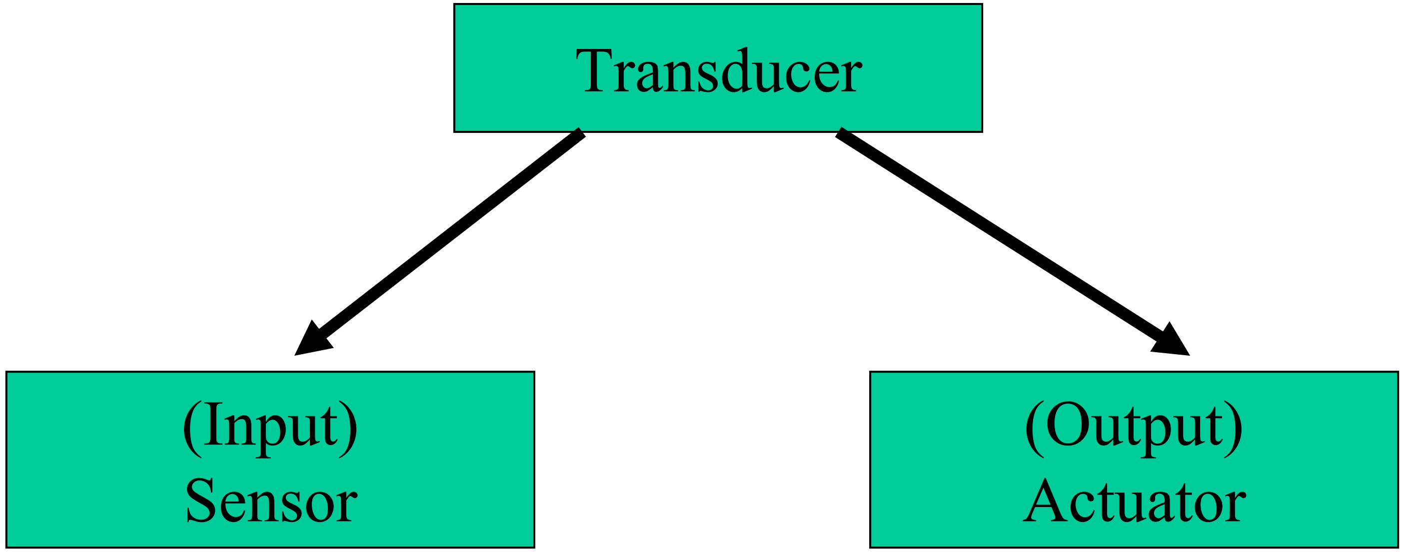
Transducer

A device to which change or converts physical quantity in a more easily measurable quantity



Sensor

A device which senses and detects the physical quantity of measurand and converts to electrical form.

Example of sensors:

Mechanical	: Bourdon tube pressure meter.
Electrical	: Potentiometer
Optical	: Photon counter
Chemical	: Thermocouples

*All sensors are transducers but not all transducers are sensors

Actuator

A device that senses and detects the electrical quantity and converts to physical form.

Example of actuator:

- Valve in heat exchanger system
- Motor speed control where the motor is driving the conveyor belt
- Magnetic relays that turn on/off of the fans
- Compressor in a control air conditioning

Transducer Basic Requirement

- Ruggedness
- Linearity
- Repeatability
- High Signal to Noise Ratio
- High stability and reliability

Transducers

- Transducer- is a device which converts the quantity being measured into an optical , mechanical or electrical signal . The energy conversion process is referred to as transduction.
- Transducers are of fundamental importance. Any application that is not
- purely electronic in nature (i.e. EVERY application) must rely on a transducer
- at some point.
- Transducer elements – most transducers consist of a sensing element and a conversion or control element .
- The relationship between the measurand and transducer output signal is usually obtained by calibration test

Variable Conversion Element

A device that converts analogue signals to digital form or vice versa.

Example of converters:

ADC -- Analogue to digital converter

DAC -- Digital to analogue converter

Transducer

- There are two further distinctions that can be made with regards to transducers:
- Passive Transducers operate without the need for an external power source
- (that is: additionally to the power being converted.)
- Active transducers must draw power from an external power source in order to work.

Transducer

- Resistance transducers
- Resistance strain gauge
- Resistance temperature transducer
- Photo-emisive cell
- Capacitive transducer
- Inductive transducer
- Linear variable differential transformer
- Piezos-electric transducer
- Electromagnetic transducers
- thermoelectric transducer
- Photoelectric cell

Electrical transducers –

- exhibit many of the ideal characteristics
- high sensitivity and useful for remote sensing.

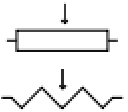
Can be classified into

- Variable- control – parameter types, which relies on an external excitation voltage e.g resistance, capacitance .
- Self generating types, which produces an output voltage in response to the measurand input and their effects are reversible e.g electromagnetic , thermoelectric ,piezoelectric.

Resistance transducers

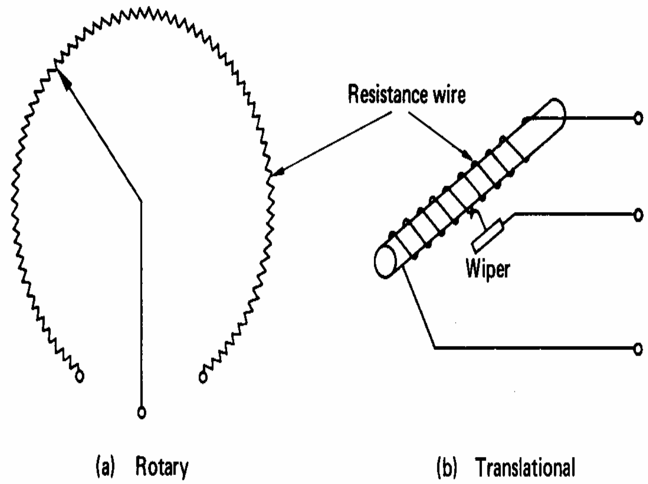
Potentiometers – the excitation voltage maybe ac or dc and output voltage is proportional to the input motion .

