

**SUBJECT- INSTRUMENTATION**

**SENSORS & TRANSDUCERS**

# Objectives

- Ability to understanding the definition, functions & categories of transducers.
- List the classes and types and examples of transducers.
- Operations and applications for each transducers

# Sensor and transducer

- 'Sensor' is `a device that detects a change in a physical stimulus and turns it into a signal which can be measured or recorded.  
E.g. : Thermistor
- 'Transducer' is 'a device that transfers power from one system to another in the same or in the different form'.  
E.g. Thermistor with it associate circuit convert heat to electricity.

## *As a comparison.....*

'Sensor' for the sensing element itself and 'transducer' for the sensing element plus any associated circuitry. All transducers would thus contain a sensor and most (not all) sensors would also be transducers.

# Sensing process

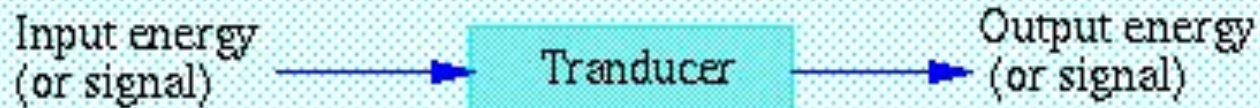


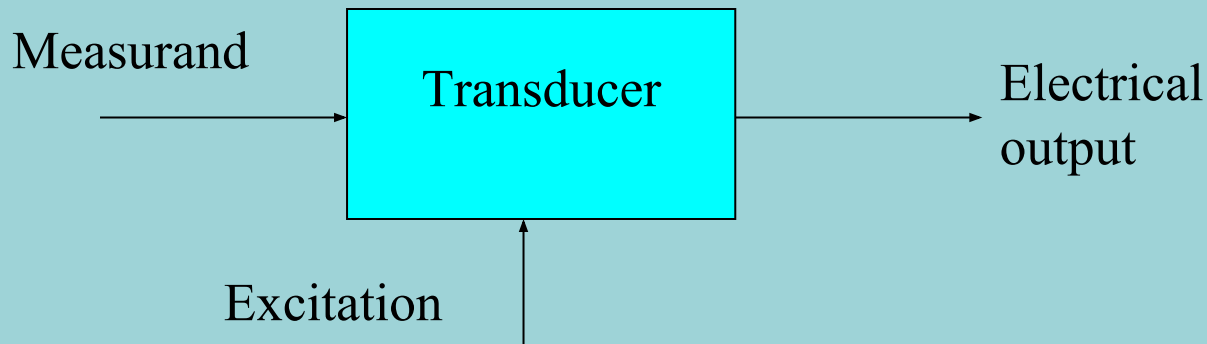
Figure 1 The sensing process

# Definition of a transducer

**Transducer** is any device that converts energy in one form to another energy. The majority either convert **electrical energy to mechanical displacement** or convert some *non-electrical physical quantity*, such as temperature, sound or light **to an electrical signal**.

# Functions of transducer

1. To *sense* the presence, magnitude, change in, and frequency of some *measurand*.
2. To *provide* an electrical output that, when appropriately processed and applied to readout device, gives accurate quantitative data about the *measurand*



*Measurand* – refers to the quantity, property or condition which the transducer translates to an electrical signal.

# Classification of transducers

Transducer can be classified according to their **application**, based primarily on the **physical quantity, property, or condition that is measured**.

The transducer can be categories into:

## A) Passive transducer:

- requires an external power
- output is a measure of some variation, such resistance and capacitance. **E.g. : condenser microphone**

## B) Self generating transducer:

- not require an external power, and they produce analog voltage or current when stimulated by some physical form of energy. **E.g. : Thermocouple**

# Selecting a transducers

1. Operating range
2. Sensitivity
3. Frequency response and resonant frequency
4. Environmental compatibility -
5. Minimum sensitivity measurand.
6. Accuracy
7. Usage and ruggedness
8. Electrical parameter



# Transducers to be covered

- Temperature transducers
- Resistive Position Transducer
- Capacitive Transducer
- Inductive Transducer
- Strain Gauge
- LVDT
- Photoelectric

# Temperature Transducers

Temperature transducers can be divided into four main categories:

1. Resistance Temperature Detectors (RTD)
2. Thermocouples
3. Thermistor
4. Ultrasonic transducers

# 1) Resistance Temperature Detector (RTD)

**Detectors of wire resistance temperature** common employ platinum, nickel or resistance wire elements, whose **resistance variation with temperature has high intrinsic accuracy**. They are available in many configurations and size and as shielded or open units for both immersion and surface applications.

