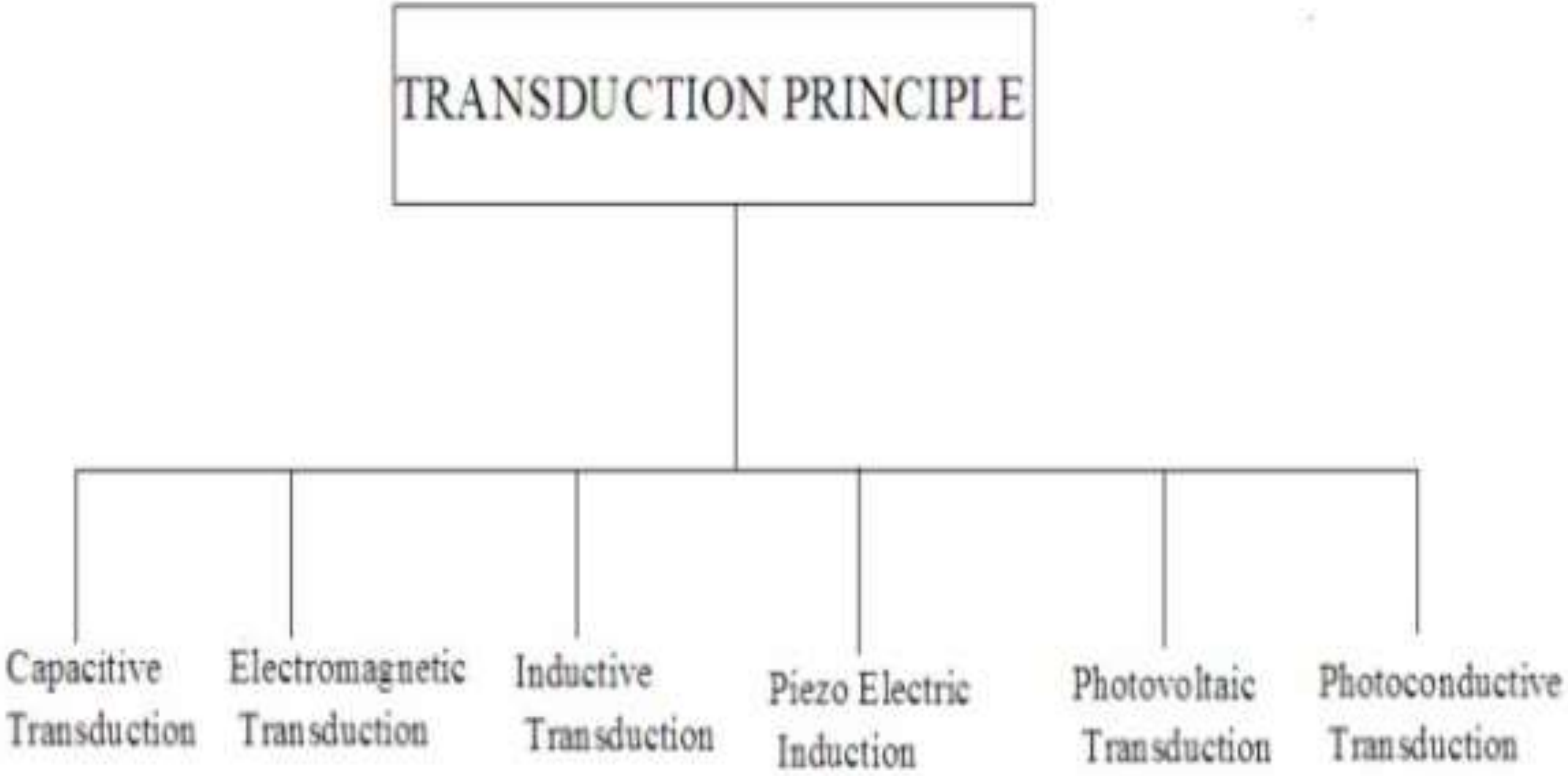


Passive Transducers

- These transducers need external source of power for their operation. So they are not self generating type transducers.
- A DC power supply or an audio frequency generator is used as an external power source.
- These transducers produce the output signal in the form of variation in electrical parameter like resistance, capacitance or inductance.
- Examples – Thermistor, Potentiometer type transducer


Passive Transducers
Variable resistance
Opto electronic
Variable reactance
Photo conductors
Strain gauge
Thermistor
Inductive
Capacitive
Variable area
Variable separation
Variable permittivity
Photo emissive
Photo junctions
Variable reluctance
Variable permeability
LVDT
Eddy current

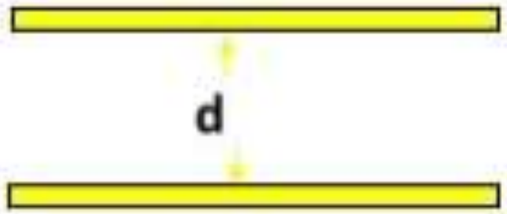
According to Transduction principle used



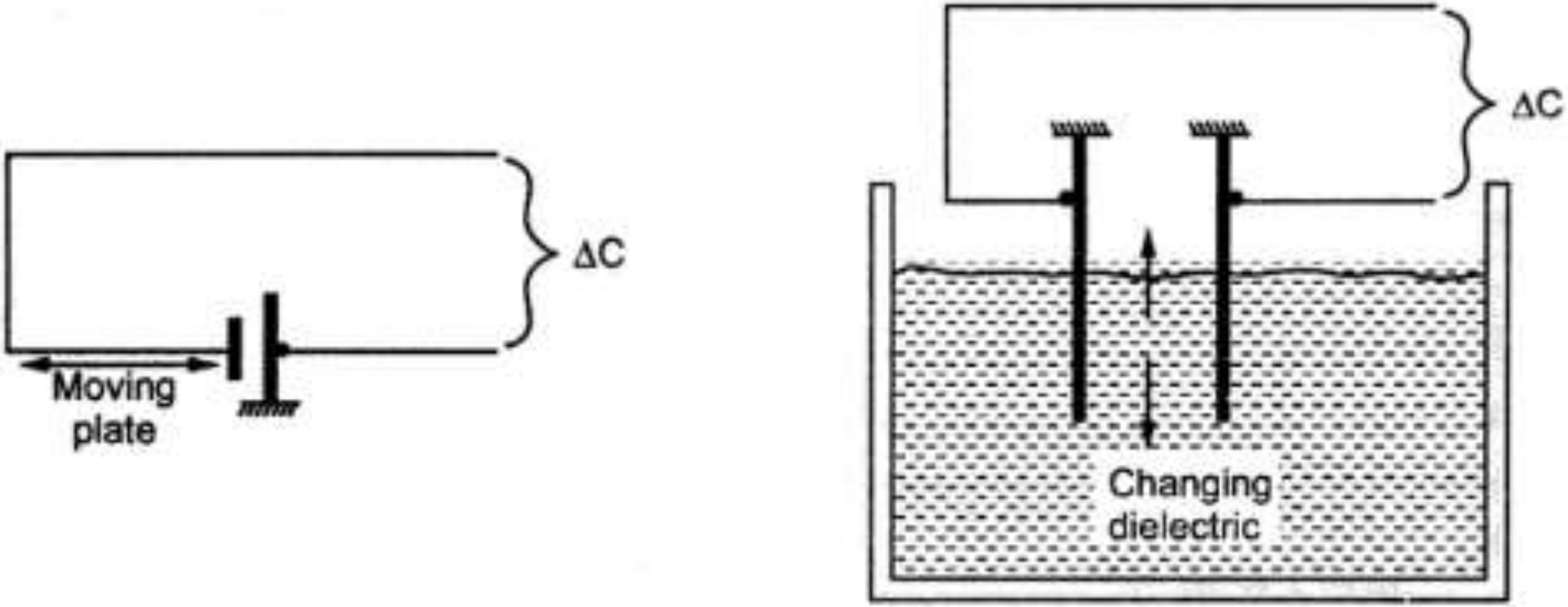
Capacitive Transduction:

- Here, the measurand is converted into a change in capacitance.

- A change in capacitance occurs either by changing the distance between the two plates or by changing the dielectric.



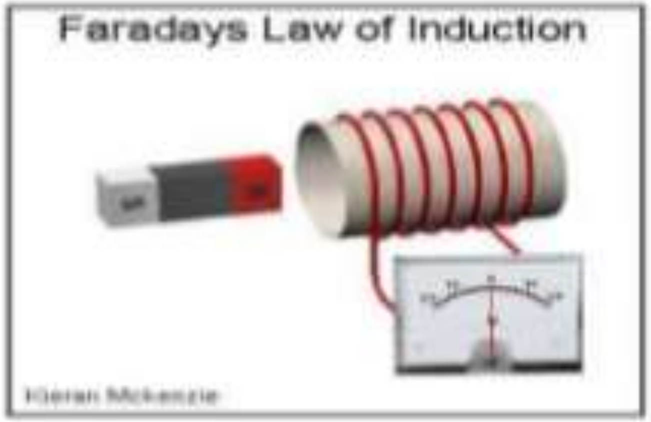
Area=A

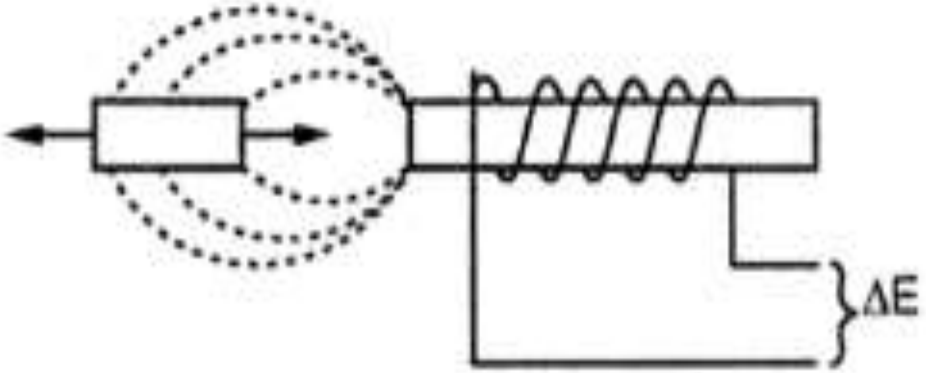


(a) **Fig. 9.5 Capacitive transduction** (b)

Electromagnetic transduction:

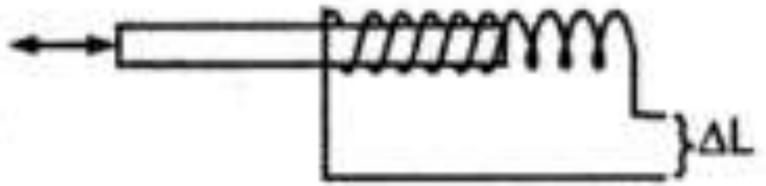
- In electromagnetic transduction, the measurand is converted to voltage induced in conductor by change in the magnetic flux, in absence of excitation.
- The electromagnetic transducer are self generating active transducers
- The motion between a piece of magnet and an electromagnet is responsible for the change in flux





Inductance Transduction:

- In inductive transduction, the measurand is converted into a change in the self inductance of a single coil. It is achieved by displacing the core of the coil that is attached to a mechanical sensing element



Inductive transduction

Piezoelectric Transduction:

- In piezoelectric induction the measurand is converted into a change in electrostatic charge q or voltage V generated by crystals when it is mechanically stressed.

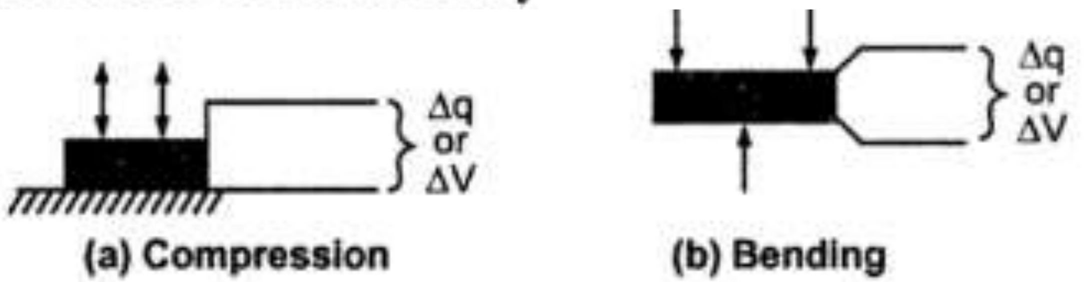


Fig. 9.8 Piezoelectric transduction

Photovoltaic Transduction:

- In photovoltaic transduction the measurand is converted to voltage generated when the junction between dissimilar material is illuminated.

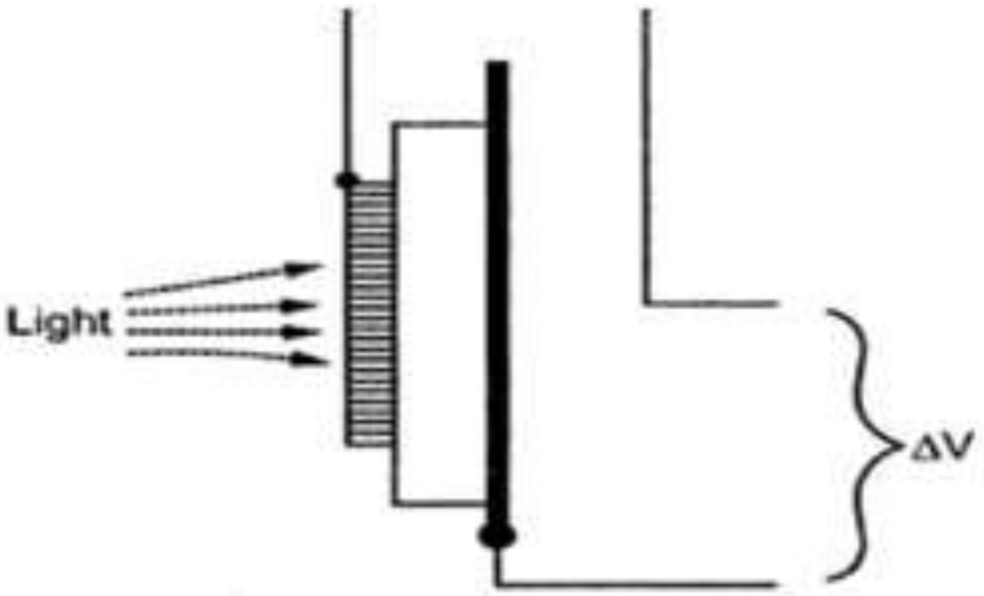


Fig. 9.9 Photovoltaic transduction

Photoconductive Transduction:

- In photoconductive transduction the measurand is converted to change in resistance of semiconductor material by the change in light incident on the material.