- The wiper displacement can be rotary ,translational or both. **Eectrical device which has a user-adjustable resistance. Usually, this is a three-terminal resistor with a sliding contact in the center (the wiper).**
- **If all three terminals are used, it can act as a variable voltage divider.**
- **If only two terminals are used (one side and the wiper), it acts as a variable resistor.**
- **Such potentiometers suffer from the linked problems of resolution and electrical noise**
-

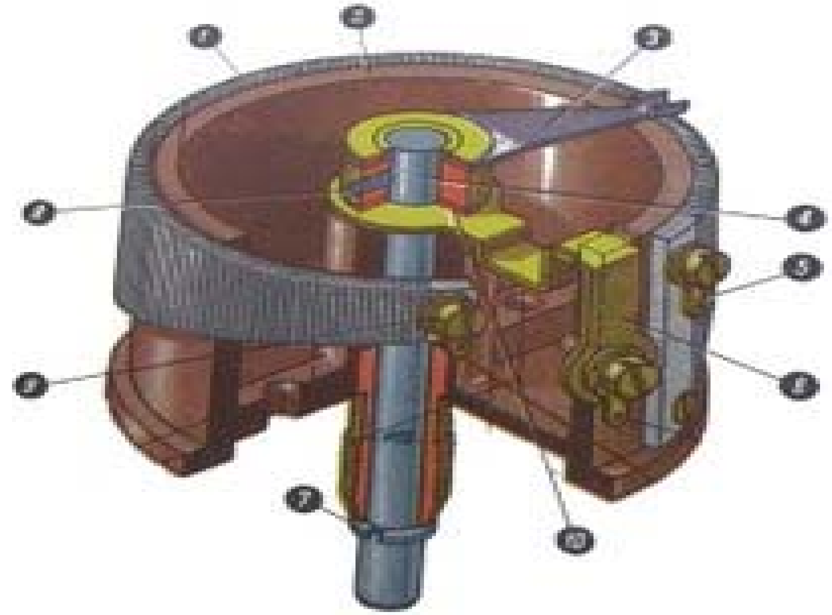


Schematic symbol for a potentiometer. The arrow represents the moving terminal, called the *wiper*.

Potentiometer



Construction principles of resistance potentiometers



•Construction of a wire-wound circular potentiometer. The resistive element (1) of the shown device is trapezoidal, giving a non-linear relationship between resistance and turn angle. The wiper (3) rotates with the axis (4), providing the changeable resistance between the wiper contact (6) and the fixed contacts (5) and (9). The vertical position of the axis is fixed in the body (2) with the ring (7) (below) and the bolt (8) (above).

Potentiometer

The output voltage v_0 of the unloaded potentiometer circuit shown is determined as follows .

Let

$$R_1 = \frac{x_i}{x_T} R_T$$

where x_i = input displacement

x_T = maximum possible displacement

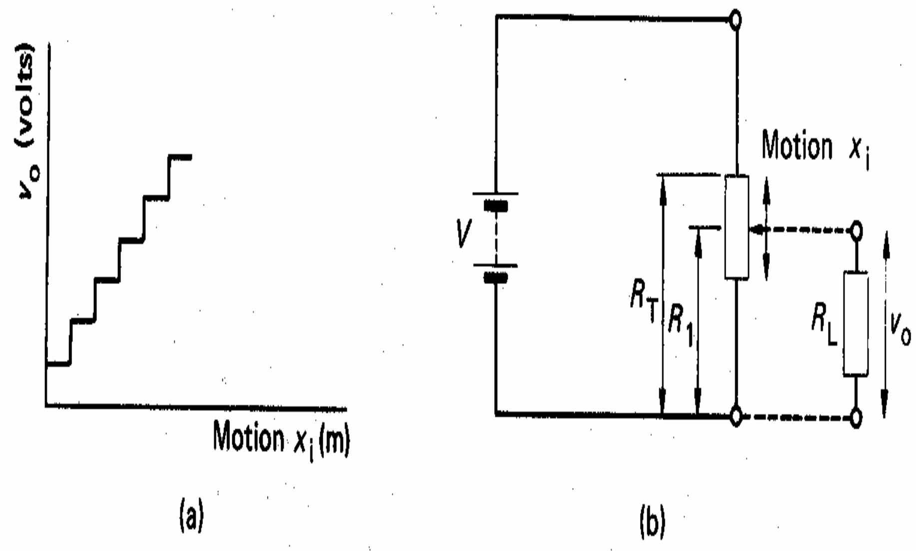
R_T = total resistance of the potentiometer

Then output voltage v_o =

$$V \times \frac{R_1}{R_1 + (R_T - R_1)} = V \frac{R_1}{R_T} = V \frac{x_i}{x_T} x \frac{R_T}{R_T} = V \frac{x_i}{x_T}$$

Maximum value of V is $V = \sqrt{P R_T}$

where P = maximum power dissipation



Resolution effects and circuit diagram of resistance potentiometer

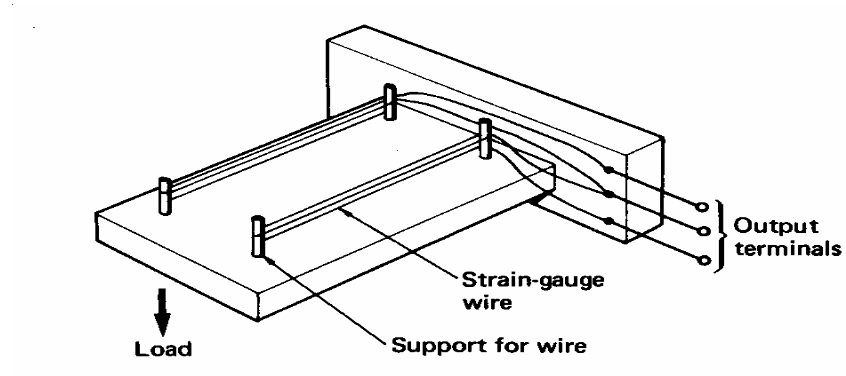
b) Resistance strain gauges

- Resistance strain gauges are transducers which exhibit a change in electrical resistance in response to mechanical strain.

Classified into

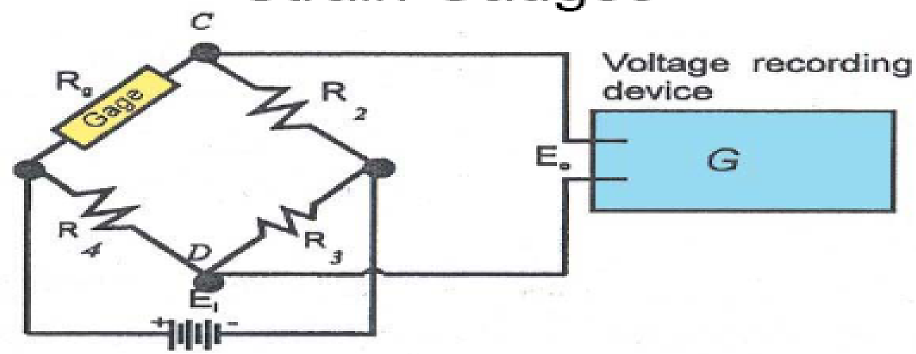
- i) Bonded
- ii) Unbonded

Strain rosettes are used to measure strain at different direction simultaneously



Unbonded strain gauge

Strain Gauges



- The Wheatstone bridge

c) Resistance Temperature Transducers (RTD)