The relationship between temperature and resistance of conductors can be calculated from the equation:

$$R = R_0 (1 + \alpha \Delta T)$$

where

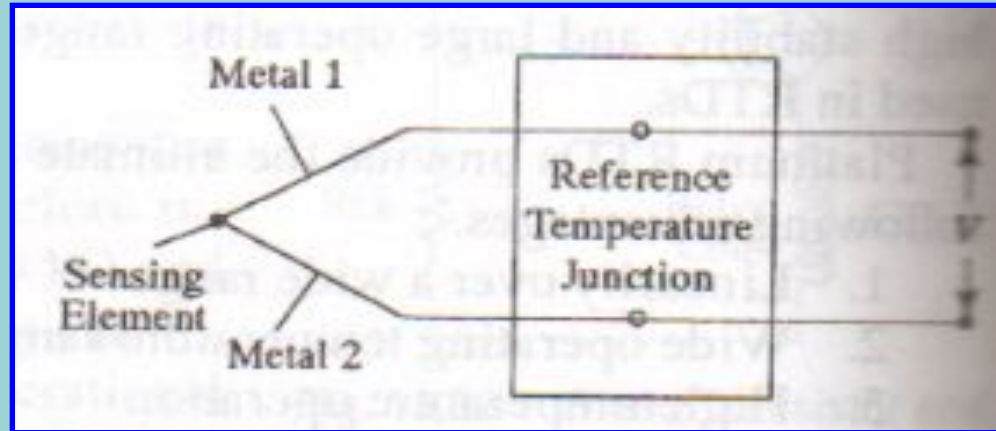
**R** = the resistance of the conductor at temperature  $t$  ( $^{\circ}\text{C}$ )

**R<sub>0</sub>** = the resistance at the reference temperature, usually  $20^{\circ}\text{C}$

**$\alpha$**  = the temperature coefficient of resistance

**$\Delta T$**  = the difference between the operating and the reference temperature

## 2) Thermocouple



It consists of two wires of different metals are joined together at one end, a temperature difference between this end and the other end of wires produces a voltage between the wires. The magnitude of this voltage depends on the materials used for the wires and the amount of temperature difference between the joined ends and the other ends.

# Cont'd

The emf of the thermocouple :

$$E = c(T_1 - T_2) + k(T_1^2 - T_2^2)$$

Where

$c$  and  $k$  = constant of the thermocouple materials

$T_1$  = The temperature of the “hot” junction

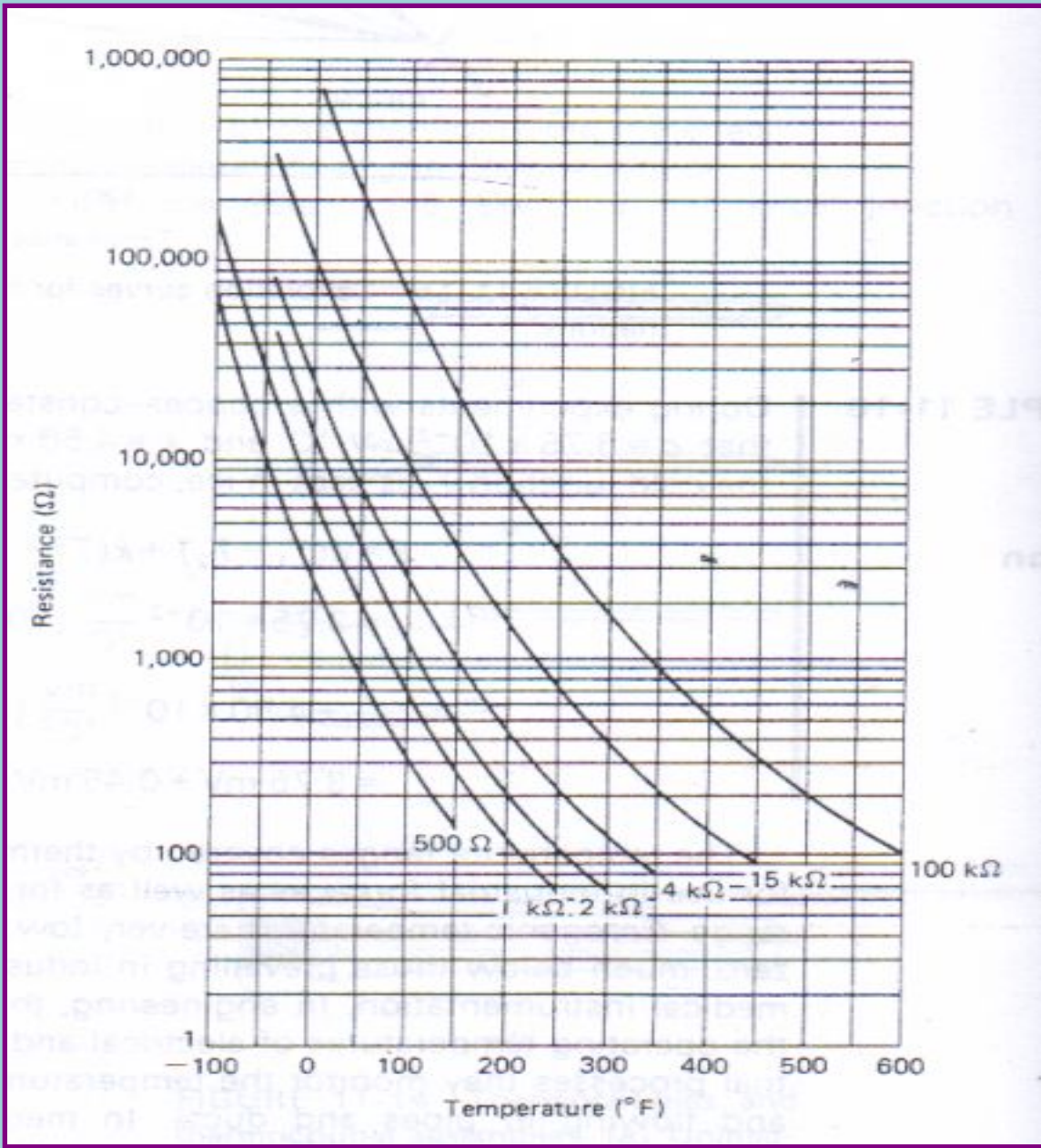
$T_2$  = The temperature of the “cold” or “reference” junction