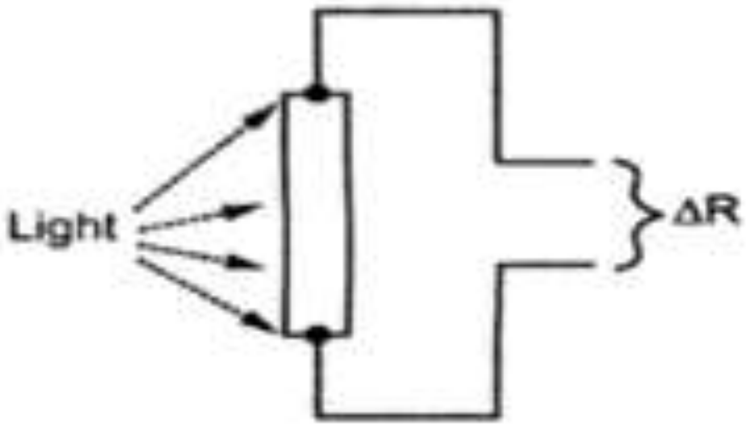


Fig. 9.10 Photoconductive transduction

Analog and Digital Transducers

Analog transducers:

- These transducers convert the input quantity into an analog output which is a continuous function of time.
- Thus a **strain gauge, an L.V.D.T., a thermocouple or a thermistor** may be called as Analog Transducers as they give an output which is a continuous function of time.

Digital Transducers:

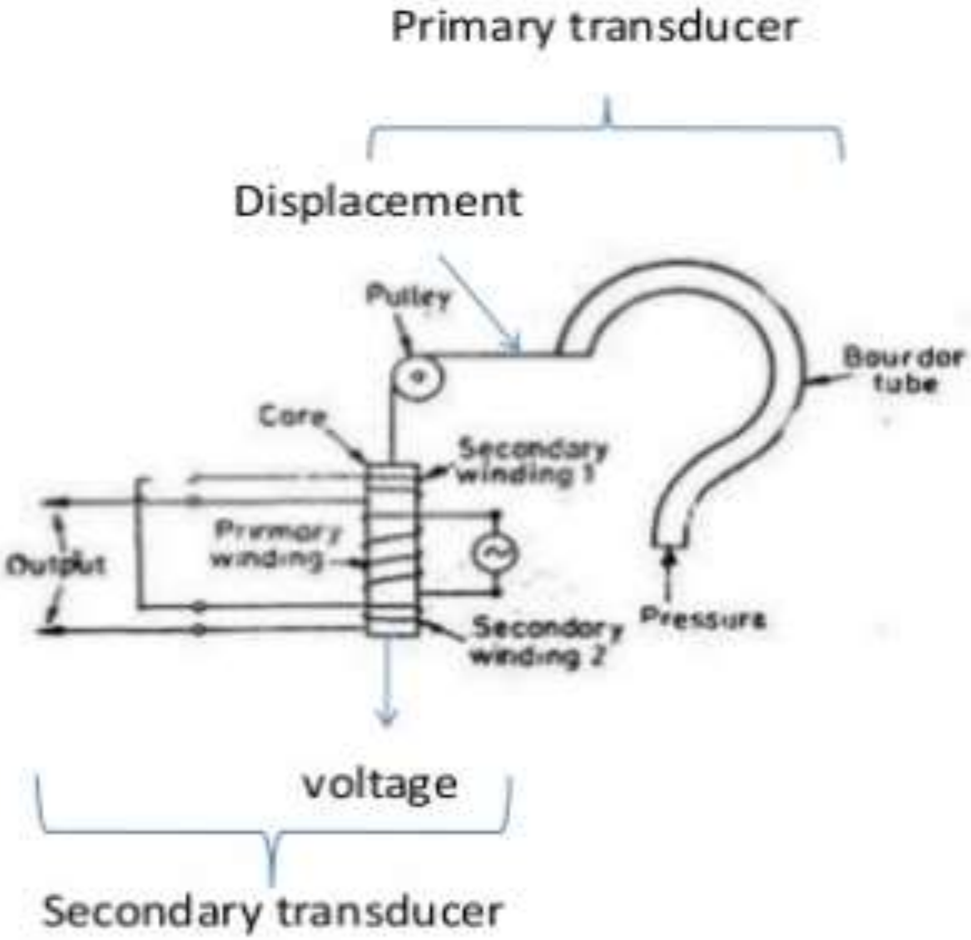
- These transducers convert the input quantity into an electrical output which is in the form of pulses and its output is represented by 0 and 1.

Primary and Secondary Transducers

- Some transducers contain the mechanical as well as electrical device. The mechanical device converts the physical quantity to be measured into a mechanical signal. Such mechanical device are called as the primary transducers, because they deal with the physical quantity to be measured.

- The electrical device then convert this mechanical signal into a corresponding electrical signal. Such electrical device are known as secondary transducers.

Example of Primary and secondary transducer



Transducer and Inverse Transducer

Transducer:

- Transducers convert non electrical quantity to electrical quantity.

Inverse Transducer:

- Inverse transducers convert electrical quantity to a non electrical quantity. A piezoelectric crystal acts as an inverse transducer because when a voltage is applied across its surfaces, it changes its dimensions causing a mechanical displacement.

Factors influencing the choice off transducers

1. Operating Principle: The transducers are many times selected on the basis of operating principle used by them. The operating principle used may be resistive, inductive, capacitive, opto electronic, piezoelectric etc.

2. Sensitivity: The transducer should give a sufficient output signal per unit of measured input in order to yield meaningful data. The transducer must be sensitive enough to produce detectable output.

3. Operating Range: The transducer should maintain the range requirements and have a good resolution over its entire range. The rating of the transducer should be sufficient so that it does not breakdown while working in its specified operating range.

4. Accuracy: High degree of accuracy assured if the transducer does not require frequent calibration and has a small value for repeatability. It may be emphasized that in most industrial applications, repeatability is of considerably more importance than absolute accuracy.

5. Cross sensitivity: It should be considered when measuring mechanical quantities. There are situations where the actual quantity is being measured is in one plane and the transducer is subjected to variations in another plane.

6. Errors: The errors inherent in the operation of the transducer itself, or those errors caused by environmental conditions of the measurement, should be small enough or controllable enough that they allow meaningful data to be taken. Transducer should maintain the input-output relationship to avoid errors.

7. **Transient and Frequency Response:** The transducer should meet the desired time domian specifications like peak overshoot, rise time, settling time and small dynamic error. It should ideally have a flat frequency response. It should have high cut off frequency to have wide bandwidth.

8. **Loading effects:** The transducer should have high input impedance and low output impedance to avoid loading effects.

9. **Environmental Compatiability**: Transducer selected to work under specified environmental conditions should maintain its input-output relationship and does not breakdown. For eg. Transducer should remain operable under its temperature range, It should work in corrosive environments, should be able to withstand pressures, shocks and other interactions to which it is subjected to.

10. In-sentivity to unwanted signals: Transducer should be minimally sensitive to unwanted signals and highly sensitive to desired signal.
11. Usage and Ruggedness: Ruggedness both mechanical and electrical intensities transducer versus its size and weight must be considered while selecting a suitable transducer.
12. Electrical aspects: Length and type of cable required need to be considered while selecting a transducer. Attention must be paid to signal to noise ratio in case transducer is used in conjunction with amplifiers.
13. Stability and reliability: It should have high degree of stability during its operation and storage life. Reliability should be assured in case of failure of transducer in order that the functioning of the instrumentation system continue uninterrupted.

14. Static Characteristics: Apart from low static error, the transducers should have a low non-linearity, low hysteresis, high resolution and a high degree of repeatability.

The transducer selected should be free from load alignment effects and temperature effects. It should not need frequent calibration should not have any component limitations and should be preferably small in size.

Resistive transducer

Resistive transducers are those transducers in which the resistance change due to the change in some physical phenomenon.

The resistance of a metal conductor(electrical conductor) is expressed by a simple equation.

$$R = \rho L/A$$

Where R = resistance of conductor in Ω

L = length of conductor in m

A = cross sectional area of conductor in m2

ρ= resistivity of conductor material in Ω-m.

The electrical resistance can be varied by varying,

(i) Length (ii) Cross-sectional area and (iii) Resistivity or combination of these.

Principle:-

- A change in resistance of a circuit due to the displacement of an object is the measure of displacement of that object.

Applications of Resistive Transducer

- **Potentiometer** – The translation and rotatory potentiometer are the examples of the resistive transducers. The resistance of their conductor varies with the variation in their **lengths** which is used for the measurement of displacement.

- **Strain gauges –**When a metal conductor is subjected to mechanical strain, change in **dimensions** of the conductor occurs, that changes the resistance of the conductor. This property of metals is used for the measurement of the pressure, force, displacement etc.

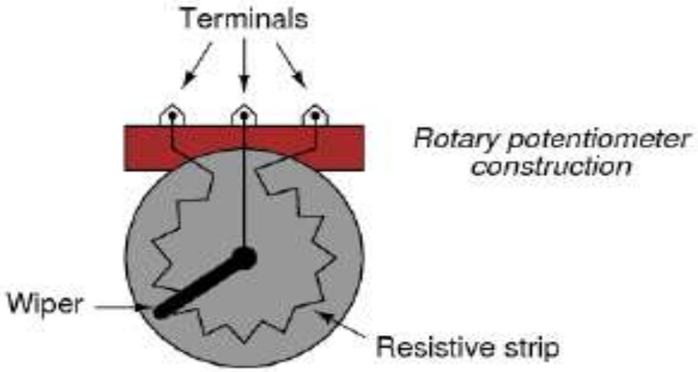
- **Resistance Thermometer** – When a metal conductor is subjected to a change in temperature and change in **resistivity** occurs which changes resistance of the conductor. This property of conductor is used for measuring the temperature

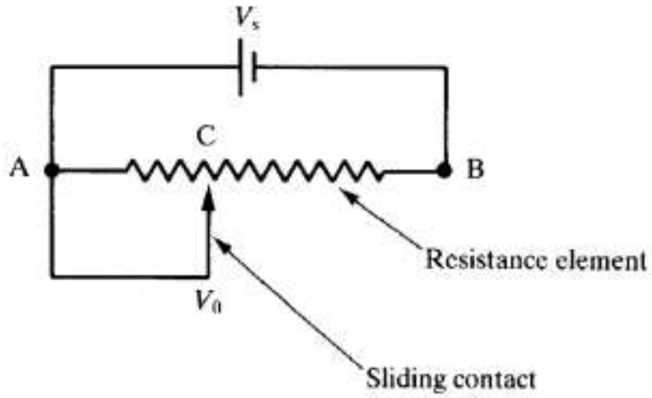
- **Thermistor** – It works on the principle that the temperature coefficient of the thermistor material varies with the temperature. The thermistor has the negative temperature coefficient. The Negative temperature coefficient means the temperature is inversely proportional to resistance.

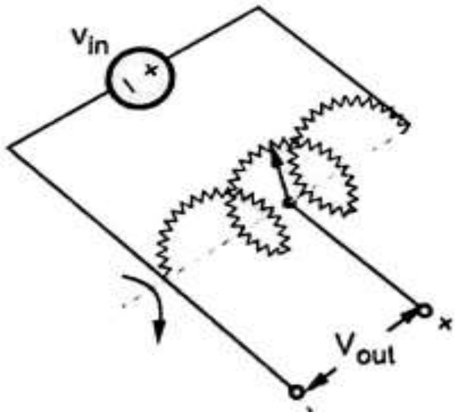
There are a number of ways because of which the resistance of the metal changes with the changed in the physical phenomenon. And this property of conductors is used for measuring the physical quantities of material.

Potentiometric resistance transducers

- It is used to measure linear and angular displacement. It consists of a resistive element and a sliding contact called wiper.
- The contact motion may be linear or rotational or combination of the two. The combinational potentiometer have their resistive element in helix form and are called helipots.







(c) Helipot

- Using resistance potentiometer, mechanical displacement is converted into an electrical output.
- Linear or angular displacement is applied to the sliding contact and then the corresponding change in resistance is converter into voltage or current.
- The resistance potentiometer may be excited by either AC voltage or DC voltage.

Advantages:

➢Simple in construction and operation.

➢Inexpensive

➢Useful for displacement measurements of large amplitudes

Disadvantages:

➢In linear POT , large force is required to move the wiper.

➢Suffer from mechanical wear and misalignment of wiper. High electronic noise in output.