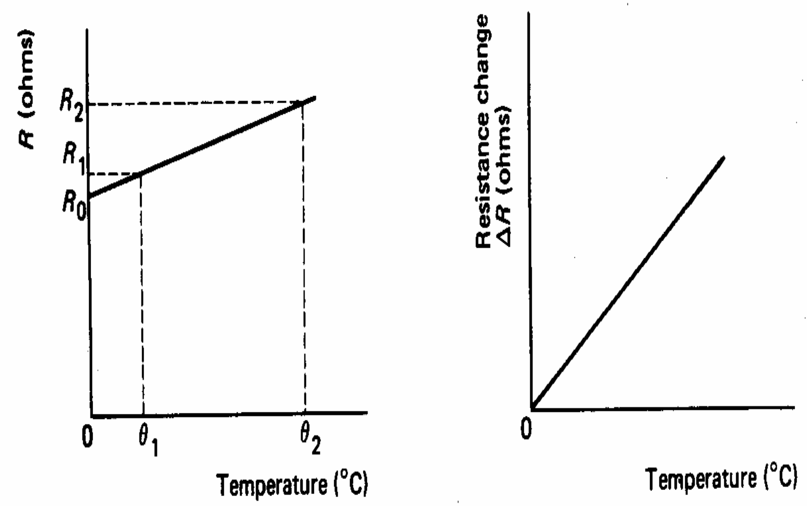
- Metals such as platinum copper ,tungsten exhibits small increase in resistance as the temperature rise.
- Positive temperature coefficient of Resistance depend upon the relationship:

$R1=Ro[1+ \alpha (\theta 1 - \theta o)]$

where

α = temperature coefficient of resistance in °C -1

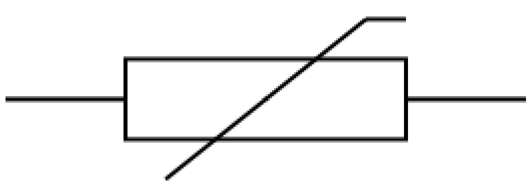
Ro= resistance in ohms at the reference temperature $\theta o = 0$ °C

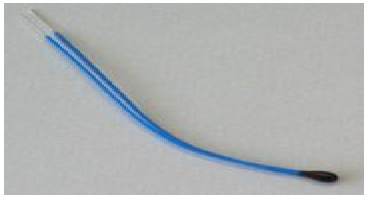


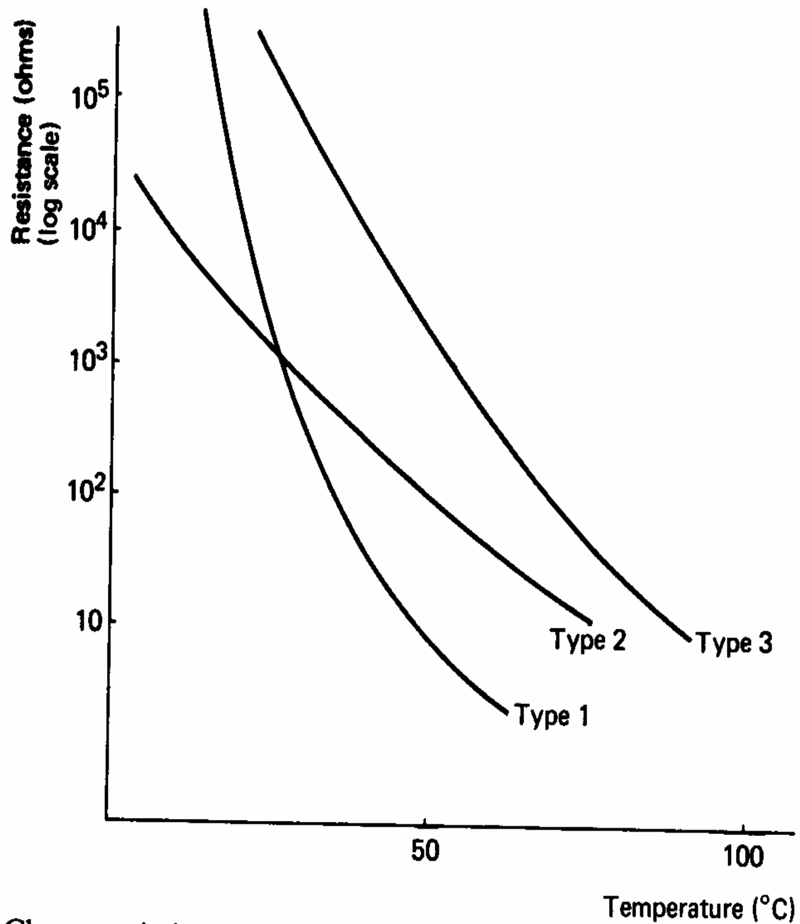
Characteristics of a platinum resistance thermometer

Semiconductors - thermistors

- A **thermistor** is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature
- Semicondictor such as thermistors which use oxides of manganese, chromium, nickel exhibits large non linear resistance changes with temperature variations.
- Negative temperature coefficient of resistance. Normally made in the form of discs or small (1mm) beads.



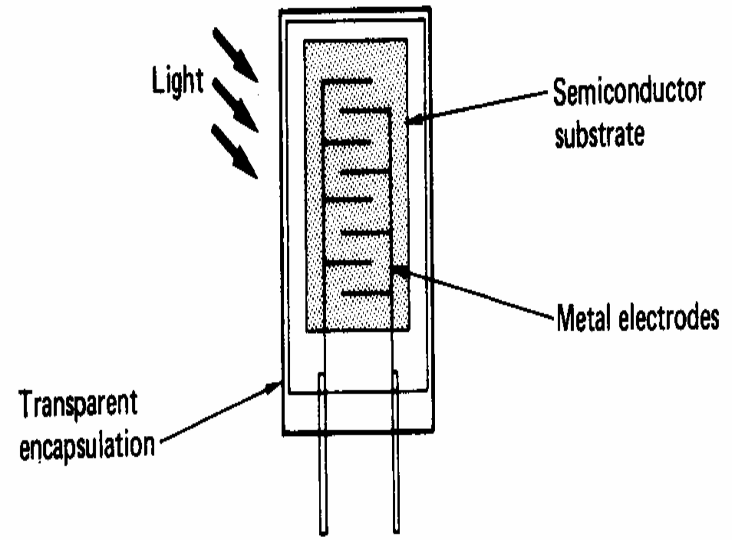




Characteristics of thermistors

d) Photoconductive cells

- Uses light sensitive semiconductors material e .g. cadmium sulphide, lead sulphide , copper doped germanium.
- When these semiconductor materials are exposed to light, their electrical conductivity is increased.
- The resistance between the metal electrodes decreases as the intensity of the light increases

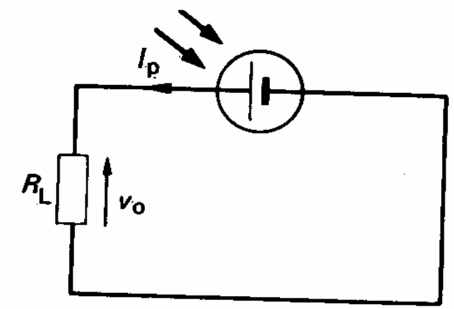


Photoconductive cell

Photoemissive cells

- When light strikes the cathode of the photo emissive cell

- Electrons are given sufficient ener to leave the cathode. The positive anode attract these electrons, produci current Ip through a resistance RL ai producing output voltage ,



Photoemissive cell

vo = IpRL .

