UNIT-2

1: Measurement of temperature Using:
(Thermistor, Thermocouple, RTD)

2: IR Detector: (Concept of thermal Imaging)

3: Measurement of position Using:
(Hall effect, Proximity sensor (Inductive & Capacitive))

4: Use of proximity sensor as:
(Accelerometer & Vibration sensor)

5: Flow sensor Using: (Ultrasonic & laser)

6: Level Sensor Using: (ultrasonic & capacitive)

1: Measurement of temperature:

The measurement of temperature has been playing a critical role in various application areas such as industry, military, spacecraft etc. There are large number of temperature sensors available in the market.

Any temperature dependent effect of materials or device (Ex. pressure, volume, Length, ~~temp~~, Resistance, Electromotive force, Intensity or radiation) can be used for measurement of temperature.

Some of the most commonly used temp

Sensors are classified as below.

(a) Liquid & gas thermometer
(b) Bimetallic strip
(c) Resistance thermometer (RTD, Thermistor)
(d) Thermocouple
(e) Junction semiconductor sensor.
(f) Radiation pyrometer.

1.1: Resistance Thermometer:

Conductor
- Temp ↑ ⇒ resistance ↓ (NTC)
- Temp ↑ ⇒ resistance ↑ (PTC)

Resistance Thermometer employing metallic conductor for temperature measurement are called Resistance temperature detector (RTD). and those employing semiconductors are called Thermistor.

1.1.1: RTD (Resistance Temperature Detector)

Based on the principle that a metalic resistance element changes its resistance with temperature in a very specific manner. Pure metal such as platinum, copper, nickel and alloy of different metals are used as resistance elements, depending upon the temperature range, sensitivity, linearity of the sensor.

$$R_t = R_0(1+\alpha_1(t-t_0)+\alpha_2(t-t_0)^2 \quad \text{——— (1)}$$

Where, R_t and R_o value at t°_c and $t_o{}^\circ c$ respectively.

α_1 and α_2 ... α_n = Constt.

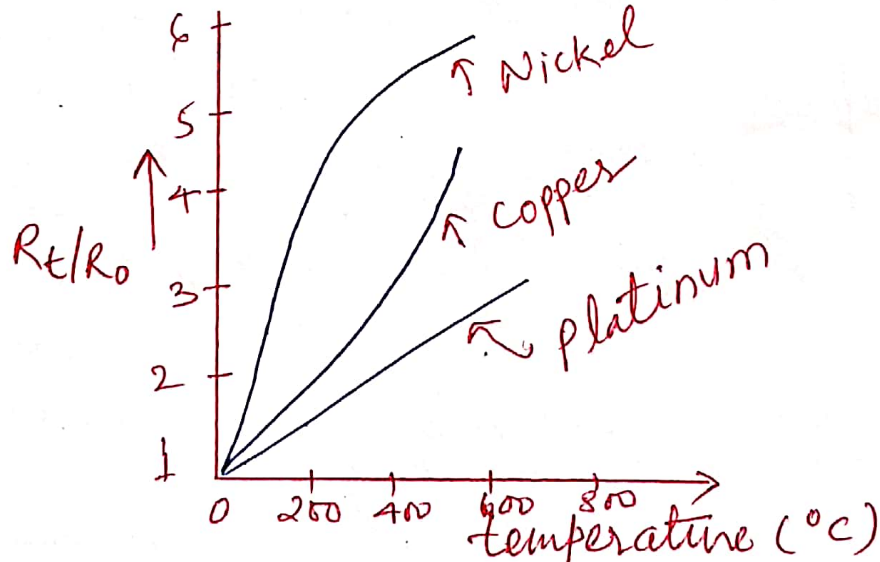
for small range of temp, the expression can be approximated as

$$R_t = R_0 (1+\alpha_1 (t-t_0)) \quad \text{—— (2)}$$

Copper, Nickel and platinum are mostly used as RTD materials.

The range of measurement is decided by the region, where the resistance-temperature characteristics are approximately linear.