Strain gauge

- The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.
- This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.
- Strain gauges are displacement-type transducers that measure changes in the length of an object as a result of an applied force. These transducers produce a resistance change that is proportional to the fractional change in the length of the object, also called strain, S, which is defined as

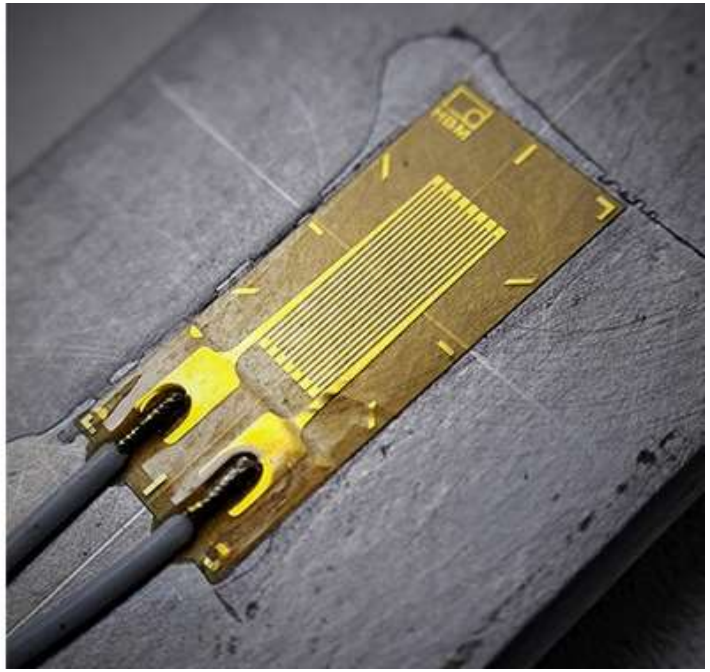
$$S=\Delta l/l$$

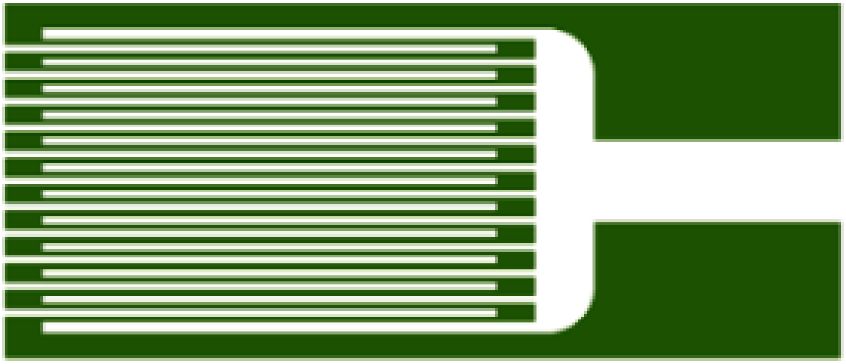
where Δl is the fractional change in length

l is the initial length of the object.

Contd….

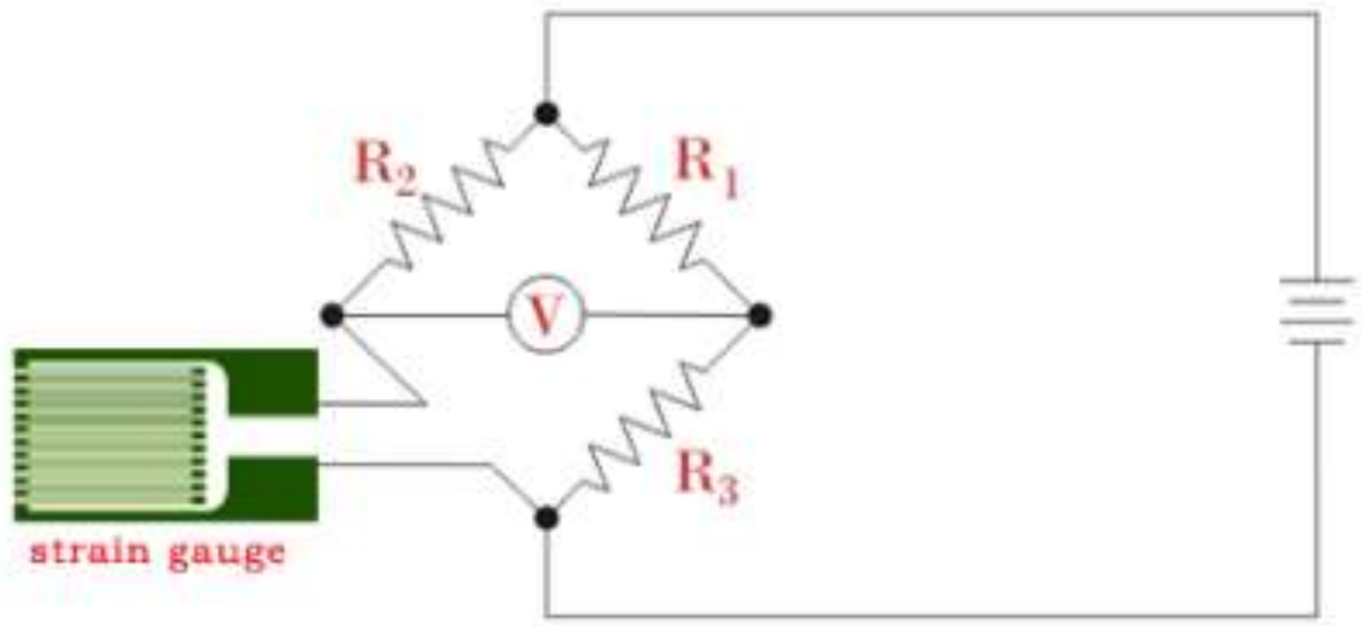
- Any basic strain gauge consists of an insulating flexible backing that supports a metallic foil pattern. The gauge is attached to the object under stress using an adhesive. The deformation in the object causes the foil to get distorted which ultimately changes the electrical resistivity of the foil. This change in resistivity is measured by a Wheatstone bridge which is related to strain by a quantity called, Gauge Factor.





Contd….

- In this circuit, R_1 and $R_3$are the ratio arms equal to each other, and R_2 is the rheostat arm has a value equal to the strain gage resistance. When the gauge is unstrained, the bridge is balanced, and voltmeter shows zero value. As there is a change in resistance of strain gauge, the bridge gets unbalanced and producing an indication at the voltmeter. The output voltage from the bridge can be amplified further by a differential amplifier.



Types of Strain Gauge

The type of strain gauge are as

- 1.Wire gauge
  - a)Unbonded
  - b)Bonded
  - c)Foil type
- 2.Semiconductor gauge

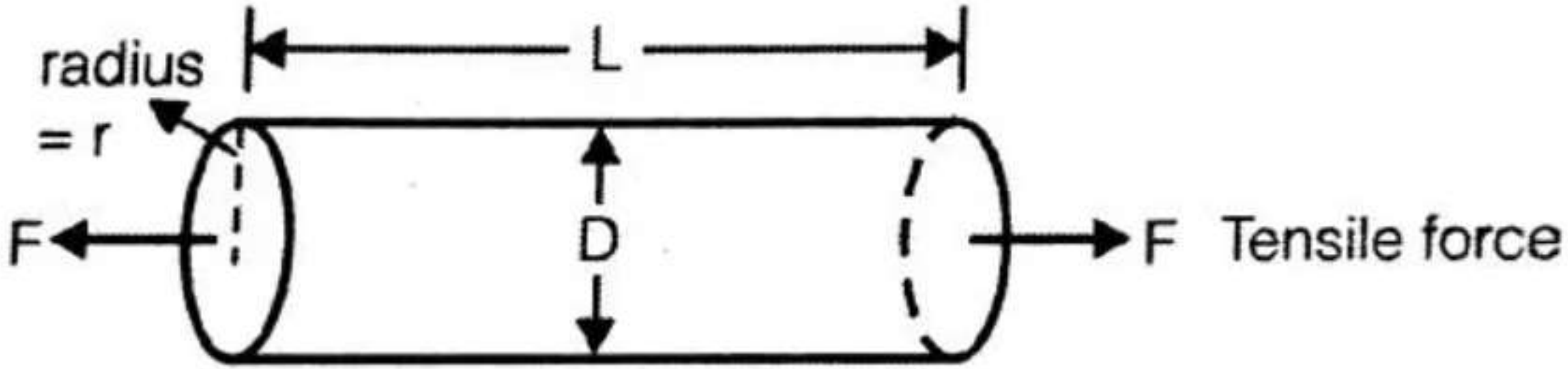
1.Wire strain gauge:-

In this type of strain gauge the strain is sensed with the help of wire.

Derivation of Gauge Factor (G_f) |Strain Gauge Factor Derivation

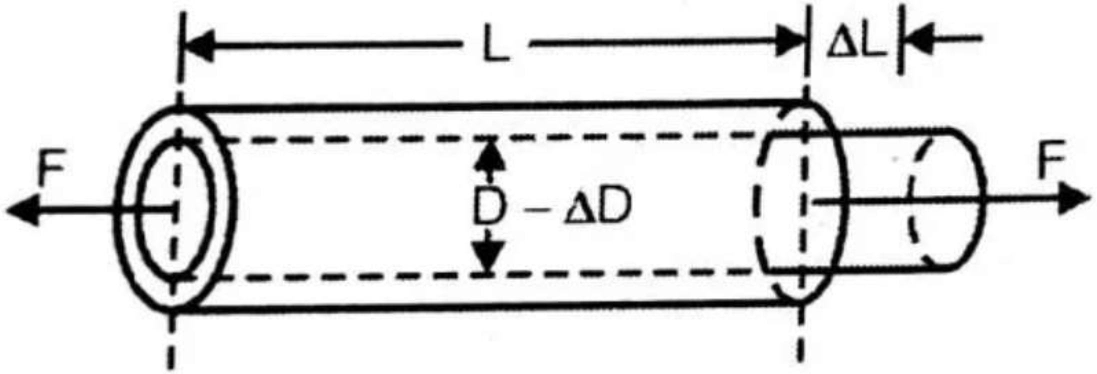
- Consider a strain gauge made of circular wire having length 'L', area 'A', and diameter 'D' before being strained. The material of the wire has a resistivity ρ.

$$\therefore \text{Resistance of unstrained gauge (R)} = \frac{\rho L}{A} \text{ .....Eq.(1)}$$



When a tensile force 'F' is applied the circular wire changes its dimensions as in the figure below.

Let a tensile stress s be applied to the wire. This produces a positive strain causing the length to increase and area to decrease as shown in Fig. 25.55. Thus when the wire is strained there are changes in its dimensions. Let ΔL = change in length, ΔA = change in area, ΔD = change in diameter and ΔR = change in resistance.



In order to find how ΔR depends upon the material physical quantities, the expression for R is differentiated with respect to stress s.

Thus we get :

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\rho A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s} \qquad \ldots(25.59)$$

Dividing Eqn. 25.59 throughout by resistance $R = \rho L/A$, we have

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad \ldots(25.60)$$

It is evident from Eqn. 25.60, that the per unit change in resistance is due to :

(i) per unit change in length $= \Delta L / L$,

(ii) per unit change in area $= \Delta A / A$, and

(iii) per unit change in resistivity $= \Delta \rho / \rho$

Area $\quad A = \frac{\pi}{4} D^2 \quad \therefore \quad \frac{\partial A}{\partial s} = 2 . \frac{\pi}{4} D . \frac{\partial D}{ds}$ ...(25.61)

or
$$\frac{1}{A}\frac{dA}{ds} = \frac{(2\pi/4)D}{(\pi/4)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \quad \text{...(25.62)}$$

$\therefore$ Equation 25.60 can be written as :

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{...(25.63)}$$

Now, Poisson's ratio

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = -\frac{\partial D / D}{\partial L / L}$$

...(25.64)

Now, Poisson's ratio

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = -\frac{\partial D / D}{\partial L / L}$$

...(25.64)

or $\partial D / D = -\nu \times \partial L / L$

$$\therefore \quad \frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \nu \frac{2}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad \text{...(25.65)}$$

For small variations, the above relationship can be written as :

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu \frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \qquad \text{...(25.66)}$$

The gauge factor is defined as the ratio of per unit change in resistance to per unit change in length.

Gauge factor $$G_f = \frac{\Delta R / R}{\Delta L / L} \qquad ...(25.67)$$

or

$$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L} = G_f \times \varepsilon \qquad ...(25.68)$$

where $\varepsilon = \text{strain} = \frac{\Delta L}{L}$

The gauge factor can be written as :

$$= 1 + 2\nu + \frac{\Delta \rho / \rho}{\varepsilon} \qquad ...(25.69)$$

$$= 1 \quad + \quad 2\nu \quad + \quad \frac{\Delta \rho / \rho}{\varepsilon}$$

Resistance change due to change of length	Resistance change due to change in area	Resistance change due to piezoresistive effect

$$G_f = \frac{\Delta R / R}{\Delta L / L} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\Delta L / L}$$

$$G_f = \frac{\Delta R / R}{\Delta L / L} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\Delta L / L}$$

The strain is usually expressed in terms of microstrain. 1 microstrain = $1\,\mu m / m$.

If the change in the value of resistivity of a material when strained is neglected, the gauge factor is :

$$G_f = 1 + 2\nu \qquad ...(25.70)$$

Equation 25.70 is valid only when **Piezoresistive Effect** *i.e.,* change in resistivity due to strain is almost negligible.

The Poisson's ratio for all metals is between 0 and 0.5. This gives a gauge factor of approximately, 2. The common value for Poisson's ratio for wires is 0.3. This gives a value of 1.6 for wire wound strain gauges.

Inductive transducer , Capacitive transducer

Inductive transducer

- An inductive electromechanical transducer is a transducer which converts the physical motion into the change in inductance.

- Inductive transducers are mainly used for displacement measurement.