Also Ip=Kt φ ,

Kt=sensitivity (A/lm) , φ = illumination input (lumen)

$C = \varepsilon_o \, \varepsilon_r \frac{A}{d}$ farads

f) Capacitive transducers

- The capacitance of a parallel plate capacitor is given by

$$C = \varepsilon_o \, \varepsilon_r \frac{A}{d} \text{ farads}$$

where

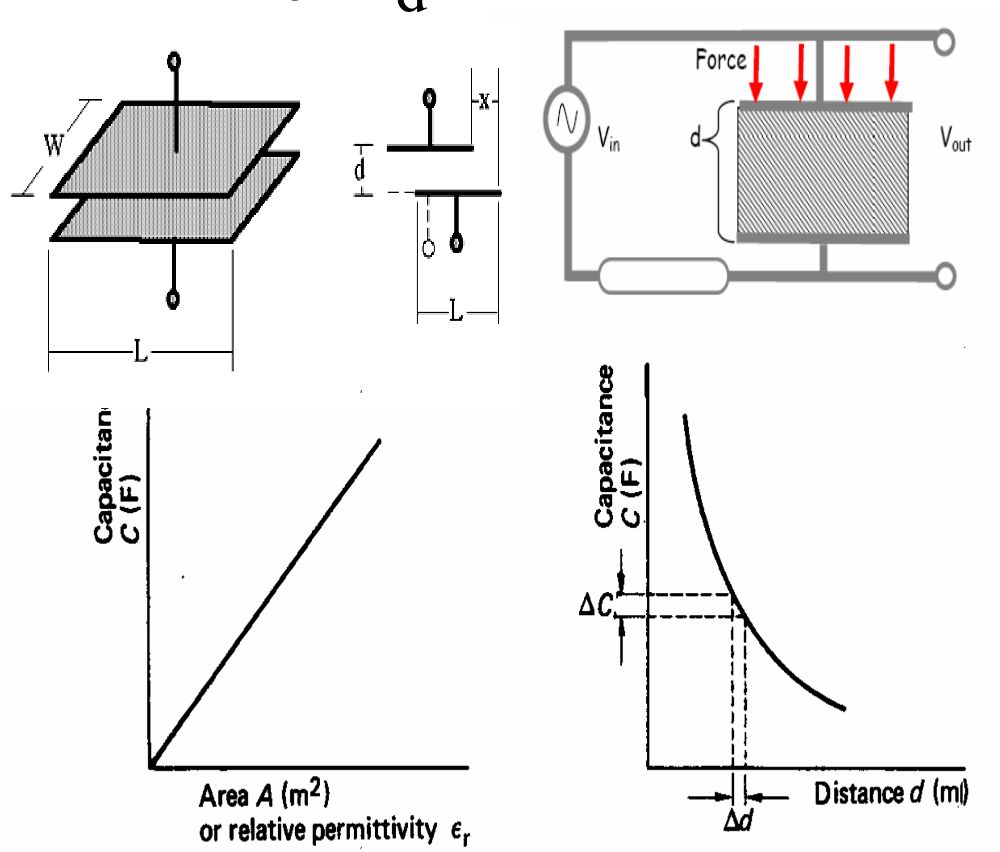
ε0 = permittivity of free space = 8.854 X 10-12 F/m

εr = relative permittivity of the material between the plates

A = overlapping or effective area between plates (m2)

d = distance between plates (m)

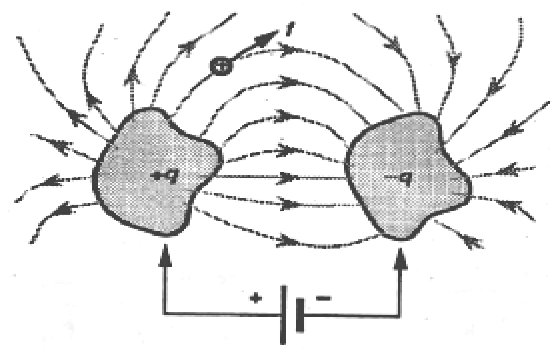
- The capacitance can thus be varied by changing either εr , A or d.