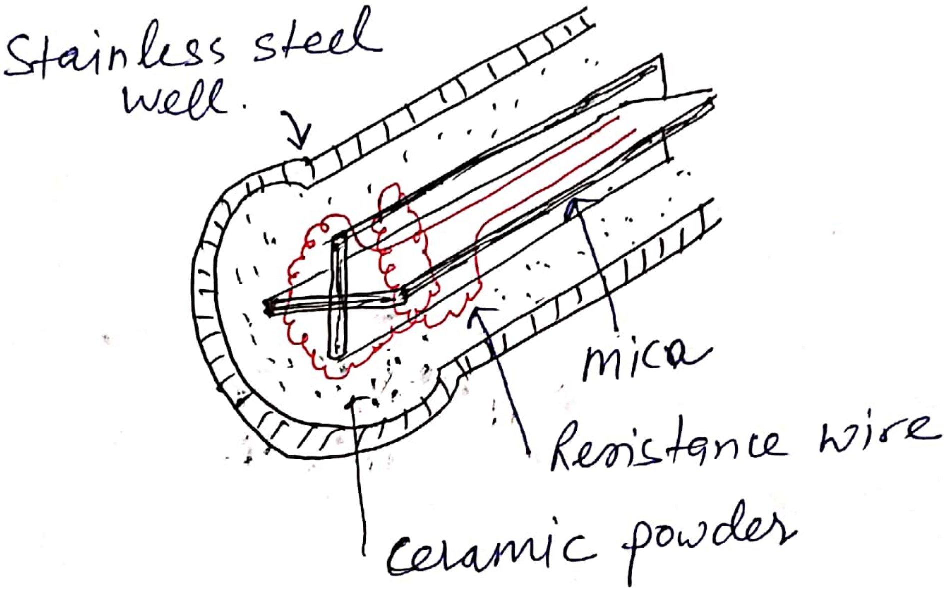
The resistance versus temperature characteristics of these material is shown in fig.



(Fig: Resistance-temperature characteristics of metal)

<u>Construction</u> :-

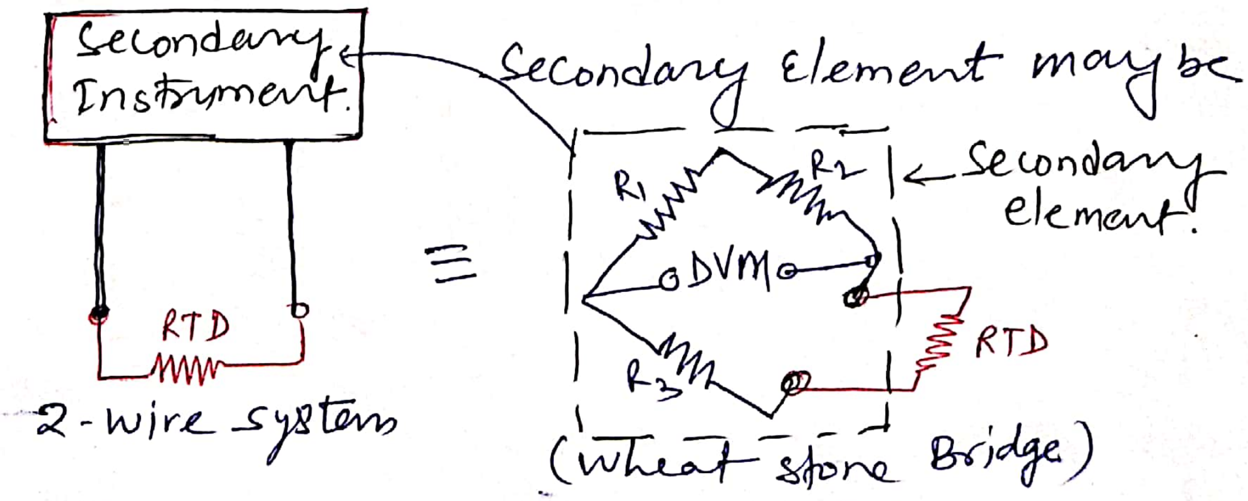
For industrial use, bare metal wires cannot be used for temperature measurement. They must have to be protected from mechanical hazards such as material decomposition, tearing and other physical damages.