# 3) Thermistor

A thermistor is a semiconductor made by sintering mixtures of metallic oxide, such as oxides of manganese, nickel, cobalt, copper and uranium.

Thermistors have **negative temperature coefficient (NTC)**. That is, their **resistance decreases** as their **temperature rises**.

Types of thermistor	Resistance
Disc	1 to 1M $\Omega$
Washer	1 to 50k $\Omega$
Rod	high resistance



This figure shows resistance versus temperature for a family thermistor. The resistance value marked at the bottom end of each curve is a value at 25°C

*Note!*  
*The resistance decreases as their temperature rises-NTC*

# Advantages of thermistor

- Small size and low cost
- Fast response over narrow temperature range
- Good sensitivity in Negative Temperature Coefficient (NTC) region
- Cold junction compensation not required due to dependence of resistance on absolute temperature.
- Contact and lead resistance problems not encountered due to large resistance



# Limitations of thermistor

- Non linearity in resistance vs temperature characteristics
- Unsuitable for wide temperature range
- Very low excitation current to avoid self heating
- Need of shielded power lines, filters, etc due to high resistance

# Resistive Position Transducer

The principle of the resistance transducer is that the physical variable under measurement causes a **resistance change** in the sensing element.

A common requirement in industrial measurement and control work is to be able to sense the position of an object or distance it has moved.

$$R = \frac{\rho L}{A} \longrightarrow \text{Potentiometer}$$

R: resistance change

$\rho$ : density

L: Length

A: area

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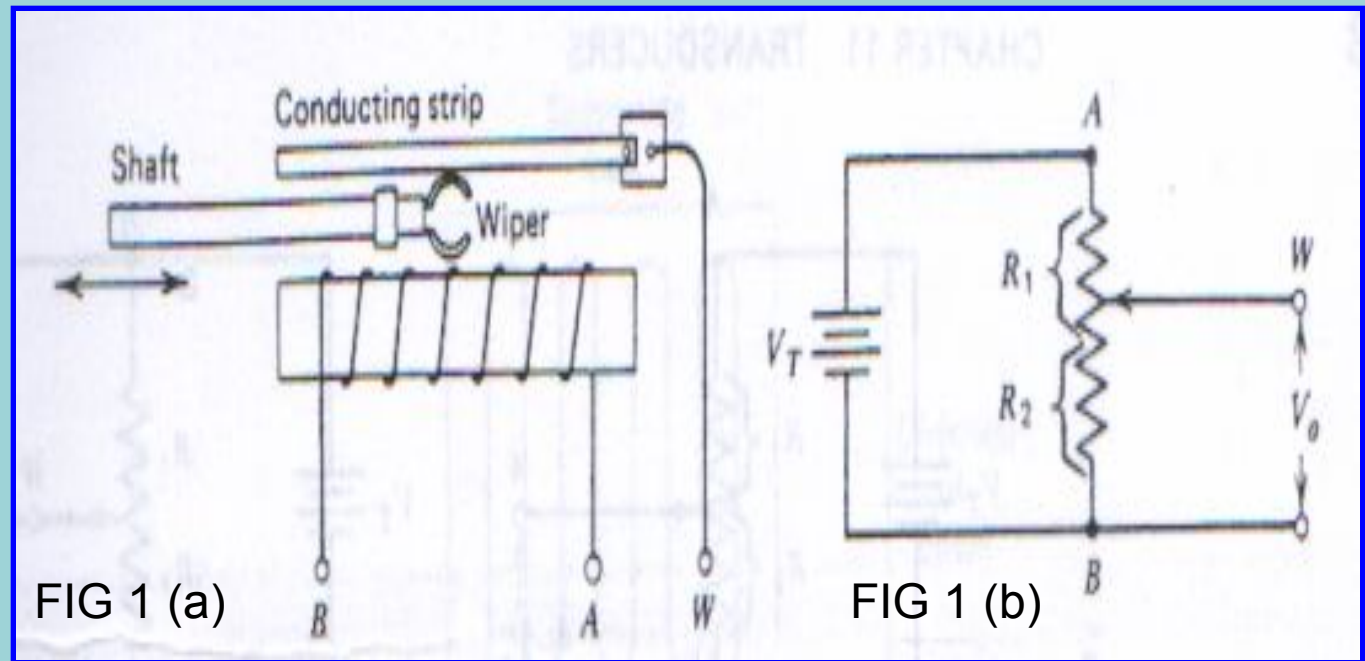


Figure shows the construction of a displacement transducer uses a resistance element with a sliding contact or wiper linked to the object being monitored.