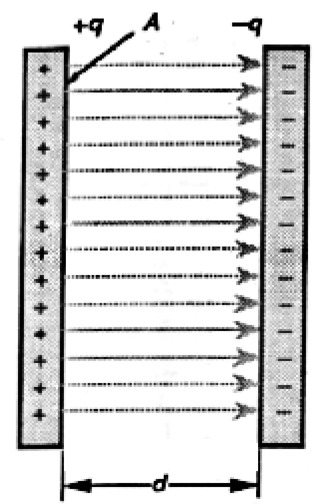


Characteristics of capacitive transducers

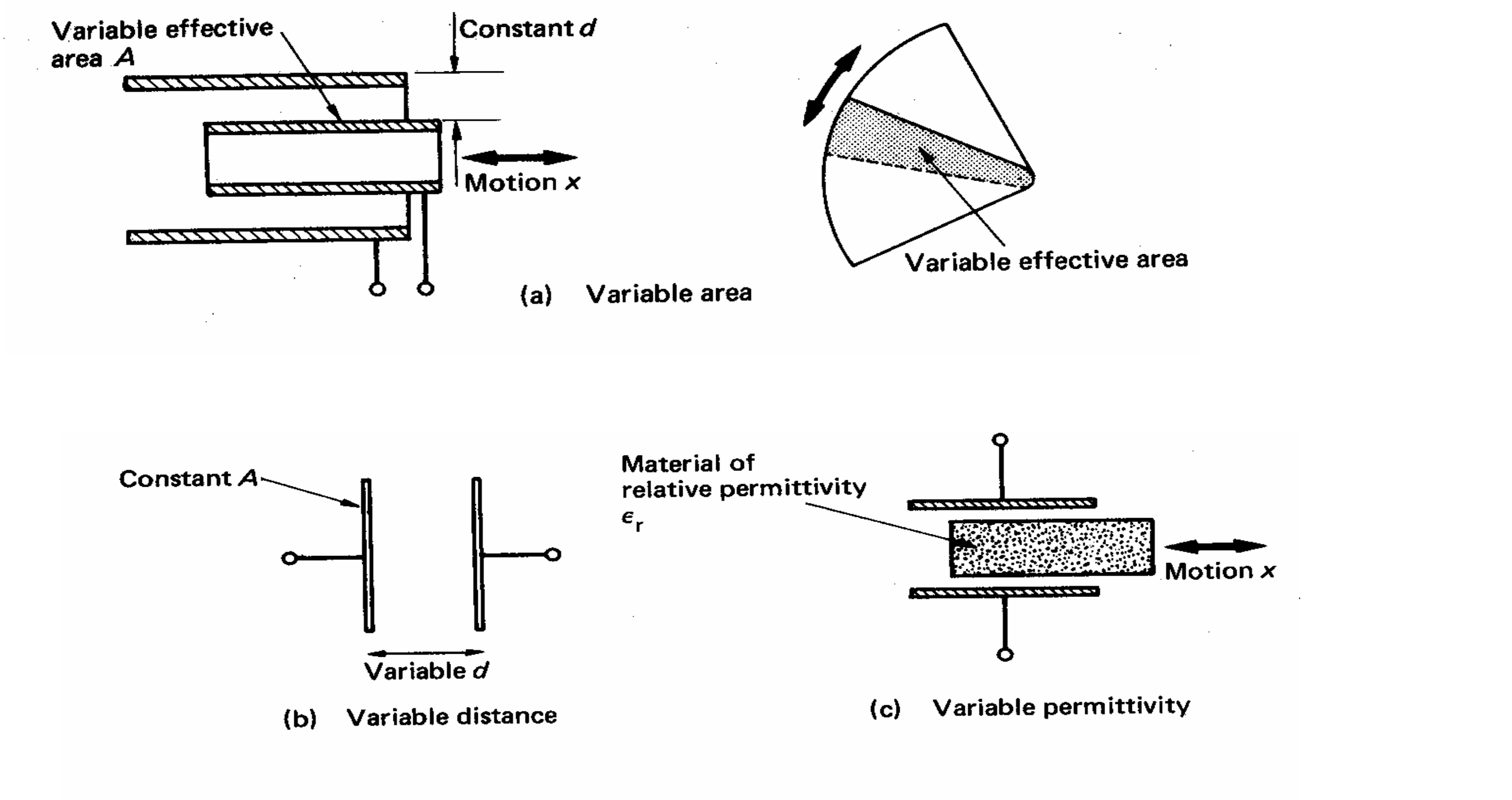
Capacitive transducers

- First, what is capacitance? Any two metallic objects, positioned in space, can have voltage applied between them .
- Depending on their separation and orientation, the amount of charge that must be applied to the two elements to establish a certain voltage level varies.
- The capacitance is defined as the ratio of the charge to the voltage for a given physical situation. If the capacitance is large, more charge is needed to establish a given voltage difference.





Example of capacitive transducer



(a) Variable area
(b) Variable distance
(c) Variable permittivity

Example of capacitive transducer

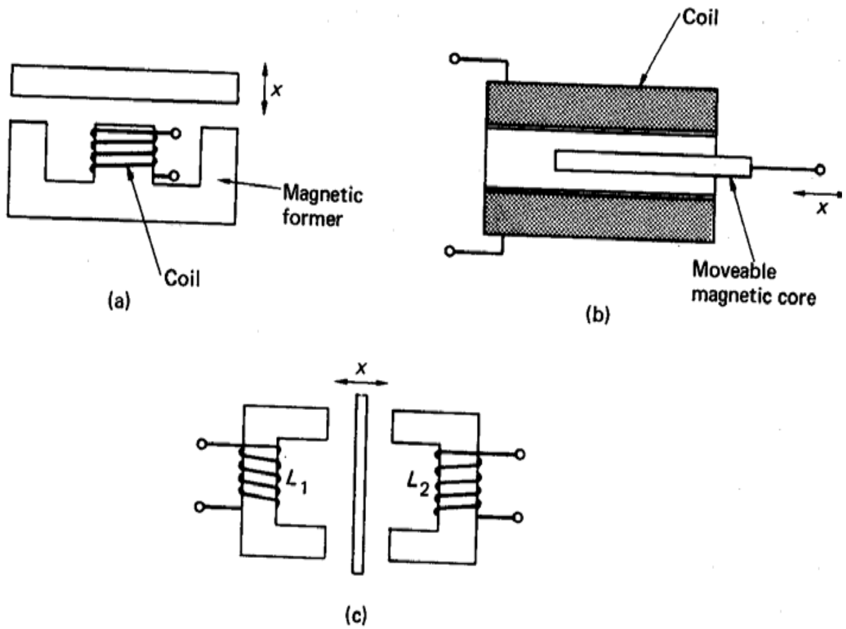
- Variable distance capacitive transducers has an infinite resolution, making it most suitable for measuring small increments of displacement.

Important features of capacitive transducers

- Resolution infinite
- Accuracy $\pm$ 0.1 % of full scale
- Displacement ranges 25 x10-6 m to 10 x10-3 m
- Rise time less than 50 μs

g) Inductive transducers

- **Characteristics of inductive**



Inductive transducers – The inductance of a coil wound a magnetic circuit is given by

$$L = \frac{\mu_o \mu_r N^2 A}{l}$$

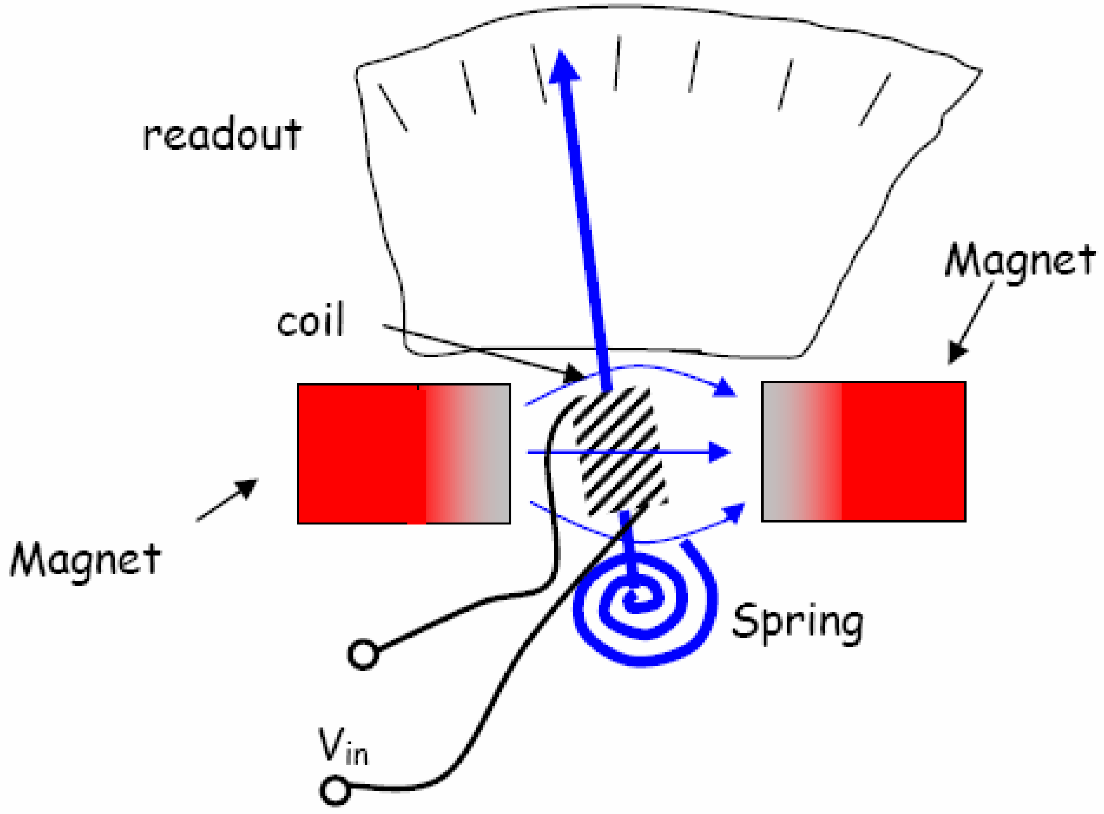
where
μo = permeability of free space =4 x 10-7 H/m
μr = relative permeability
N = number of turns of coil l = length of magnetic circuit (m)
A = cross sectional area of magnetic circuit (m2)