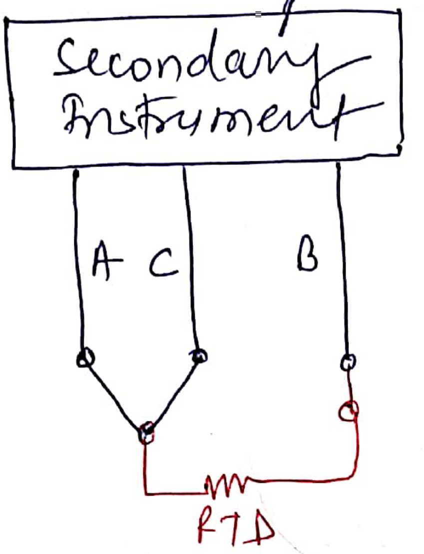
(Fig: construction of RTD)

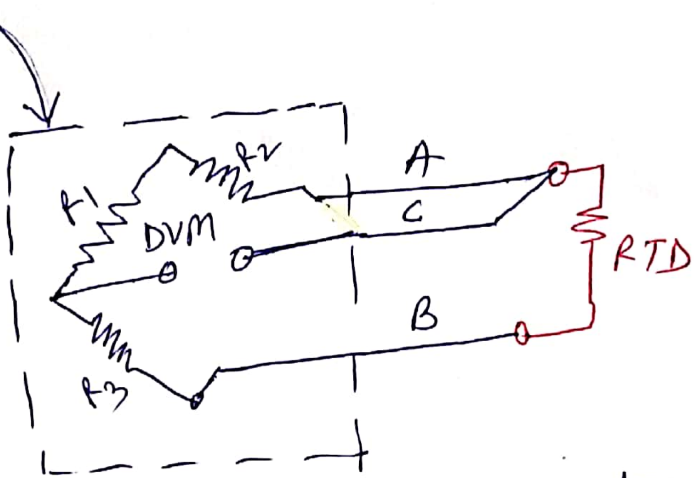
Resistance Temperature Detector (RTD) - 2 wire, 3 wire & 4 wire System :-

The various wiring arrangements are designed to reduce and/or eliminate any errors introduced due to resistance changes of lead wire when they also go through temperature changes.



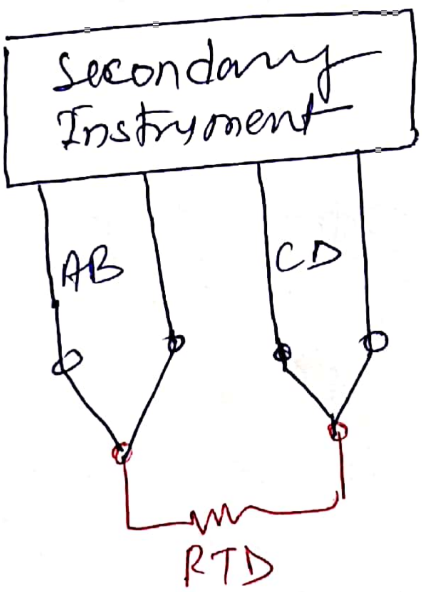
Similarly,

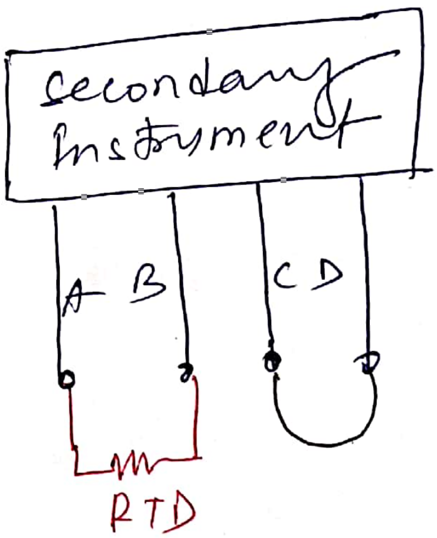




Secondary Instrument
(Wheatstone Bridge)

(3-wire system)





(4 wire system having Paired lead wire)

(4 wire system having compensating loop)

Requirement of conductor material to be used in RTD :

✓ Change in resistance of material per unit change in temperature should be large as possible.