The resistance between the slider and one end of the resistance element depends on the position of the object. The output voltage depends on the wiper position and therefore is a function of the shaft position

Consider Fig 1 (b), if the circuit is unloaded, the output voltage  $V_0$  is a certain fraction of  $V_T$ , depending on the position of the wiper:

$$\frac{V_0}{V_T} = \frac{R_2}{R_1 + R_2}$$

This equation shows that the output voltage is directly proportional to the position of the wiper, if the resistance of the transducer is distributed uniformly along the length of travel of the wiper

### EXAMPLE 1

A displacement transducer with a shaft stroke of 4 in. is used in the circuit of figure 1 (b).  $R_1 + R_2$  is 1000  $\Omega$  and  $V_T = 4$  V.

The wiper is 1.5 in from B. Find  $V_0$ ?

# Capacitive Transducer

The capacitance of a parallel plate capacitor is given by

$$C = \frac{kA\varepsilon_0}{d} \text{ (Farads)}$$

where

k = dielectric constant

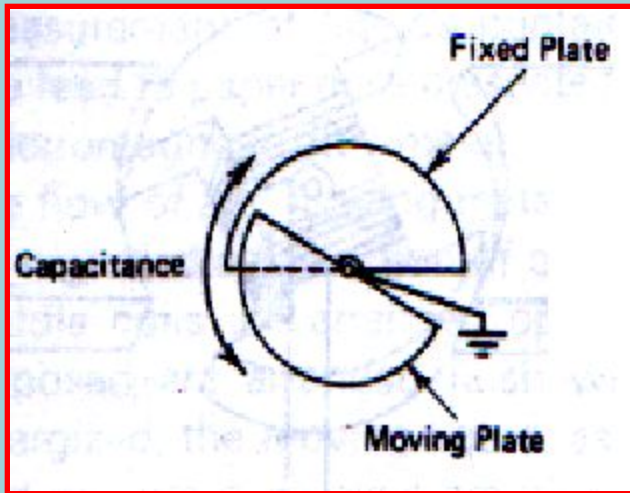
A = the area of the plate, in m<sup>2</sup>

$\varepsilon_0$  = 8.854 x 10<sup>-12</sup> F/m

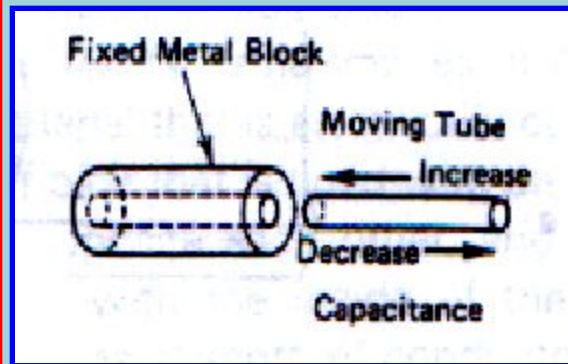
d = the plate spacing in m

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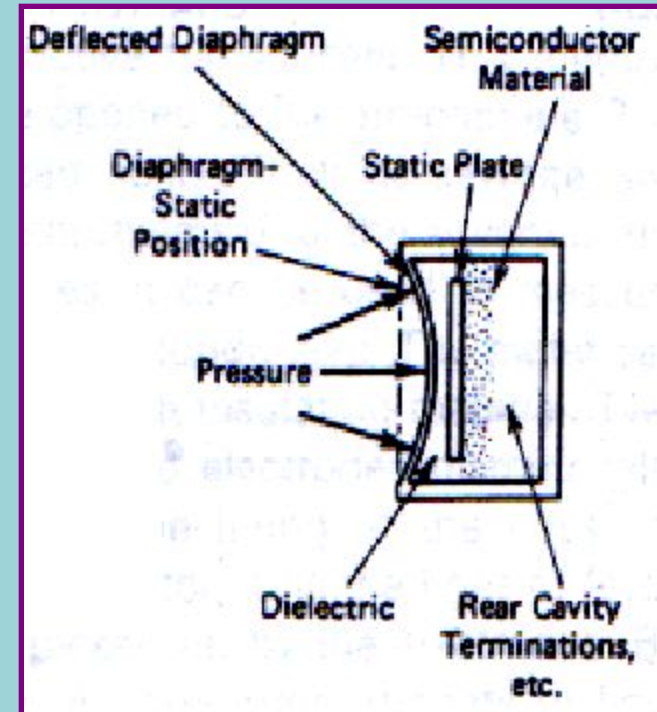
## Forms of Capacitance Transducers