This can be written as

$$L = \frac{N^2}{S}$$

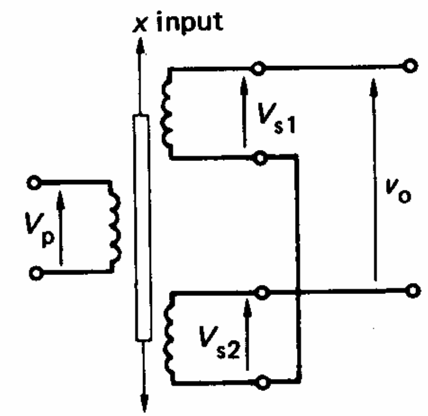
Where S = l /($\mu_o \mu_r$A) = magnetic reluctance of the inductive circuit

Inductive transducers

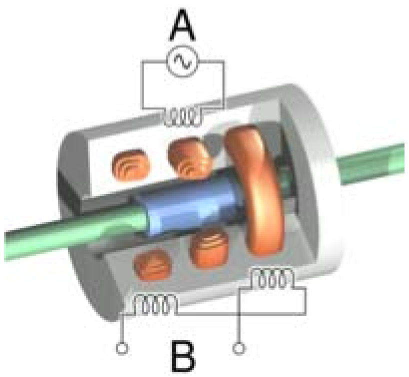


h) Linear Variable-Differential Transformer – LVDT

- Consist of a primary coil , two secondary coil and a movable magnetic core.
- When excitation voltage Vp is applied to the primary winding, due to transformer action
- voltages Vs1 and Vs2 are induced in the primary coils.



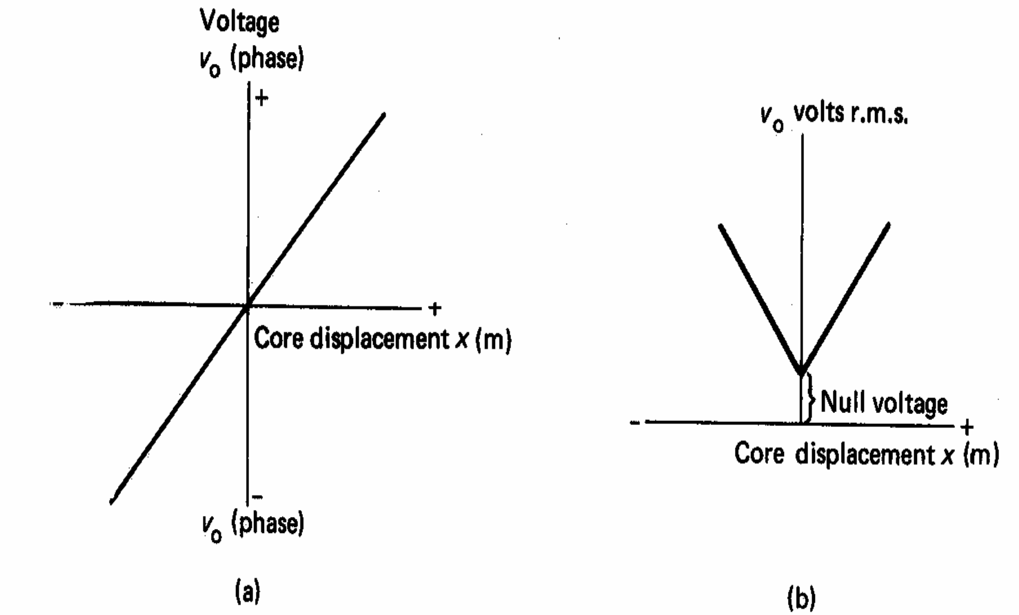
Details of an l.v.d.t.



Cutaway view of an LVDT. Current is driven through the primary coil at *A*, causing an induction current to be generated through the secondary coils at *B*.

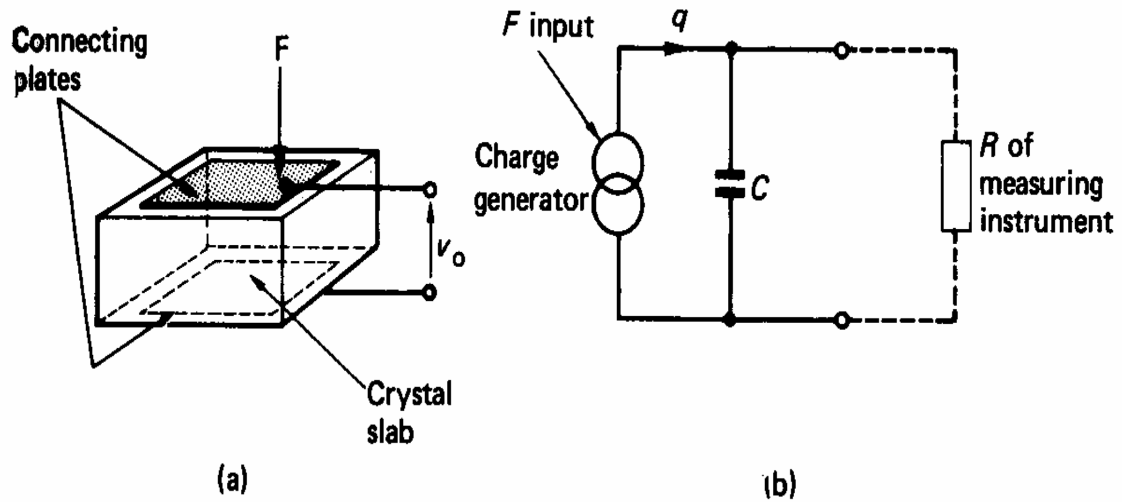
LVDT

- The amplitudes of these secondary voltages are dependent on the core displacement x



i) Piezo-electric transducers

- **Piezoelectricity** is the ability of crystals and certain ceramic materials to generate a voltage in response to applied mechanical stress.