- The inductive transducers are of the self generating or the passive type. The self generating inductive transducers use the basic generator principle i.e. the motion between a conductor and magnetic field induces a voltage in the conductor.

Inductive transducer

- The variable inductance transducers work on the following principles.

    - Variation in self inductance
    - Variation in mutual inductance

PRINCIPLE OF VARIATION OF SELF INDUCTANCE

- Let us consider an inductive transducer having N turns and reluctance R. when current I is passed through the transducer, the flux produced is

$$\Phi = Ni / R$$

Differentiating w.r.t. to t,

$$d\Phi/dt = N/R * di/dt$$

The e.m.f. induced in a coil is given by

$$e = N * d\Phi/dt$$

$$e = N * N/R * di/dt$$

$$e = N^2 / R * di/dt$$

Self inductance of an inductor is given by

$$L = e/di/dt = N^2 / R$$

Contd….

The reluctance of the magnetic circuit is $R = l/\mu A$

Therefore $L = N^2 / l/\mu A = N^2 \mu A / l$

N→ number of turns of coil

μ → Permeability of core

A→ Area of magnetic circuit through which flux is passing

l → Length of the magnetic circuit

- Variation of self inductance may be due to

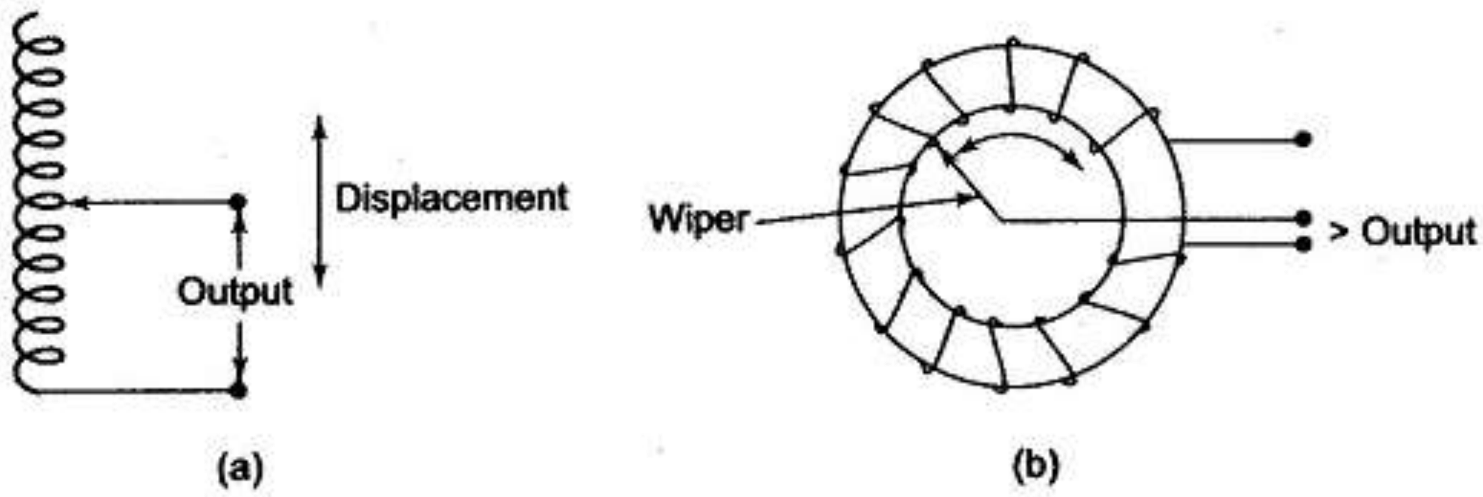
(i) change in number of turns

(ii) change in reluctance

(iii) Change in permeability

CHANGE IN SELF INDUCTANCE WITH CHANGE IN NUMBER OF TURNS N

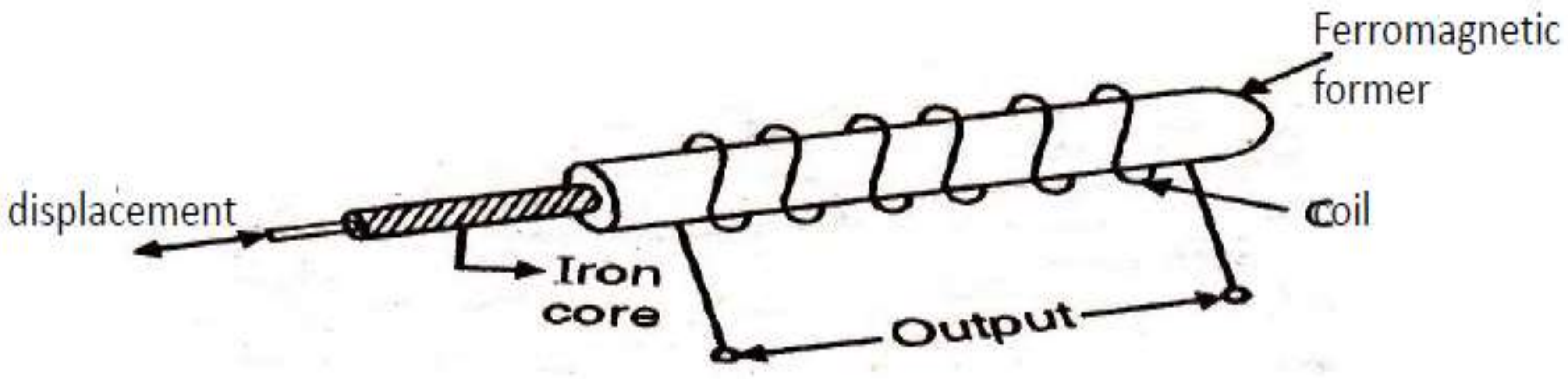
- From equation $L = N^2 \mu A / l$, L vary with the variation in the number of turns.
- As inductive transducers are mainly used for displacement measurement, with change in number of turns the self inductance of the coil changes in-turn changing the displacement
- Fig shows transducers used for linear and angular displacement



(a) Linear Inductive Transducer (Using Air Core) (b) Angular Inductive Transducer (Using Ferrite Core)

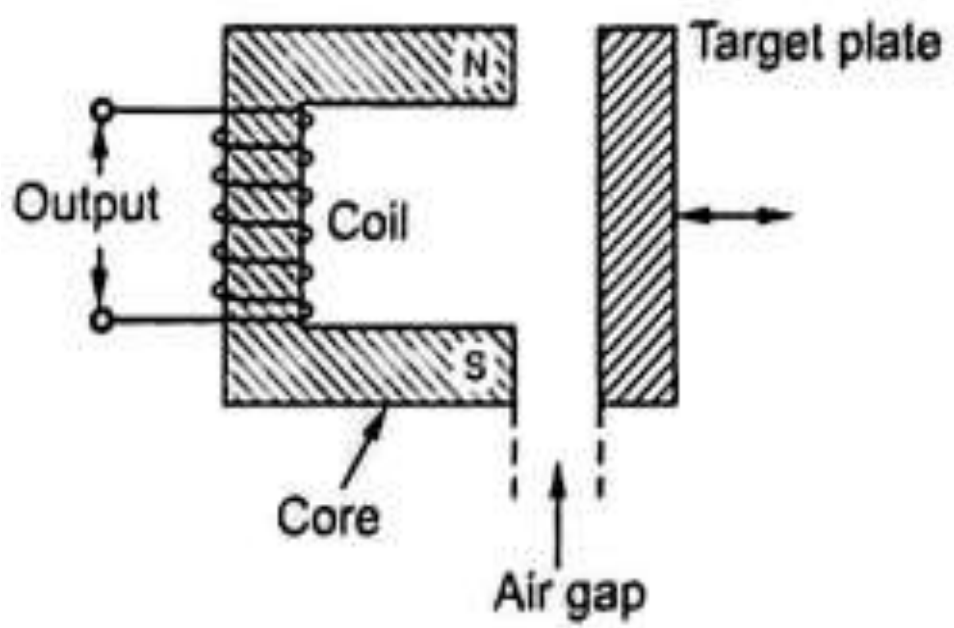
CHANGE IN SELF INDUCTANCE WITH CHANGE IN PERMEABILITY

- The value of self inductance of a coil also depends on the permeability.
- The iron core is surrounded by a winding. The displacement to be measured is applied to the rod which moves in and out of the ferrite core according to the direction of the displacement.
- When iron core moves in, permeability increases when iron core moves out permeability decreases. This cause the self inductance of the coil to increase or decrease depending on the permeability and accordingly the output voltage changes.



VARIABLE RELUCTANCE INDUCTIVE TRANSDUCER

- From equation $L = N^2 / R$, L is inversely proportional to reluctance.
- The coil is wound on the ferromagnetic iron core. The target and core are not in direct contact with each other. They are separated by an air gap. The size of the air gap determines the reluctance of the magnetic circuit, which in turns decides the self inductance.
- The displacement is applied to the target plate. According to the displacement the target plate moves which changes the air gap and hence the self inductance.



PRINCIPLE OF CHANGE IN MUTUAL INDUCTANCE

- The mutual inductance between two coils is given by

$$M = K\sqrt{L_1 L_2}$$

Where M : mutual inductance

K : coefficient of coupling

L1:self inductance of coil 1

L2 : self inductance of coil 2

- By varying the self inductance or the coefficient of coupling the mutual inductance can be varied

Linear Variable Differential Transducer (LVDT)

- Displacement is a vector quantity representing a change in position of a body or a point with respect to a reference. It can be linear or angular motion.

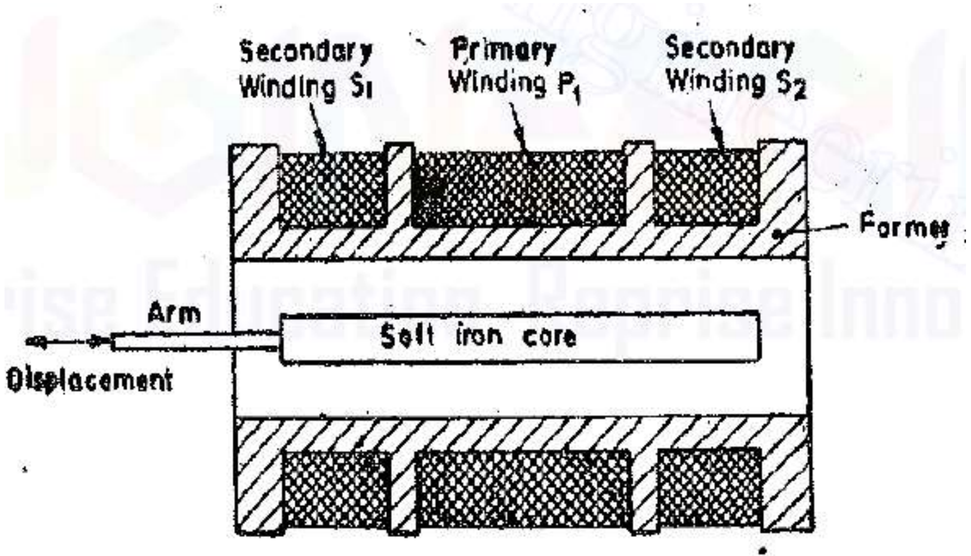
- By using displacement transducer many other quantities such as force, stress, pressure, velocity and acceleration also can be found.

- A simple and most popular type of displacement transducer is **variable inductance type transducer** wherein the inductance is varied according to displacement.

- It is achieved by varying the mutual inductance between the coil or by varying the self inductance.

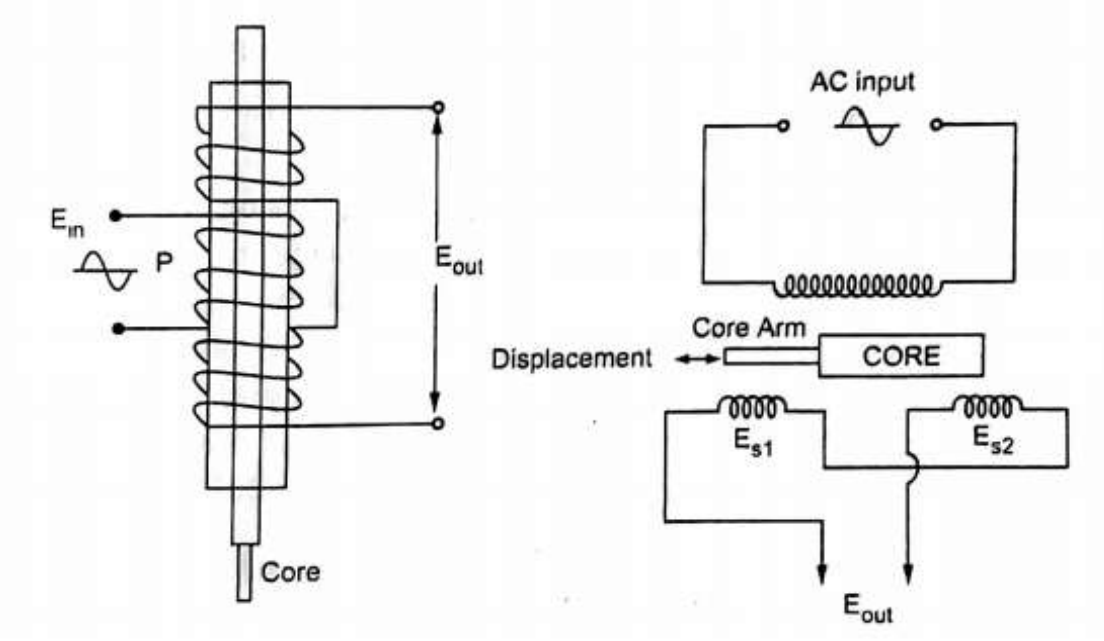
Construction of LVDT

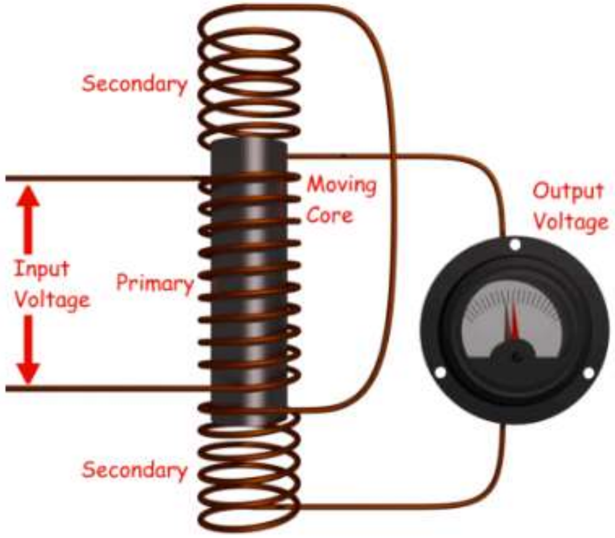
- The most widely used inductive transducer to translate the linear motion into electrical signal is the **Linear Variable Differential Transformer (LVDT)**
- The transformer consists of a single primary winding P and two secondary windings S1,S2 sound on a cylindrical former.
- The secondary windings have equal number of turns and are identically placed on either side of the primary winding.
- The primary winding is connected to the alternating current source. A movable soft iron core is placed inside the former.
- The displacement to be measured is applied to the arm attached to the soft iron core.



- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.

- The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.

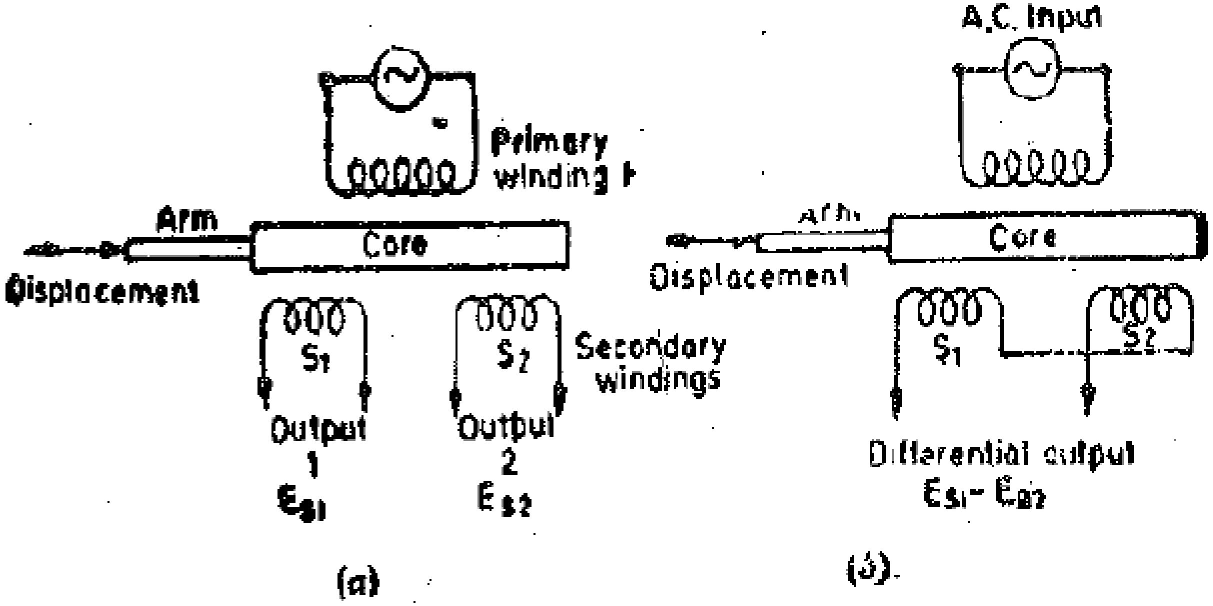




working of LVDT

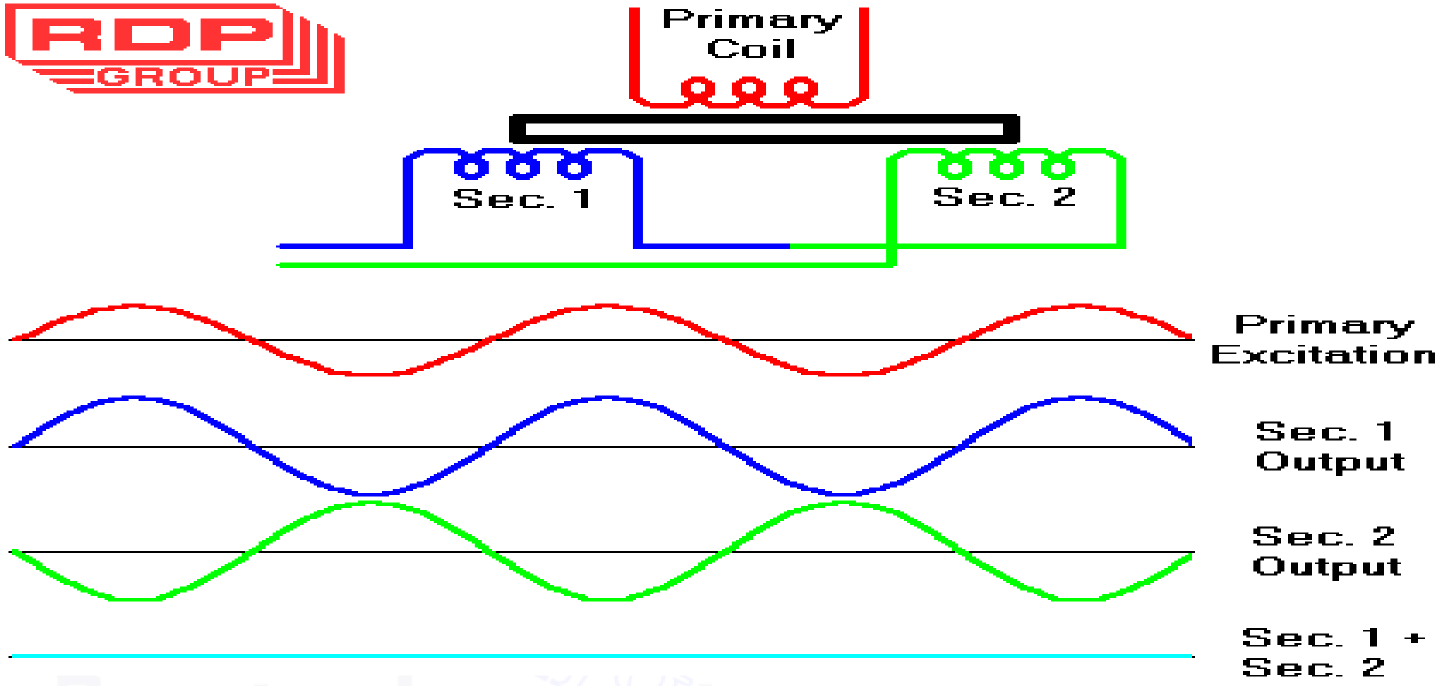
- As the primary is connected to an AC source so alternating current and voltages are produced in the two secondary windings of the LVDT.
- The output in secondary S_1 is Es_1 and in the secondary S_2 is Es_2.
- In order to convert the output from s_1 and s_2 into a single voltage signal, the two secondaries are connected in series opposition.
- Thus the output voltage of the transducer is the difference of the two voltages . So the differential output voltage is ,

$$E_o = E_{s1} - E_{s2}$$

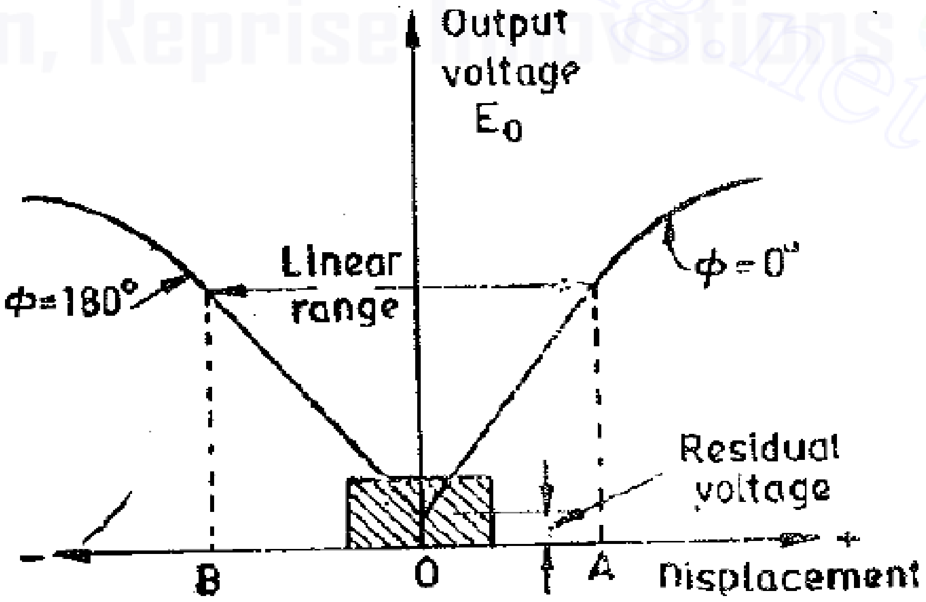


Now three cases arise according to the locations of core which explains the working of LVDT.

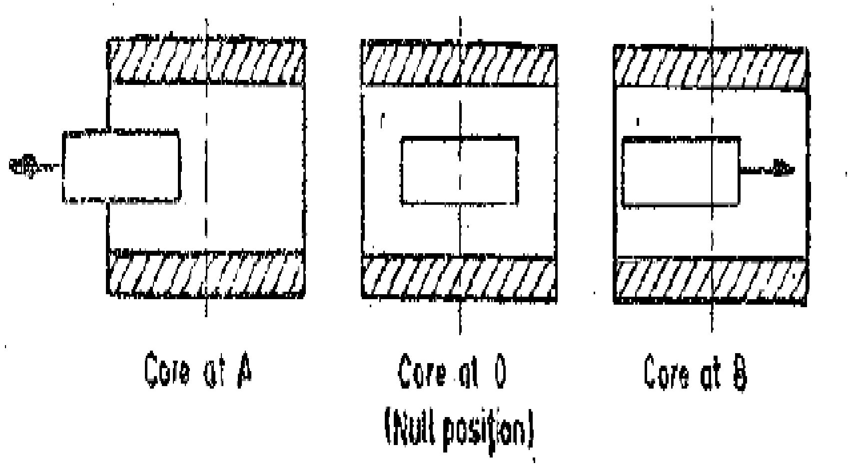
- **CASE I** : When the core is at null position (for no displacement) then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output Eo is zero as Es_1 and Es_2 both are equal. So it shows that no displacement took place.
- **CASE II :** When the core is moved to the left of null position the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this Es_1 will be more as that of Es_2. Due to this output voltage Eo is positive and the output voltage is in phase with the primary voltage.
- **CASE III** :When the core is moved to right of Null position , the flux linking with secondary winding S_2 is more as compared to flux linking with $S_{1.}$ Due to this Es_2 will be more as that of Es_1. Due to this output Eo will be negative and the differential output voltages are 180^o out of phase with each other.



Primary Coil
Sec. 1
Sec. 2
Primary Excitation
Sec. 1 Output
Sec. 2 Output
Sec. 1 + Sec. 2



Output voltage E_0
Linear range
$\phi = 180°$
$\phi = 0°$
Residual voltage
B
O
A
Displacement



Core at A
Core at 0 (Null position)
Core at B

Some important points about magnitude and sign of voltage induced in LVDT

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.

- By noting the output voltage increasing or decreasing the direction of motion can be determined

- The output voltage of an LVDT is linear function of core displacement .

Advantages of LVDT

- High Range – The LVDTs have a very high range for measurement of displacement. They can used for measurement of displacements ranging from 1.25 mm to 250 mm
- No Frictional Losses – As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device.
- High Input and High Sensitivity – The output of LVDT is so high that it doesn't need any amplification. The transducer posseses a high sensitivity which is typically about 40V/mm.
- Low Hysteresis – LVDTs show a low hysteresis and hence repeatability is excellent under all conditions
- Low Power Consumption – The power is about 1W which is very as compared to other transducers.
- Direct Conversion to Electrical Signals – They convert the linear displacement to electrical voltage which are easy to process

Disadvantages of LVDT:

- Relatively large displacements are required for appreciable differential output.
- LVDT is sensitive to stray magnetic fields so it always requires a setup to protect them from stray magnetic fields.
- LVDT gets affected by vibrations and temperature.

Applications :

1. It can measure a displacement ranging from few mm to cm
2. Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure. The force or pressure to be measured is first converted into a displacement using primary transducer. Then this displacement is applied to LVDT to get the proportional output voltage.

Piezoelectric transducer , Hall effect transducer

Piezoelectric transducer

- Piezoelectric transducer is an electrical transducer which can convert any form of physical quantity into an electrical signal.

- It is used for measuring the physical quantity like force, pressure, stress, etc., which is not possible to measure directly.

- The piezoelectric transducer uses the piezoelectric material which has a special property, i.e. the material induces voltage when the pressure or stress applied to it. The material which shows such property is known as the electro-resistive element.

- The common piezoelectric material include Rochelle salt, ammonium dihydrogen phosphate, lithium sulphate, dipotassium tatarate, potassium dihygrogen phosphate, quartz and ceramics A and B.