Rotary plate capacitor

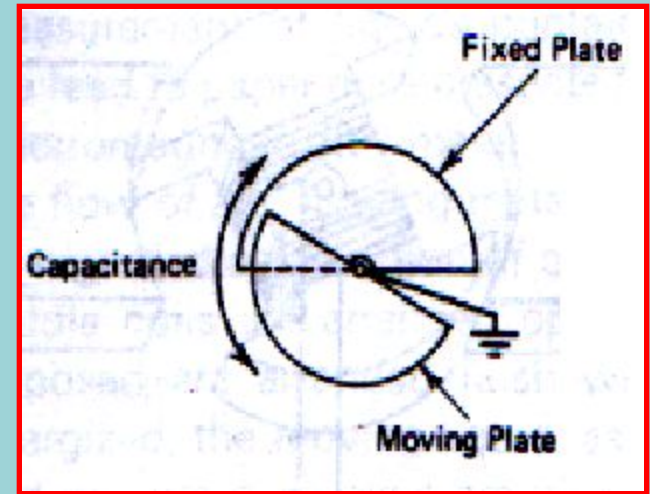


Rectilinear Capacitance Transducer



Thin diaphragm

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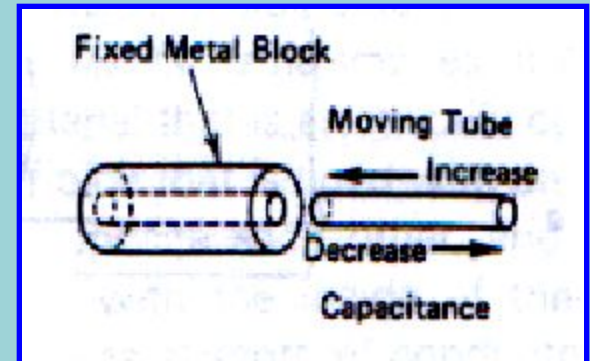
## Rotary plate capacitor:

The capacitance of this unit **proportional to the amount of the fixed plate that is covered, that shaded by moving plate.** This type of transducer will give sign proportional to curvilinear displacement or angular velocity.

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## Rectilinear capacitance transducer:

It consists of a fixed cylinder and a moving cylinder. These pieces are configured so the moving piece fits inside the fixed piece but insulated from it.



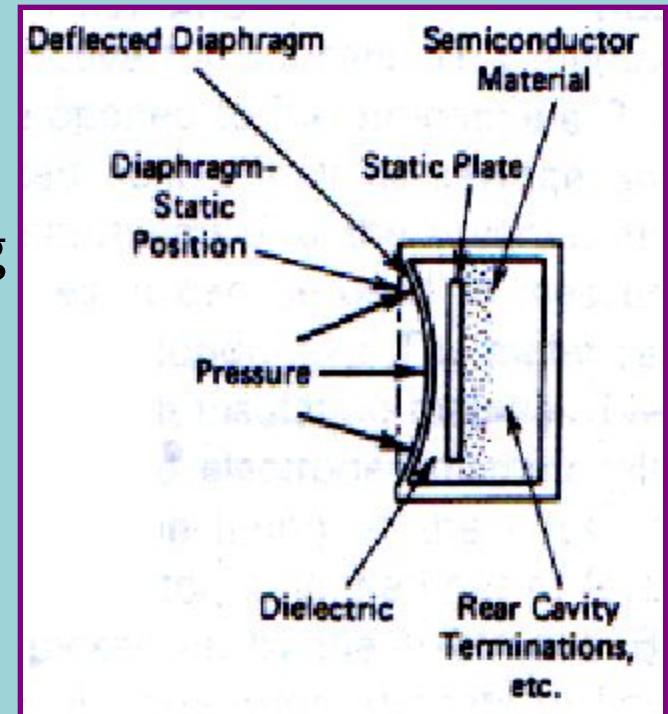


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## Thin diaphragm:

A transducer that varies the spacing between surfaces. The dielectric is either air or vacuum.

Often used as Capacitance microphones.



# Cont'd

## **Advantages:**

1. Has excellent frequency response
2. Can measure both static and dynamic phenomena.

## **Disadvantages:**

1. Sensitivity to temperature variations
2. the possibility of erratic or distortion signals owing to long lead length

## **Applications:**

1. As frequency modulator in RF oscillator
2. In capacitance microphone
3. Use the capacitance transducer in an ac bridge circuit

# Inductive Transducer

Inductive transducers may be either of the **self generating** or **passive type**. The **self generating type** utilises the **basic electrical generator principle**, i.e, a motion between a conductor and magnetic field induces a voltage in the conductor (generator action). This relative motion between the field and the conductor is supplied by changes in the measurand.