Piezo-electric transducer

- When a force is applied across the faces of certain crystal materials- electrical charges (proportional to the applied force) of opposite polarity appear on the faces .
- These transducers are made from natural crystals such as quartz ,Rochelle salt, Lithium sulphate or barium titanate.
- To enhance the response of the transducer charge amplifier is normally used.

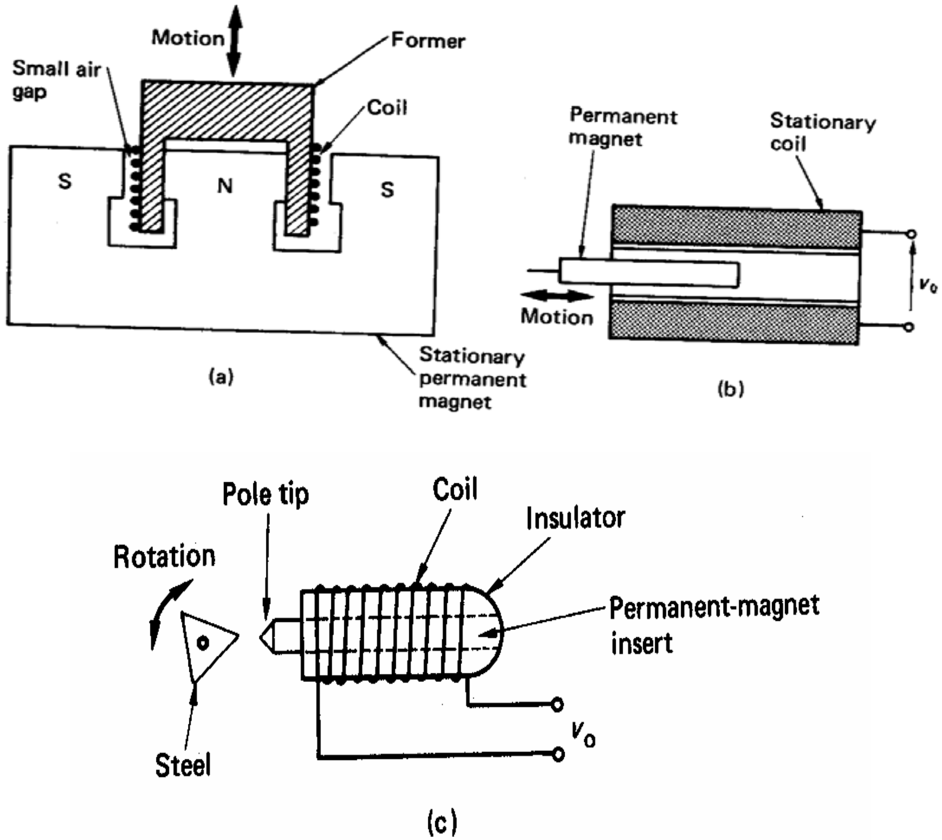
J) Electromagnetic transducers

- Employs the generator principle of a coil moving in a magnetic field. The output voltage of the transducer is given
- as follows . Widely used as velocity transducers.

Output voltage $v_o = -N\frac{d\varphi}{dt}$

N = number of turns on coil

$\frac{d\varphi}{dt}$ = rate of flux changes (Wb/s)



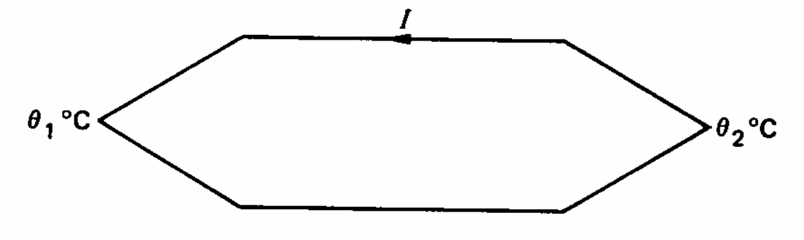
For the single conductor moving in a magnetic field,

Output voltage v0 = Blv

B = flux density (T), l = length of conductor (m), v = velocity of conductor perpendicular to flux direction (m/s)

k) Thermoelectric transducers(thermocouple)

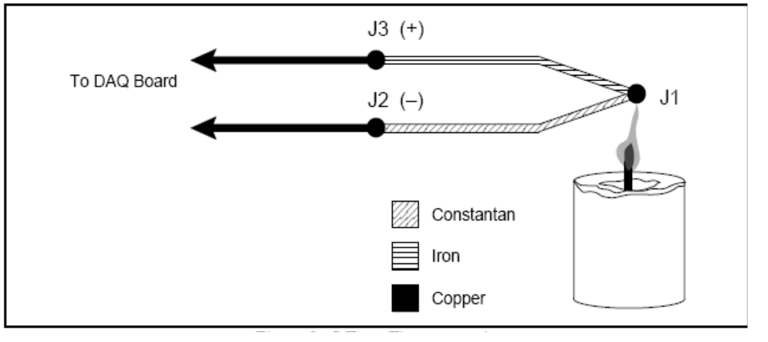
- When two dissimilar metals or alloys are joined together at each end to form a thermocouple and the ends are at different temperatures, an emf will be developed causing a current to flow around the circuit



Thermocouple circuit

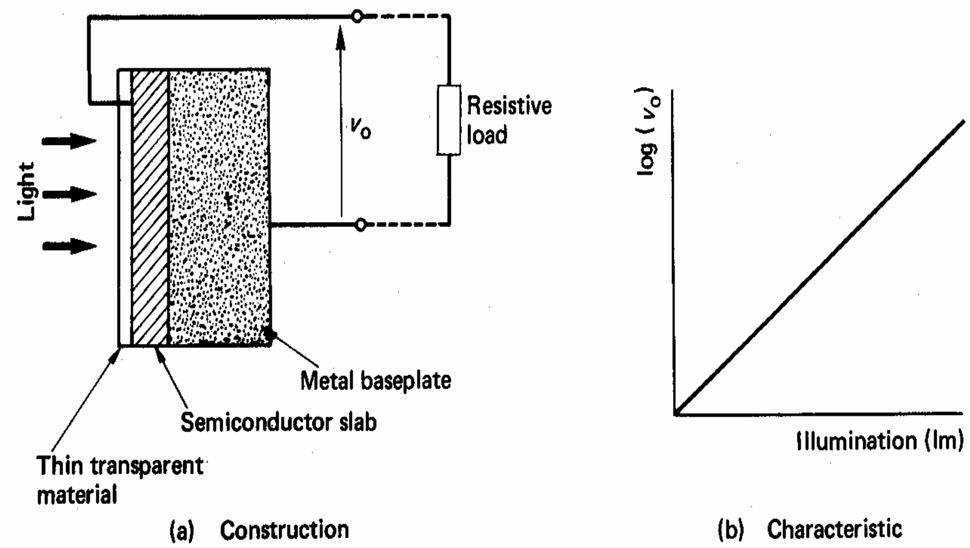
- The emf is proportional to the temperature gradien

- This is called Seebeck effect This transducers has operating range from –250 °C- 2600 °C .



l) Photoelectric cells

- Make use of the voltaic effect ,which is the production of the emf by light energy ,incident on the junction of two dissimilar materials.
- The transducer is highly sensitive ,good frequency response and can be used for wide range of light intensities.