✓ high value of resistivity to minimise the volume

✓ Resistance of material should have continous and stable relationship with temperature.

Application of RTD:

✓ RTD sensor is used in automotive to measure the engine temperature, an oil level sensor, intake air temperature sensor.

✓ In communication and instrumentation for sensing the over the temperature of amplifiers, transistor gain stabilizers etc.

✓ RTD is used in power electronics, computer, consumer electronics, food handeling and processing, industrial electronics, medical electronics, military and aerospace.

Advantages of RTD:

✓ Very stable output

✓ Linearity is higher compare to thermocouple.

✓ High accuracy

✓ Stability maintained over long period of time

✓ No necessity of temperature compensation.

Disadvantages of RTD:

✓ Slower response time than a thermocouple

✓ Self heating posibility

✓ Sensitivity is low

✓ price is high.

1.12 : Thermistor :

Thermistor is semiconductor type resistance thermometers. They have high sensitivity but highly nonlinear characteristics.

Ex. Thermistor → 1°C rise in temp, 5% ↑ in resistance

(Typical Thermistor 2000 Ω) → at 25°C → change in resistance is 80Ω/°C

(For platinum RTD 2000 Ω) → at 25°C → change in resistance is 7Ω/°C.

Thermistor can be of two types:

- ✓ Negative temperature co-efficient (NTC) thermistor
- ✓ positive temperature co-efficient (PTC) thermistor.

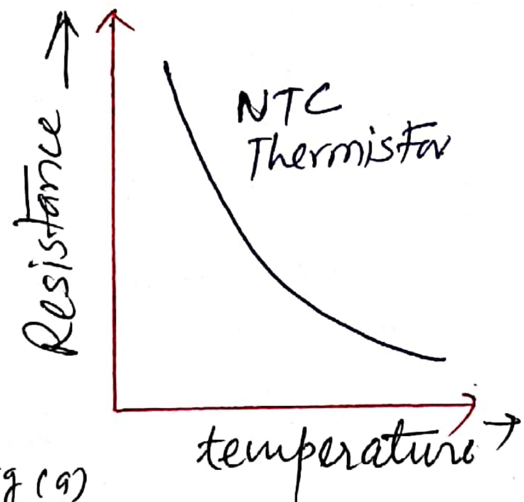
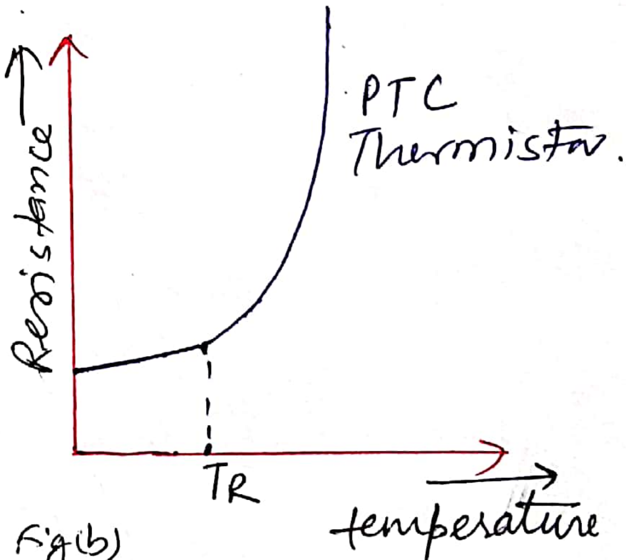


Fig (a)
(Characteristics of NTC thermistor)