Piezoelectric transducer

- The word piezoelectric means the electricity produces by the pressure.
- The Quartz is the examples of the natural piezoelectric crystals, whereas the Rochelle salts, ammonium dehydration, phosphate, lithium sulphate, dipotassium tartrate are the examples of the man made crystals. The ceramic material is also used for piezoelectric transducer.
- **Quartz** is a highly stable crystal which is naturally available but it has small output levels. Slowly varying parameters can be measured with quartz.
- **Rochelle salt** gives the highest output values but it is sensitive to environmental conditions and cannot be operated above 1150F.

Piezoelectric transducer

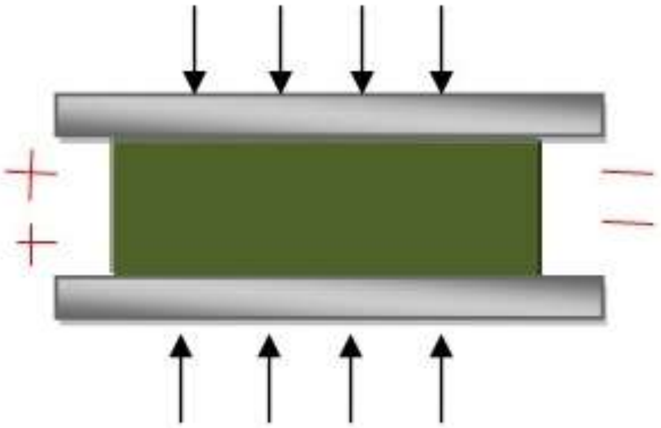
- The **ceramic** material does not have the piezoelectric property. The property is developed on it by special polarizing treatment. The ceramic material has several advantages.

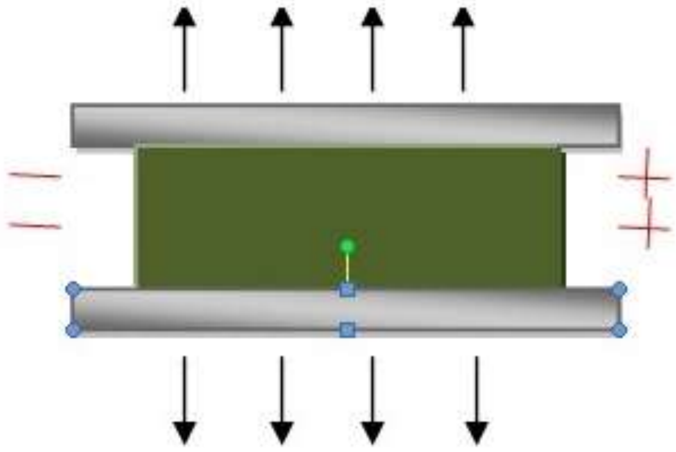
- It is available in different shapes and sizes. The material has the capability of working at low voltages, and also it can operate at the temperature more than 3000ºC

- The following are the properties of the Piezoelectric Crystals.
    - The piezoelectric material has high stability.
    - It is available in various shapes and sizes.
    - The piezoelectric material has output insensitive to temperature and humidity.

Piezoelectric Transducer Working

- **Piezoelectric Transducer** works with the principle of piezoelectricity. The faces of piezoelectric material, usual quartz, is coated with a thin layer of conducting material such as silver. When stress has applied the ions in the material move towards one of the conducting surface while moving away from the other. This results in the generation of charge.
- This charge is used for calibration of stress. The polarity of the produced charge depends upon the direction of the applied stress. Stress can be applied in two forms as Compressive stress and Tensile stress as shown below.





Piezoelectric Transducer Working

- Crystal in a transducer can be arranged in **longitudinal position** or **transverse position**.

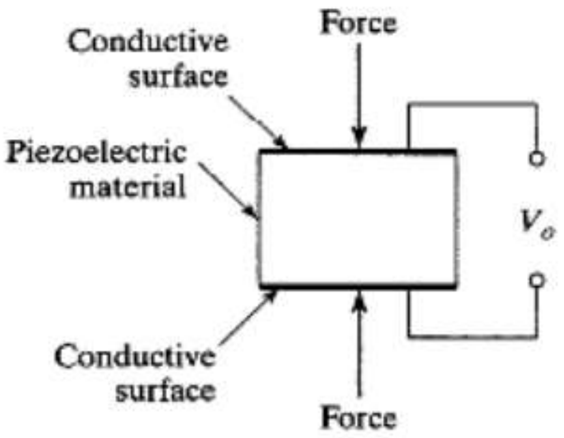


fig: Long

- The arrangement shown in the above figure is called longitudinal effect. For this arrangement, the charge generated is given by

$$Q = F \times d$$

where, F is the applied force

d is the piezoelectric coefficient of the material.

Piezoelectric Transducer Working

- The piezoelectric coefficient, d, depends on the piezoelectric material and its crystal orientation relative to the force, F.

- For a typical quartz element, d has a value of $2.3\times10^{(-12)}$ C/N.

- The above equation shows that the charge is proportional to the applied force which can also be viewed as being proportional to the displacement.

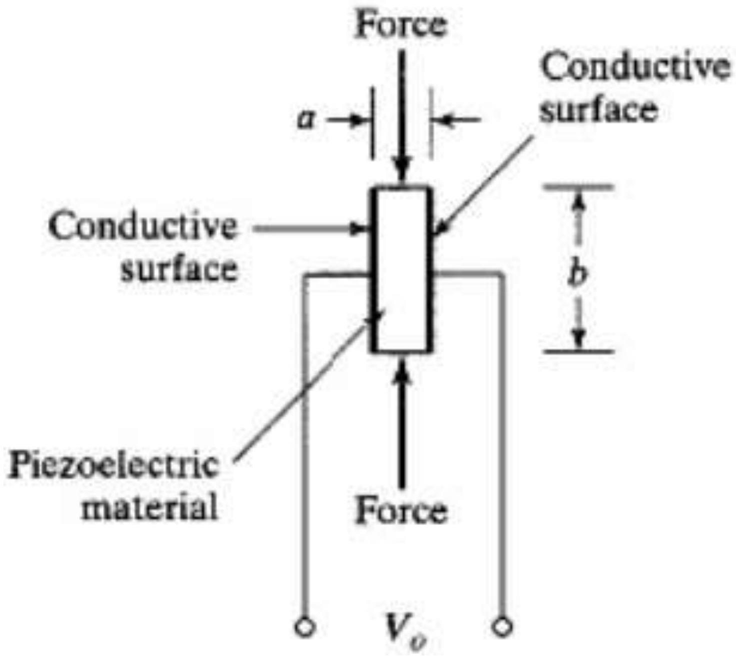
- The piezoelectric element is slightly flexible, and the imposition of a force produces a small, proportional displacement.

Piezoelectric Transducer Working

- Another configuration of the piezoelectric sensor is called transverse effect which is shown below.
- The charge generated in this configuration is given by

$$Q = F \times d \times (b/a)$$

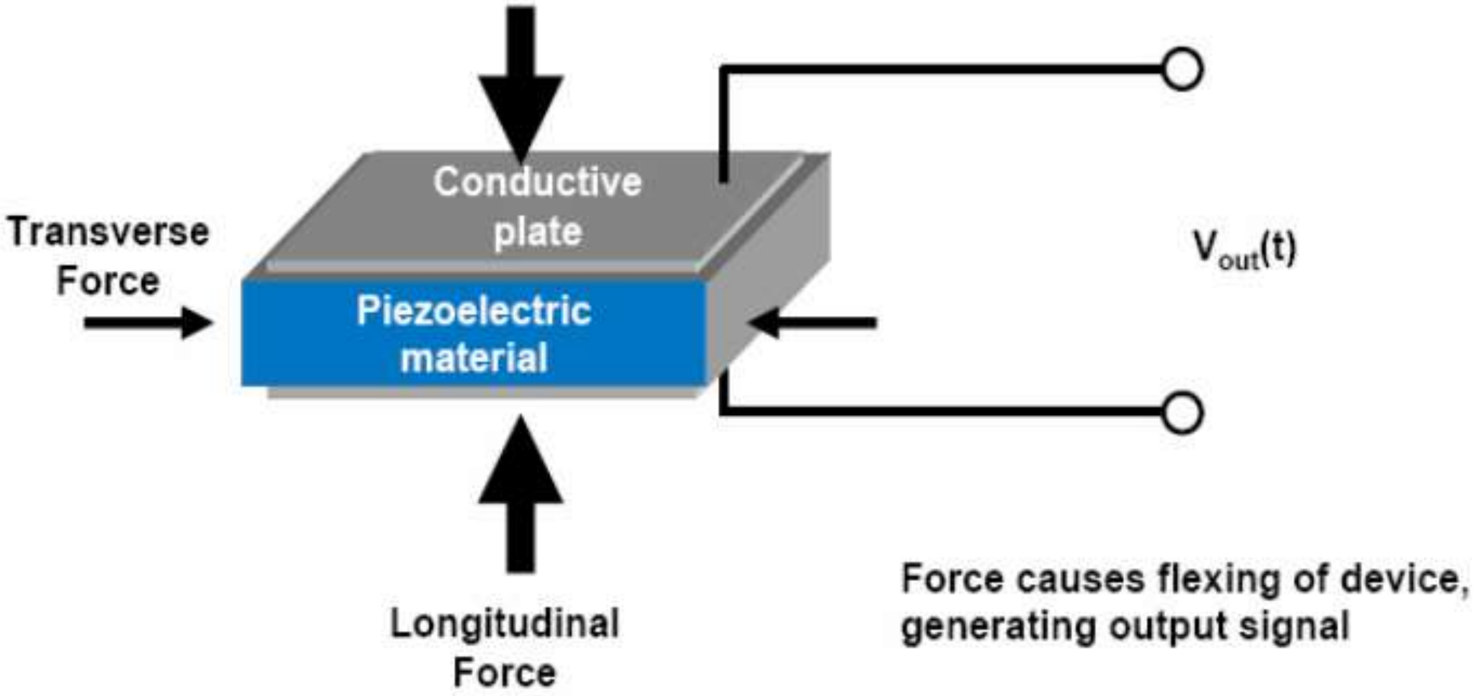
- If the ratio of the dimensions, b/a, is greater than one (the usual case), the transverse effect produces a greater charge than the longitudinal effect.



Piezoelectric Transducer Working

- With either loading, the charge is proportional to the applied force.

- This charge results in a voltage. However, this voltage depends not only on the capacitance of the piezoelectric element but also on the capacitances of the lead wires and the signal-conditioner input.



Advantages :

- Very high frequency response.
- Self generating, so no need of external source.
- Simple to use as they have small dimensions and large measuring range.
- Barium titanate and quartz can be made in any desired shape and form. It also has a large dielectric constant. The crystal axis is selectable by orienting the direction of orientation.

Disadvantages:

- Temperature and environmental conditions can affect the behavior of the transducer.
- It is not suitable for measurement in static condition.
- The relative humidity rises above 85% or falls below 35%, its output will be affected. If so, it has to be coated with wax or polymer material.

Applications:

- In microphones, the sound pressure is converted into an electric signal and this signal is ultimately amplified to produce a louder sound.
- Automobile seat belts lock in response to a rapid deceleration is also done using a piezoelectric material.
- It is also used in medical diagnostics.
- It is used in electric lighter used in kitchens. The pressure made on piezoelectric sensor creates an electric signal which ultimately causes the flash to fire up.
- They are used for studying high-speed shock waves and blast waves.
- Used infertility treatment.
- Used in Inkjet printers
- 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 a person is near the door pressure is exerted person weight on the sensors due to which the electric effect is produced and the door opens automatically.

UNIT – V

Optical encoder type digital transducer

Introduction

- In modern PC based automation systems, it is necessary to connect the output of the transducer to the computer. For this connectivity the output of the transducer must be in digital form.

- Transducers available at large are primary analogue at nature, and some form of conversion is needed to convert to transform them into digital form.

- Analogue transducers with A/D convertors can serve the purpose of digital transducers

- Few transducers are available which give digital output. Therefore the transducers which provide digital output is called as Digital transducers. They can be directly interfaced with a digital computer.

- The available digital transducers are in the form of linear or rotary displacement transducers

Introduction

- Digital transducers are called **Encoders**. They are also called digitizer as they convert continuous analog signal into binary or decimal point.