An **inductive electromechanical transducer** is a device that **converts physical motion (position change) into a change in inductance**. Transducers of **variable inductance** type work upon one of the following principles:

1. **Variation of self inductance**
2. **Variation of mutual inductance**

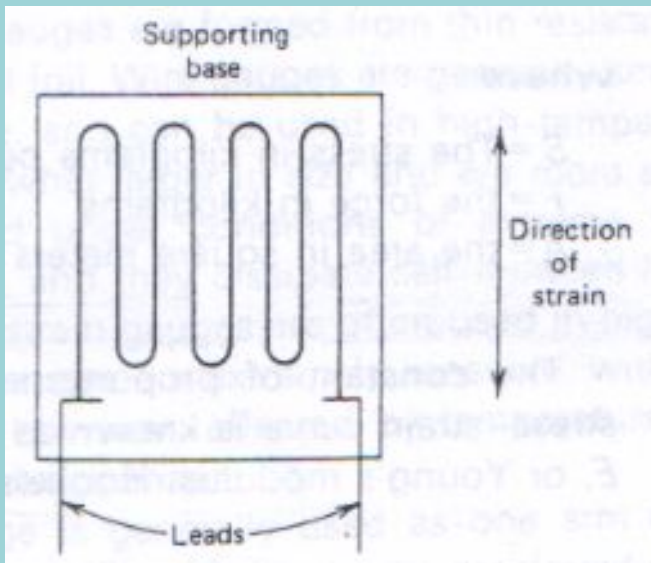
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Inductive transducers are mainly used for the **measurement of displacement**. The displacement to be measured is arranged to cause **variation** in any of three variables:

1. **Number of turns**
2. **Geometric configuration**
3. **Permeability of the magnetic material or magnetic circuits**

# Strain Gauge

The strain gauge is an example of a passive transducer that uses electric resistance variation in wires to sense the strain produced by a force on wires. It is a very versatile detector and transducer for measuring weight, pressure, mechanical force, or displacement.



The construction of a bonded strain gauge (see figure) shows a fine wire element looped back and forth on a mounting plate, which is usually cemented to the member undergoing stress. A tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area.

The combined effect is an increase in resistance:

$$R = \frac{\rho L}{A}$$

Where,

$\rho$ : the specific resistance of the conductor material in ohm meters

$L$  : length of conductor (meters)

$A$  : area of conductor ( $m^2$ )

As consequence of strain, 2 physical qualities are particular interest:

- 1) **The change in gauge resistance**
- 2) **The change in length**

The relationship between these two variables called gauge factor,  $K$ , is expressed mathematically as

$$K = \frac{\Delta R / R}{\Delta L / L}$$

Where

K= the gauge factor

R=the initial resistance in ohms (without strain)

$\Delta R$ = the change in initial resistance in ohms

L= the initial length in meters (without strain)

$\Delta L$ =the change in initial length in meters

$\Delta L/L$  same unit with G, therefore

$$K = \frac{\Delta R / R}{G}$$

From Hooke theory, stress,  $S$ , is defined as internal force/area.

$$S = \frac{F}{A}$$

Where

$S$ = the stress in kilograms per square meter

$F$ = the force in kilograms

$A$ = area in square meters

Then the modulus of elasticity of material  $E$  or called Young's modulus (Hooke's Law) is written as:

$$E = \frac{S}{G}$$

Where,

$E$ = Young modulus in kg per square meter

$S$ = the stress in kilograms per square meter

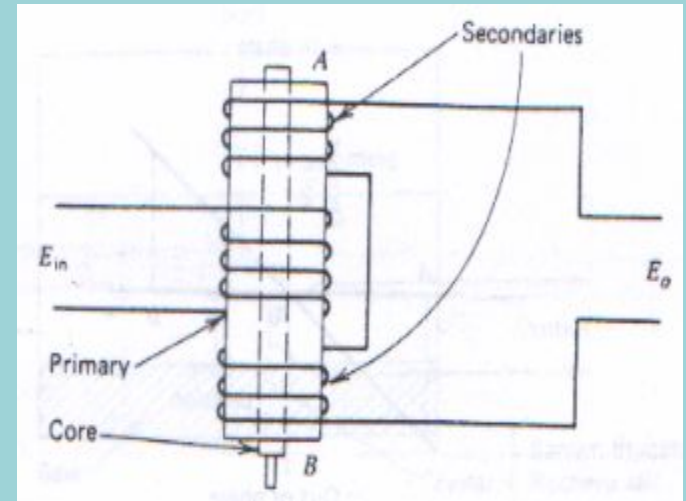
$G$ = the strain (no units)



- ❖ Metallic strain gauge – formed from thin resistance wire or etched from thin sheets of metal foil.
- ❖ Wire gauge (small) – to minimum leakage – for high T applications
- ❖ Semiconductor strain gauge – high output transducers as load cells
- ❖ Strain gauge is generally used as one arm of bridge