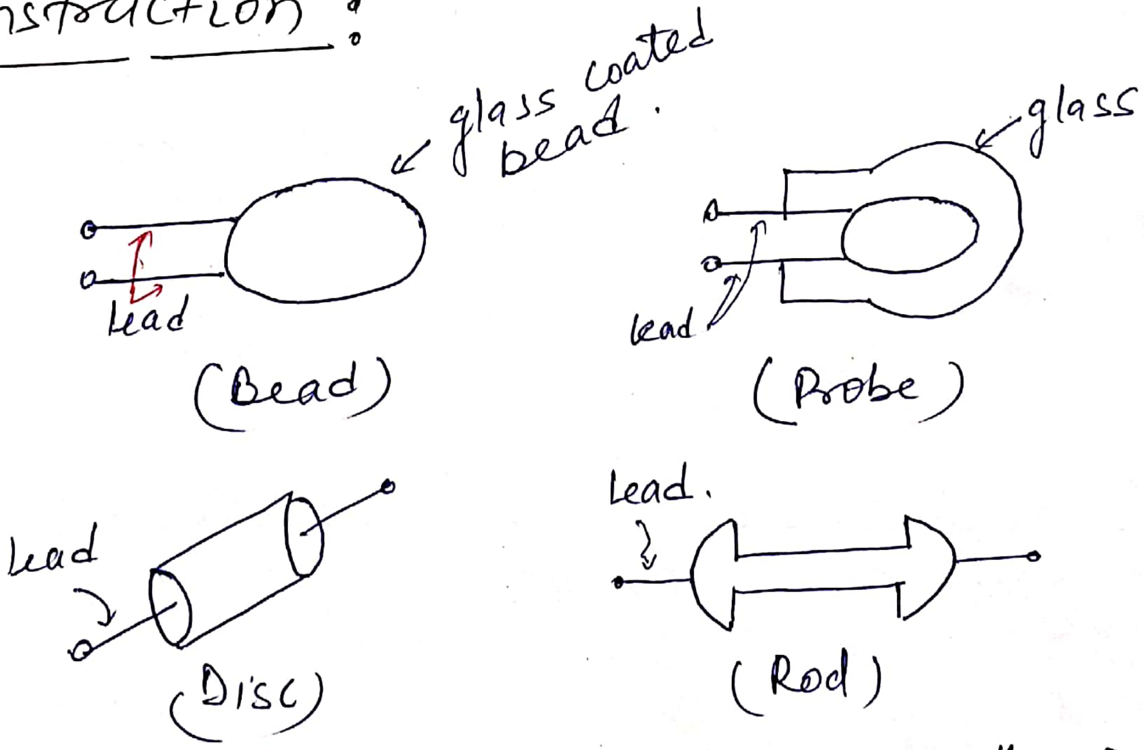


Fig(b)
(Characteristics of PTC Thermistor)

→ NTC thermistor, the variation of resistance with temperature is nonlinear and decreases with temperature. NTC thermistor are made of sintered ceramics, usually from mixtures of oxides of iron, manganese, nickel, cobalt and copper in the form of beads, rod, probes or discs.

→ PTC Thermistor have limited use and they are particularly used for protection of motor and transformer windings, time delay, and self regulating heater. They have low and constant resistance blow a threshold temperature TR, beyond which the resistance increase rapidly as shown in fig 6. The PTC thermistor is made from compound of barium, lead and strontium titanate.

Construction :



(Different form of construction of thermistor)

Bead diameter – 0.15 to 1.25 mm
Probe – diameter – 2.5 mm, length from 6mm to 50mm.
etc.