- Digital encoding transducers or **digitizers** enable linear or rotary displacement to be directly converted into digital form without intermediate ADC . Such digitiser is known as digital encoder or linear digitiser or for rotary application shaft digitiser or shaft encoder.
- Mechanical disks (or bar) with optical receivers and transmitters can act as digital displacement transducers. This type of transducers called optical encoder.
- Optical encoders can be used to measure linear and angular displacements. Therefore, optical encoders can be classified as:
  - Rotary encoders
  - Linear encoders

Optical Linear Encoder

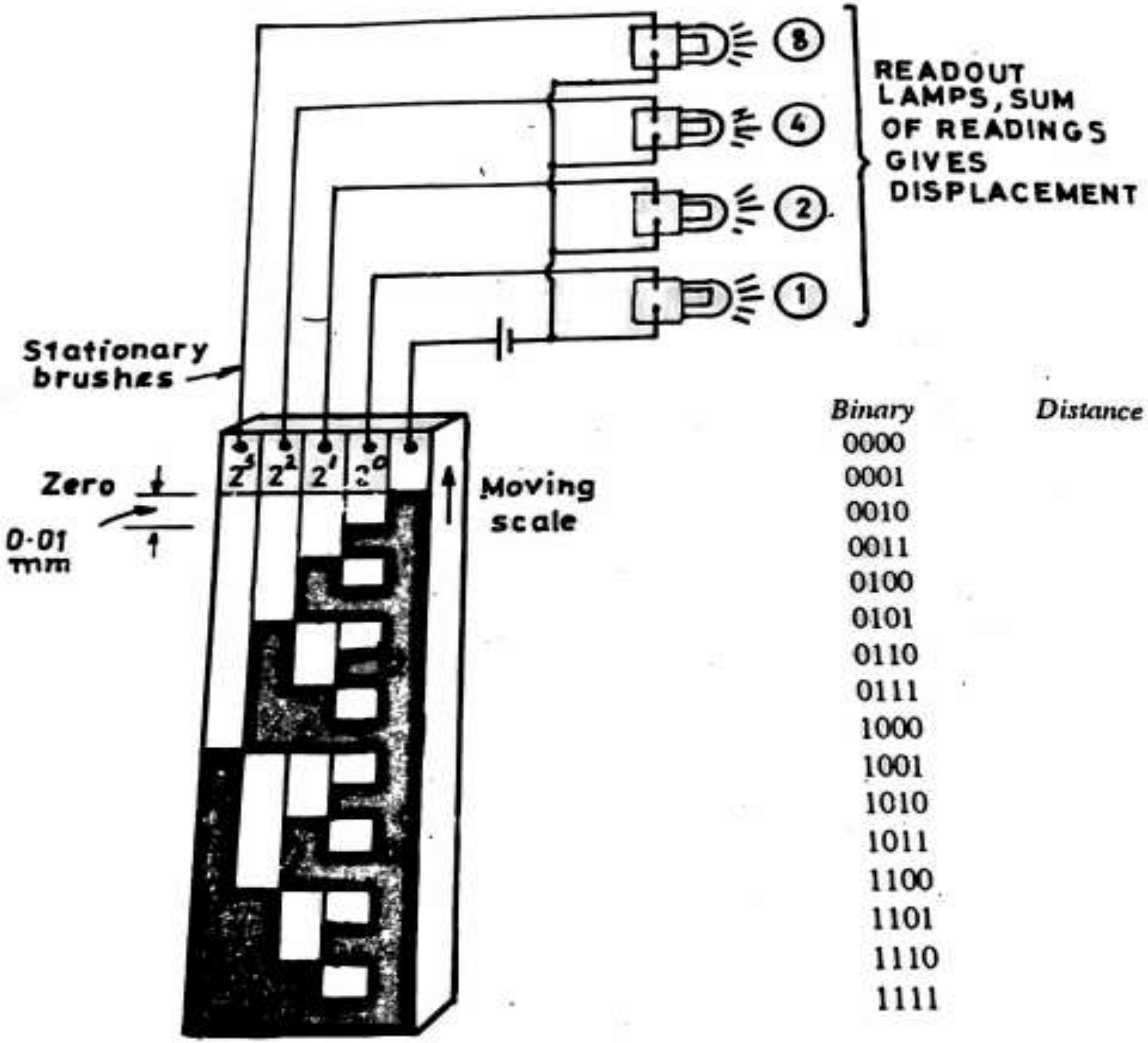
- Encoder can be constructed as

  (i) Contacting type

  (ii) Non-contacting type.

- **Contacting or Brush type(Resistive encoders)**

- The shaded areas are made of conducting material and the unshaded areas are made of non conducting material.
- Brushes are placed on the transducer which acts as sliding contacts.
- The circuit of sliding contacts, which come in contact with conducting areas are completed, which makes in contact with insulating area are not completed.
- Thus the encoder gives out a digital readout which is an indication of position and hence the encoder determines the displacement.



Binary	Distance in 0.01 mm
0000	0
0001	1
0010	2
0011	3
0100	4
0101	5
0110	6
0111	7
1000	8
1001	9
1010	10
1011	11
1100	12
1101	13
1110	14
1111	15

Fig: Translational encoder

- The voltages on the four lamps lines could be sent to a digital computer directly.
- If a visual readout were desired, these four voltages would be applied to a binary to decimal conversion module and then the readout decimally on a display.

Advantages:

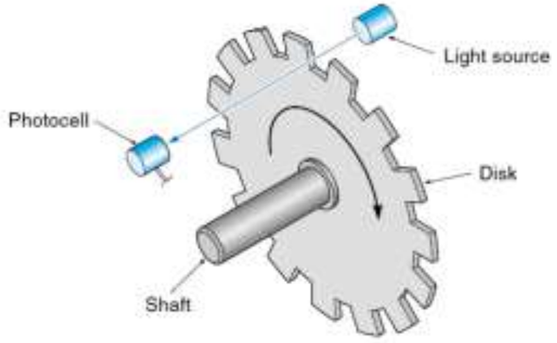
- It is relatively inexpensive
- It can be made to any degree of desired accuracy provided that the sector is made large enough to accommodate the required number of rows for binary numbers and are quite adequate for slowly moving system .

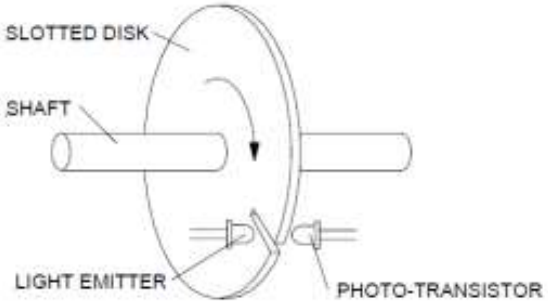
Disadvantages:

- Major problem with these encoders in on account of were of contactors ad maintenance of contacts.

Optical Rotary Encoder

- An optical rotary encoder produces angular position data directly in digital form, eliminating any need for the ADC converter. The concept is illustrated in following figure, which shows a slotted disk attached to a shaft. A light source (LED) and light receiver (phototransistor or photodiode) arrangement are mounted so that the slots pass the light beam as the disk rotates. The angle of the shaft is deduced from the output of the photocell.
- There are two types of optical rotary encoders:
    - ➢the absolute encoder
    - ➢the incremental encoder

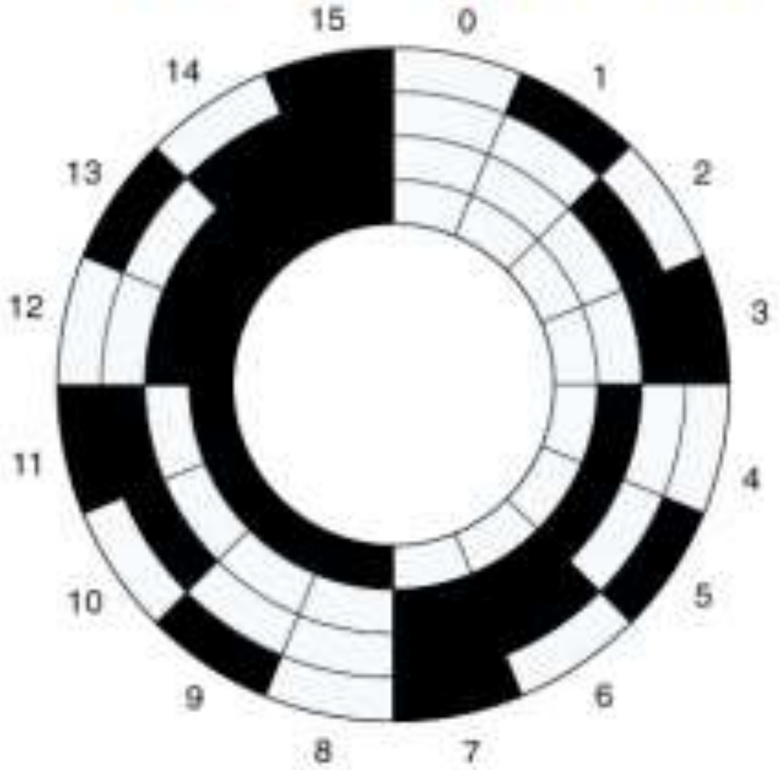


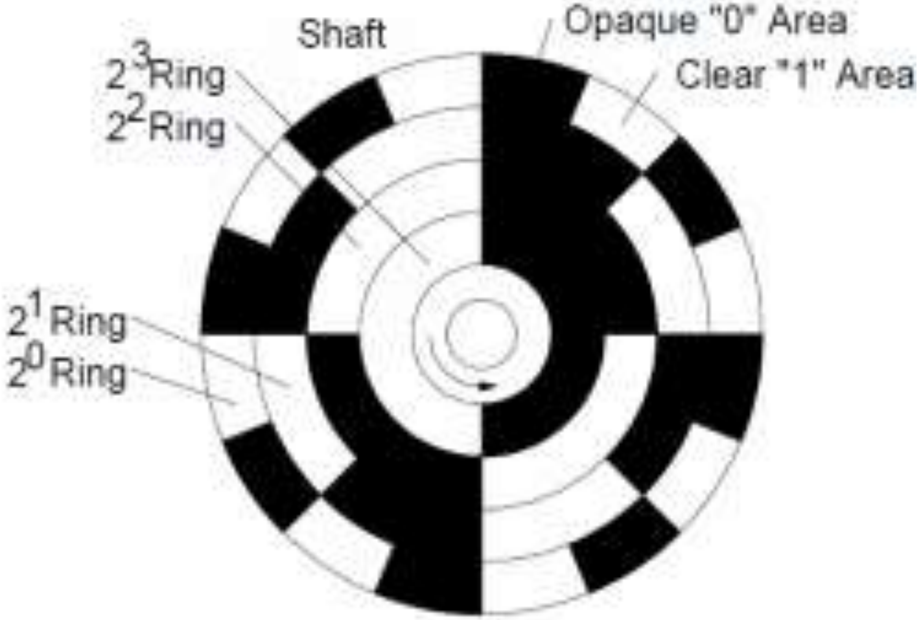


- Absolute Rotary Encoder
- The output of the absolute rotary encoder is in the form of a binary word which is proportional to the angle of the shaft.
- The absolute encoder does not need to be homed because when it is energized, it simply outputs the shaft angle as a digital value.
- Absolute optical encoders use a glass or plastic disk marked off with a pattern of concentric tracks as shown in the figure.
- A separate light beam is sent through each track to individual photo sensors. Each photo sensor contributes 1 bit to the output digital word.
- The encoder in the figure outputs a 4-bit word with the LSB coming from the outer track (note that this is for illustrative purposes only and a 4-bit encoder is of little practical use). The disk is divided into 16 sectors, so the resolution in this case is 360°/16 = 22.5°.

- Absolute Rotary Encoder
- The absolute angle of the encoder shaft can be found by multiplying the binary output of the encoder times the resolution. For example, assume our 4-bit encoder has an output of 1101 (decimal 13). The encoder shaft would therefore be at an angle of 13 x 22.5 degrees = 292.5 degrees. Because of the relatively poor resolution of this encoder, the shaft could be at some angle between 292.5 degrees and 292.5+22.5 degrees.
- For better resolution, more tracks would be required. For example, eight tracks (providing 256 states) yield 360°/256 = 1.4°/state, and ten tracks (providing 1024 states) yield 360°/1024 = 0.35°/state.

Absolute Rotary Encoder





- Absolute Rotary Encoder
- An a**dvantage** of this type of encoder is that the output is in straightforward digital form and, like a pot, always gives the absolute position. This is in contrast to the incremental encoder that, as will be shown, provides only a relative position.

- A **disadvantage** of the absolute encoder is that it is relatively expensive because it requires that many photocells be mounted and aligned very precisely

DIGITAL STORAGE OSCILLOSCOPE (DSO)

Digital Storage Oscilloscope

Disadvantages of analog storage CRT

i) The waveform can be preserved for finite amount of time only and eventually the waveform will be lost.

ii) As long as image is required to be stored, the power must be supplied to the tube.

iii) The trace obtained from the storage tube is not fine as compared to the conventional oscilloscope tube.

iv) The writing rate of storage tube is less than that of conventional cathode ray tube. This limits the speed of the storage tube.