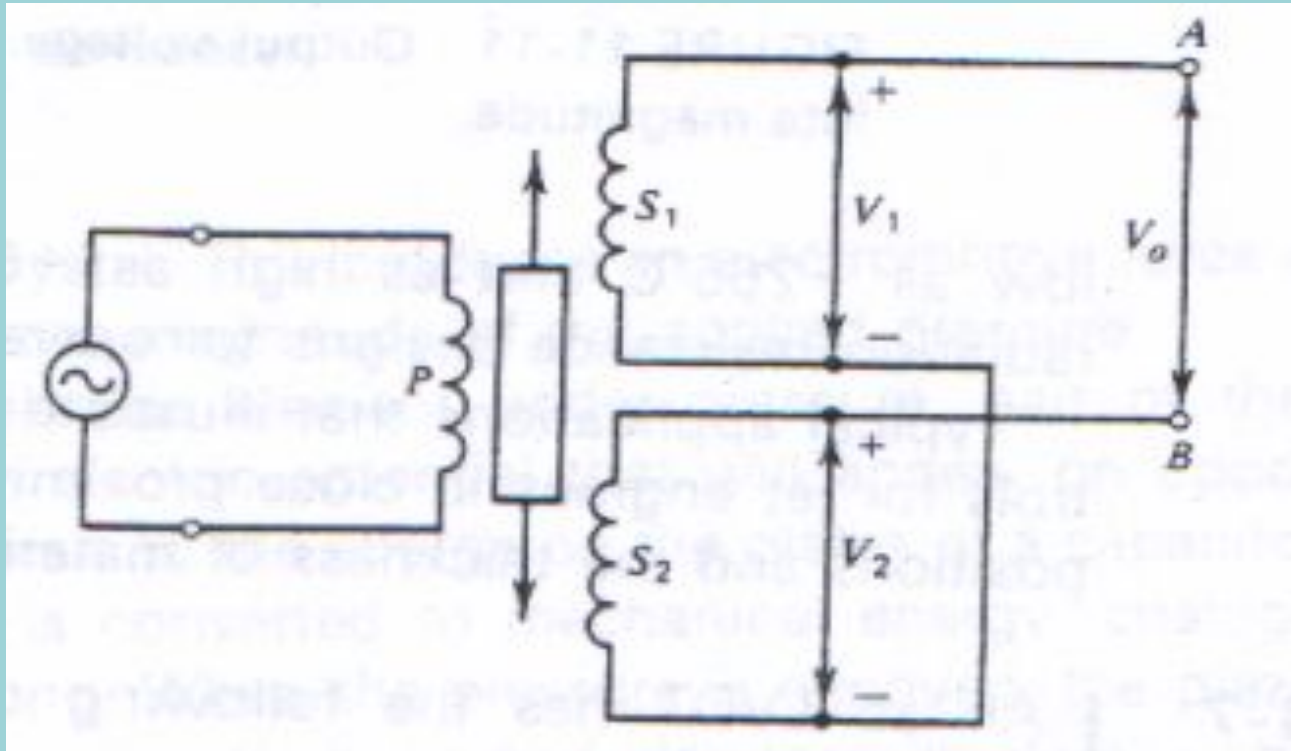
# LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

It consists basically of a **primary winding** and **two secondary windings**, wound over a hollow tube and positioned so the **primary winding is between two secondaries**. In figure shows the construction of the LVDT.