Photoelectric cell

Mechanical transducers

- **Mechanical transducers –** convert measurand into mechanical parameters eg displacement, pressure or force. Often used in cascade with electrical transducers.

a) Force- to- displacement transducers

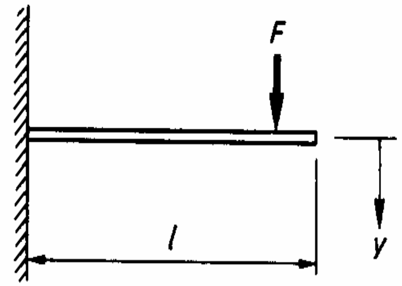
Spring – is the simplest form of mechanical transducer

$F = \lambda x$

λ = spring siffness (N/m) and sensitivity = i.e the stiffer the spring the smaller the sensitivity .

- Cantilever – the deflection, y caused by force F, is **$y = k F$**

k = a constant depending on the material and dimensions of the cantilever .



Cantilever

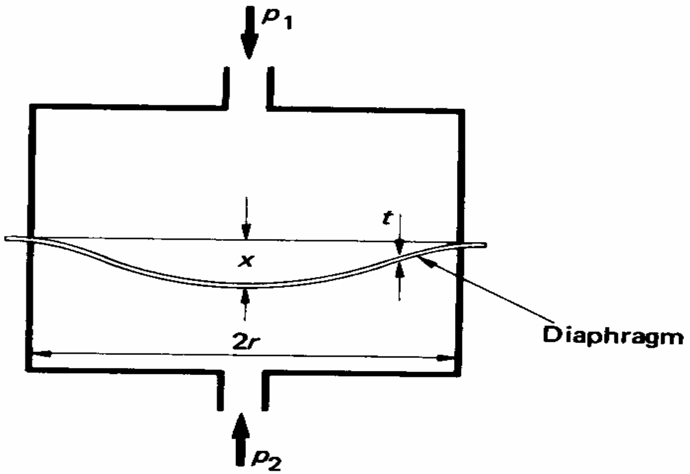
Mechanical transducers

b) Pressure- to- displacement transducers

i) Diaphragms-displacement, x is proportional to the pressure difference.

$$\mathbf{x = k\,(p1 - p2)}$$

; k depend on material and dimensions.

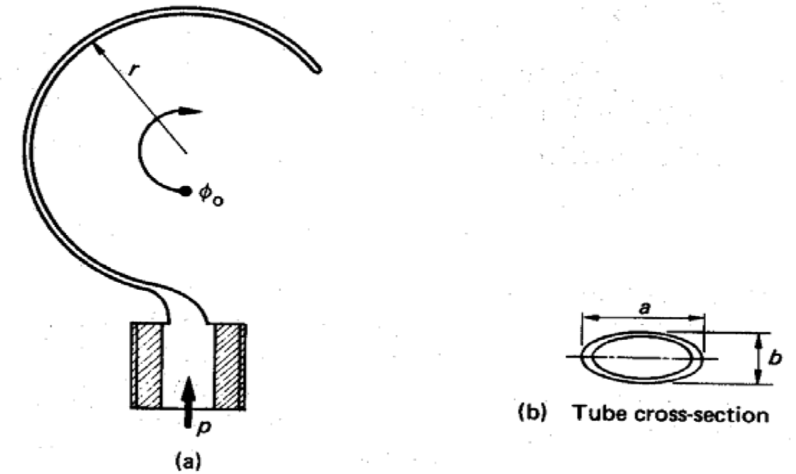


Diaphragm

Mechanical transducers

ii) Bourdon tubes – widely used in pressure gauges. The relationship between pressure, p and deflection ϕ is ;

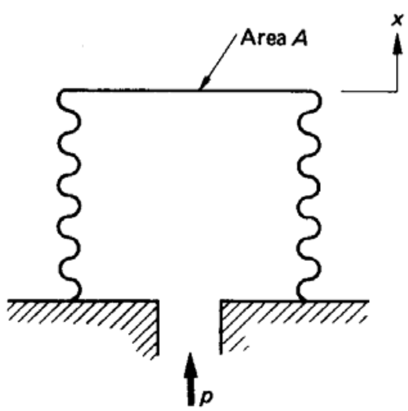
- $\boldsymbol{\phi = k\,p}$



Bourdon tube

Mechanical transducers

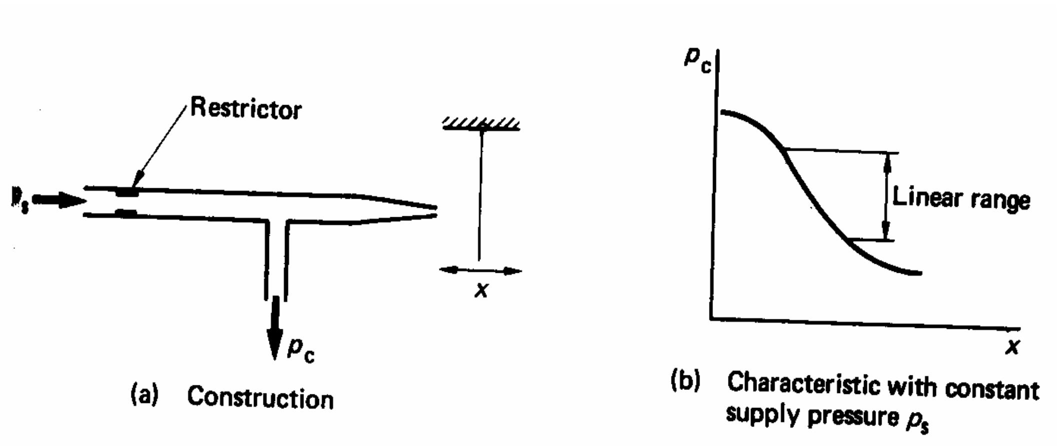
iii) Bellows – also known as pneumatic spring .The relationship between defection, x, Area A and stiffness λ is given by ;



Bellows

Mechanical transducers

- **c) Displacement –to –pressure transducers – Fapper –Nozzle**



- Control pressure pc varies with flapper movement, x if supply pressure p is constant