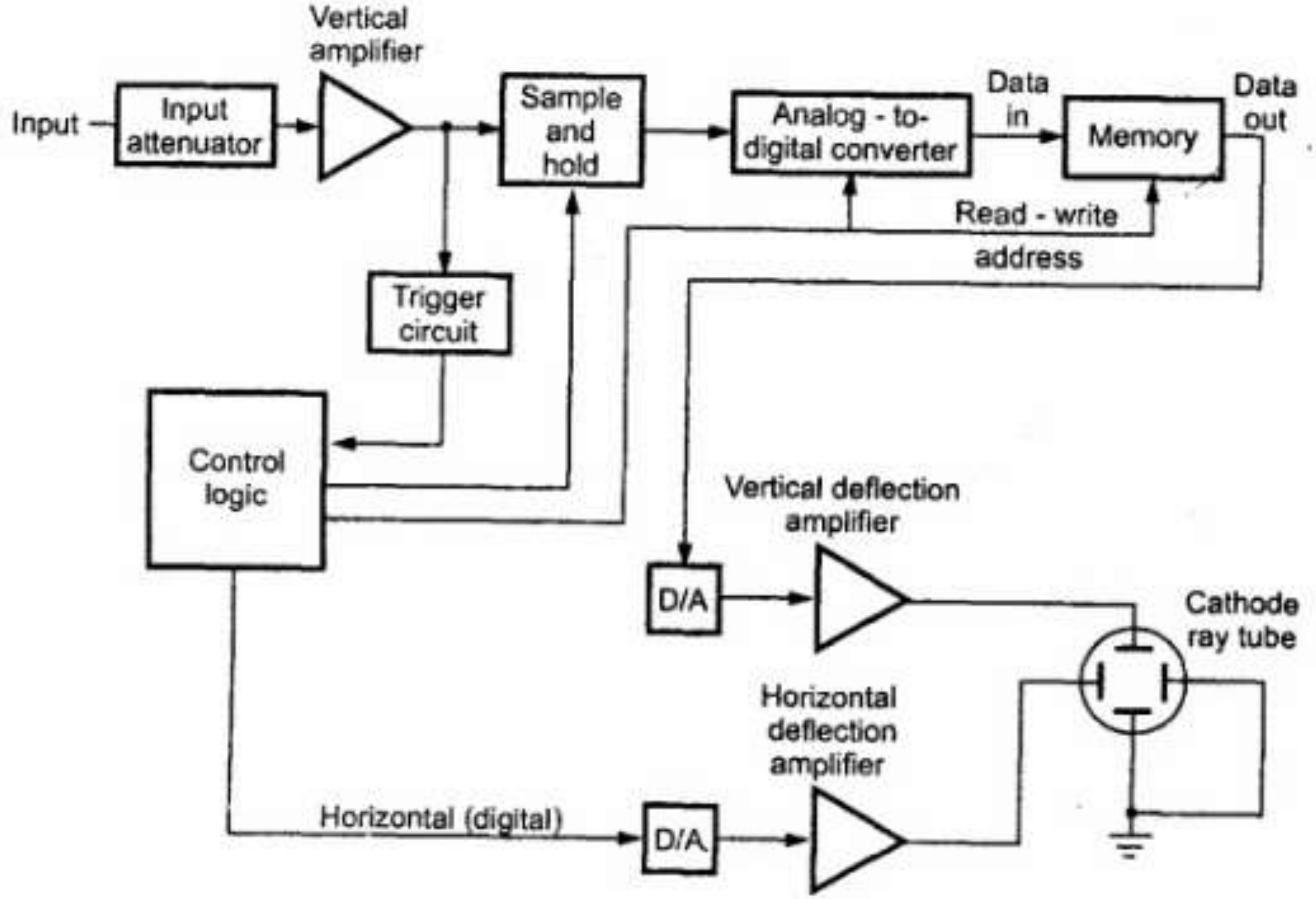
v) The storage cathode ray tube is very much expensive than conventional cathode ray tube.

vi) The storage cathode ray tube requires additional power supplies.

vii) Only one waveform can be stored in storage tube. If two traces are to be compared, they are required to be superimposed on the same screen and must be displayed together.

viii) The stored waveform cannot be reproduced on the external device like computer.

BLOCK DIAGRAM



The input signal is applied to the amplifier and attenuator section.

➢ The oscilloscope uses same type of amplifier and attenuator circuitry as used in the conventional oscilloscopes.

➢The attenuated signal is then applied to the vertical amplifier.

➢To digitize the analog signal, analog to digital (A/D) converter is used.

➢The output of the vertical amplifier is applied to the A/D converter section.

➢The successive approximation type of A/D converter is most oftenly used in the digital storage oscilloscopes.

➢The sampling rate and memory size are selected depending upon the duration & the waveform to be recorded.

➢Once the input signal is sampled, the A/D converter digitizes it.

➢The signal is then captured in the memory.

➢Once it is stored in the memory, many manipulations are possible as memory can be readout without being erased.

- To digitize analog signal, analog to digital (A/D) converter is used.

- Digitizing means taking samples at periodic intervals of the input signal.

- Rate of sampling should be at least twice as fast as the highest frequency present in the input signal.

- For 12-bit converter, 0.025% resolution is obtained.

  10 –bit ADC , 0.01% resolution and freq response of 25kHz is obtained .

- Total digital storage capacity is 4096 for a single channel, 2048 for two channels and 1024 for four channels.
- Once input is sampled, ADC digitize it. Signal is captured in memory. It can be used for many manipulations

Modes of operation

- One important feature of DSO is its mode of operation called Pretrigger view.
- Modes means that the oscilloscope can display what happened before a trigger input is applied.
- Single shot events, such as the waveform of an explosion are transient in nature and very quickly lost.
- Such events are stored in memory of DSO

Three modes of operation :

- **1.Roll Mode**: Very fast varying signals are displayed in this mode. The input signal is not triggered at all. Fast varying signal is displayed as it if changing slowly, on the screen in this mode.

Store Mode

This is most commonly used and called **refresh mode.**

In this mode, the input initiates a trigger circuit. This initiates the memory write cycle. The digital data is transferred to the memory. When the memory is full, the write cycle stops.

Using digital to analog converter, the memory data is converted to analog and then displayed on the screen.

When the next trigger occurs the memory is refreshed.

Hold or Save Mode

This is called **automatic refresh mode.** When new sweep signal is generated by time base generator, the old contents get overwritten by new one.

If a particular signal is to be stored then by pressing hold or save button, overwriting can be stopped and previously saved signal is locked.

Advantages of DSO

- It is easier to operate and has more capability.
- The storage time is infinite.
- The display flexibility is available. The number of traces that can be stored and recalled depends on the size of the memory.
- The cursor measurement is possible.
- The characters can be displayed on screen along with the waveform which can indicate waveform information such as minimum, maximum, frequency, amplitude etc.
- The X-Y plots, B-H curve, P-V diagrams can be displayed.
- The pretrigger viewing feature allows to display the waveform before trigger pulse.
- Keeping the records is possible by transmitting the data to computer system where the further processing is possible
- Signal processing is possible which includes translating the raw data into finished information e.g. computing parameters of a captured signal like r.m.s. value, energy stored etc.

Acquisition methods

- In DSO it is necessary to capture the digital signal and store it.

  There are three different acquisition methods used in DSO.

1.Real time sampling

2. Random repetitive sampling.

3. Sequential repetitive sampling.

Real time sampling

- In response to single trigger event, the complete record of n_m samples is simultaneously captured on each and every channel.

- Three important features of this method:

1. Display and analysis of waveform can be carried out at later stage while the signal gets recorded in memory at an earlier stage.

2. Very easy to capture the signals that happen before the trigger event.

3. Simultaneous capture of multiple signals is automatic.

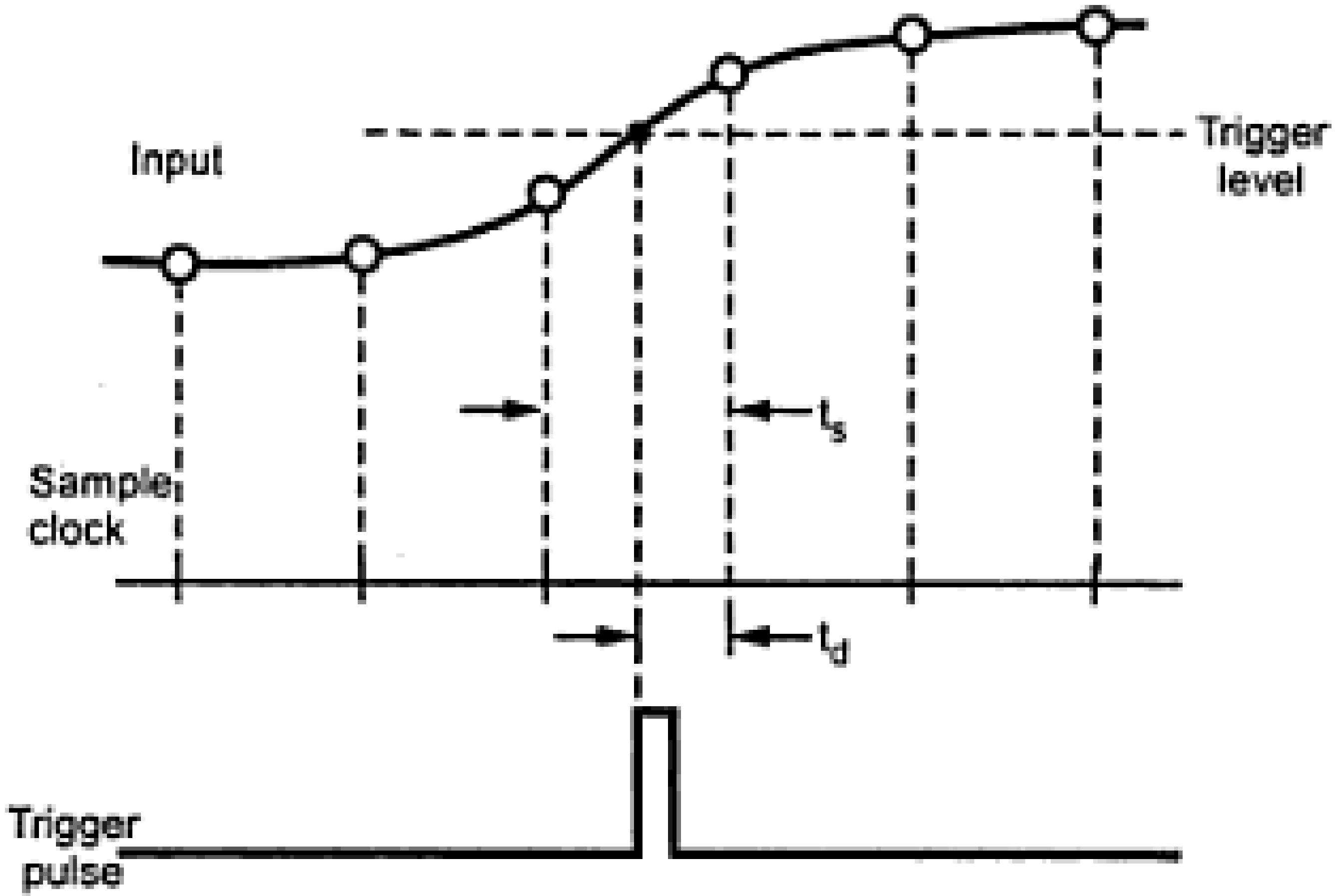
Random repetitive sampling.

- Repeated real time data acquisition cycles are performed. Still each value is plotted independently on display as a dot.

- Each acquisition cycle produces random time interval t_d between trigger point and sample clock.

- Time between the samples from that capture is t_s with an offset of t_d from the trigger point.

- Disadvantage of this method is that the abilities to capture a nonrecurring transient is lost.



Random repetitive sampling

Sequential repetitive sampling.

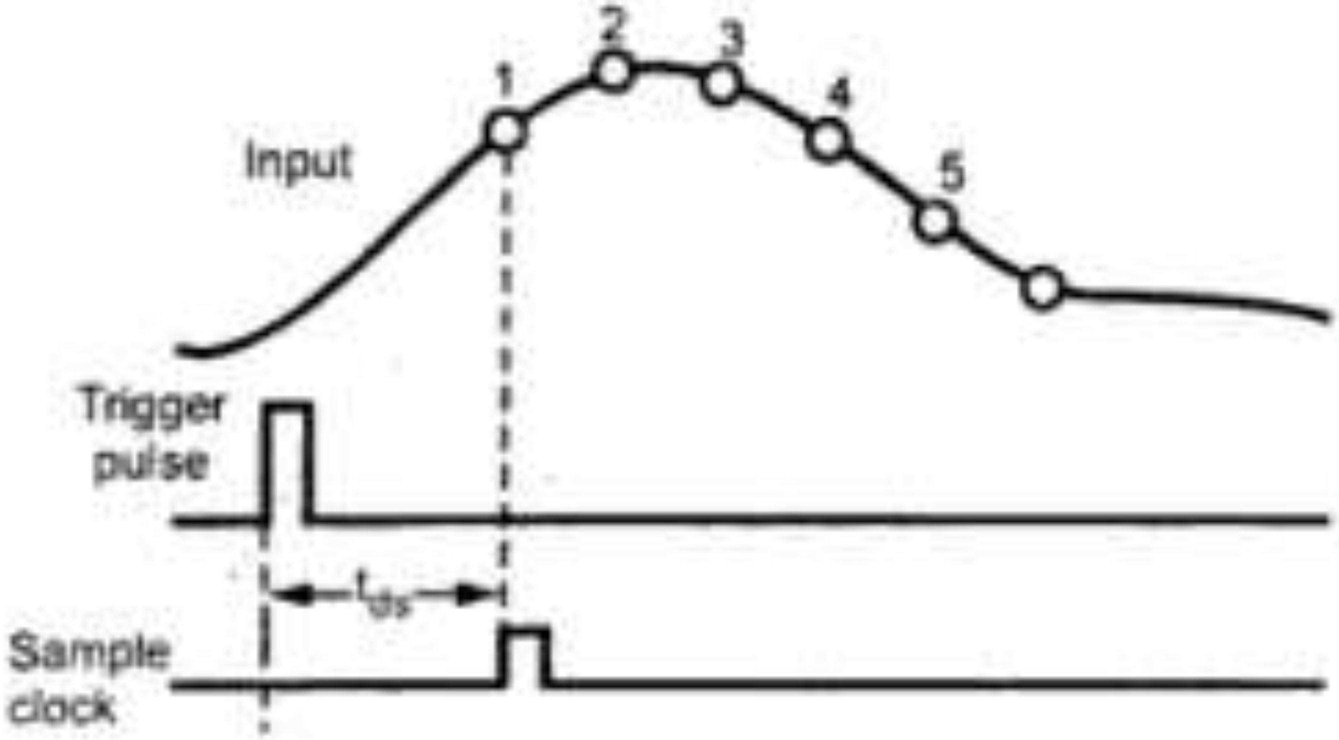
- Oscilloscopes having bandwidth 20 to 50GHz need very fast sweep speed settings. Hence sequential repetitive sampling is used.

- In this method one sample value per trigger event is captured at controlled time delay t_{ds} after the triggering pulse.

- This delay is increased by small amount t_{se} after each point is captured. This increase in delay s the effective sample time.

- This method cannot capture trigger event pretrigger information.

- Major disadvantage of this method is pretrigger view feature gets lost. Hence this method is used only in microwave bandwidth digital oscilloscopes.



Input
1
2
3
4
5
Trigger
pulse
t_{ds}
Sample
clock