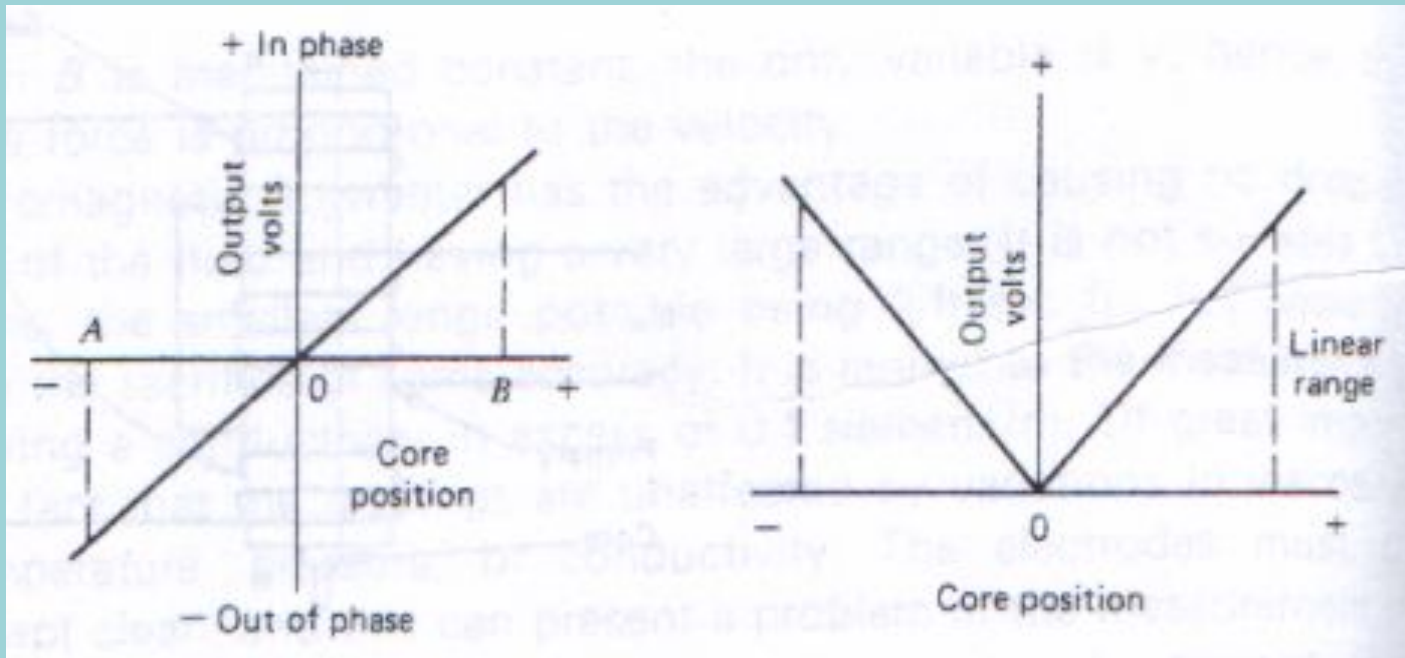


An **iron core slides** within the tube and therefore **affects the magnet coupling between the primary and the two secondaries**. When the core is in the centre, voltage induced in the two secondaries is equal. When the core is moved in one direction from centre, the voltage induced in one winding is increased and that in the other is decreased. Movement in the opposite direction reverses this effect

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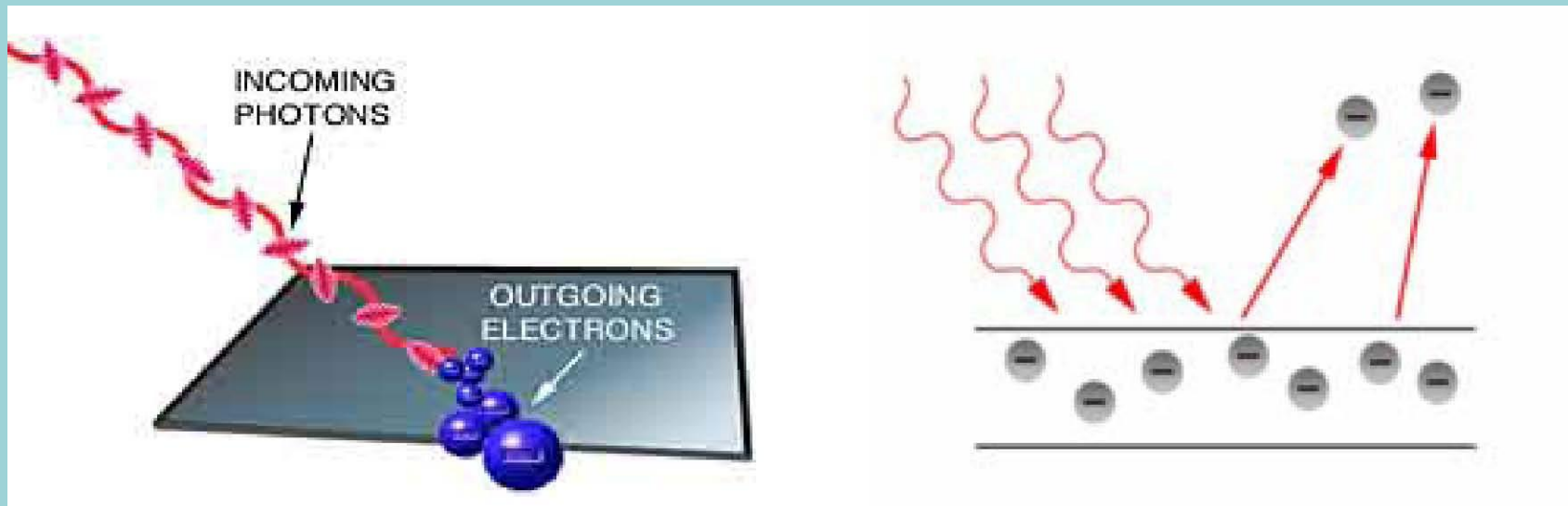


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# • What's Photoelectric Effect?

*-is the emission of electrons from matter upon the absorption of electromagnetic radiation, such as ultraviolet radiation or x-rays.-refers to the emission, or ejection, of electrons from the surface of, generally, a metal in response to incident light.*



# Photoelectric Transducer

Can be categorized as: photoemissive, photoconductive, or photovoltaic.

No.	Types	Characteristics
1.	Photoemissive	radiation falling into a cathode causes electrons to be emitted from cathode surface.
2.	Photoconductive	the resistance of a material is change when it's illuminated.
3.	Photovoltaic	Generate an output voltage proportional to radiation intensity

- **Examples of Photoelectric Transducer**
- (i) The Photomultiplier Tube
- (ii) Photoconductive Cells OR Photocells  
the electrical resistance of the materials varies with the amount of light striking.
- (iii) The Photovoltaic Cell or solar cell  
- produce an electrical current when connected to the load.