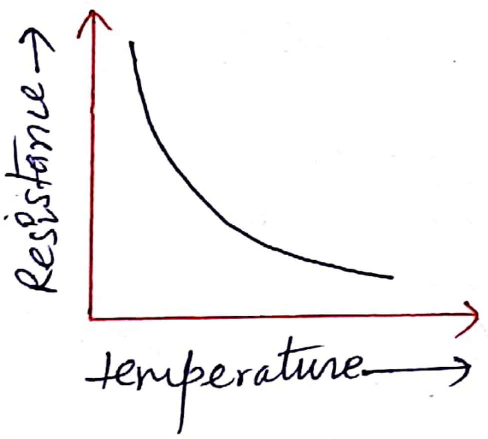
Typical Characteristics of thermistor:

There are three electrical characteristics that are taken into account for all the applications in which NTC thermistor are used.

- ✓ Resistance-Temperature characteristics
- ✓ Current-time characteristics
- ✓ Voltage - current characteristics.

→ Resistance temperature Characteristics (of NTC Thermistor)

NTC thermistor exhibits the negative temperature characteristics when the resistance increase with the slight decrease in temperature, as shown.



Mathematical expression

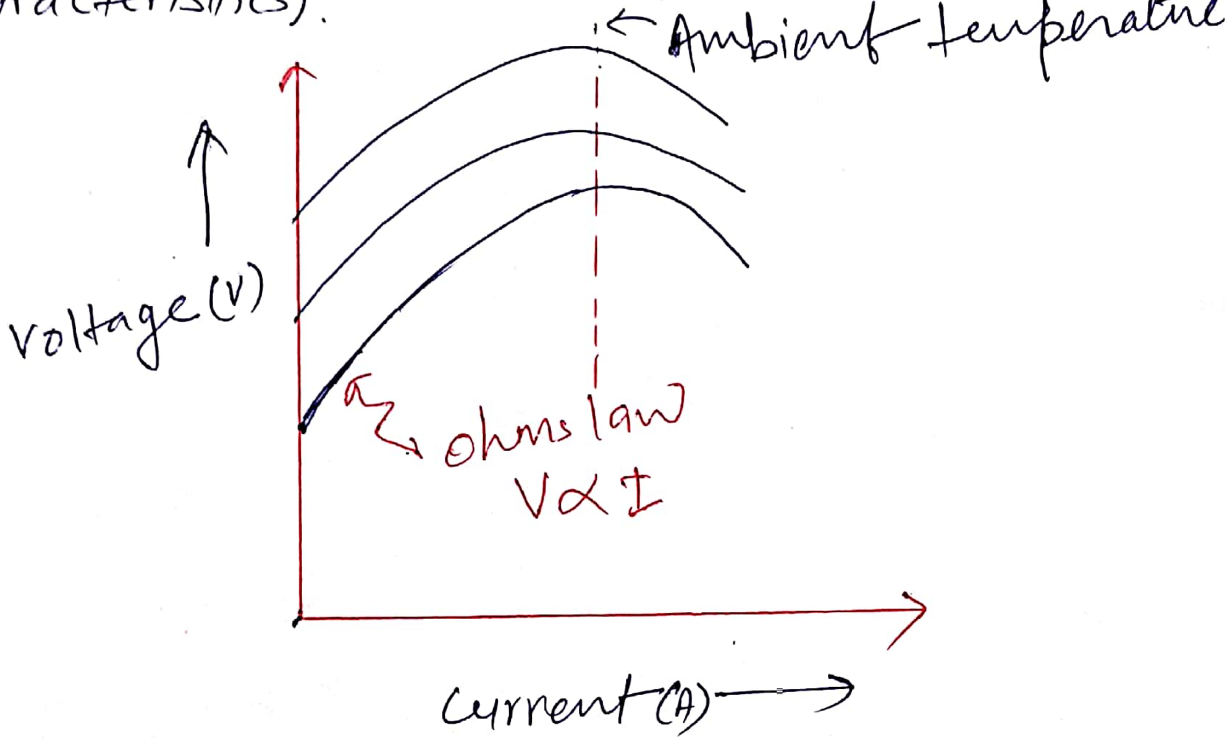
$$R_T = a e^{\beta/T}$$

$$R_{T_1} = R_{T_2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right].$$

where, β = constt, depending upon the material of thermistor (3500 to 4500)

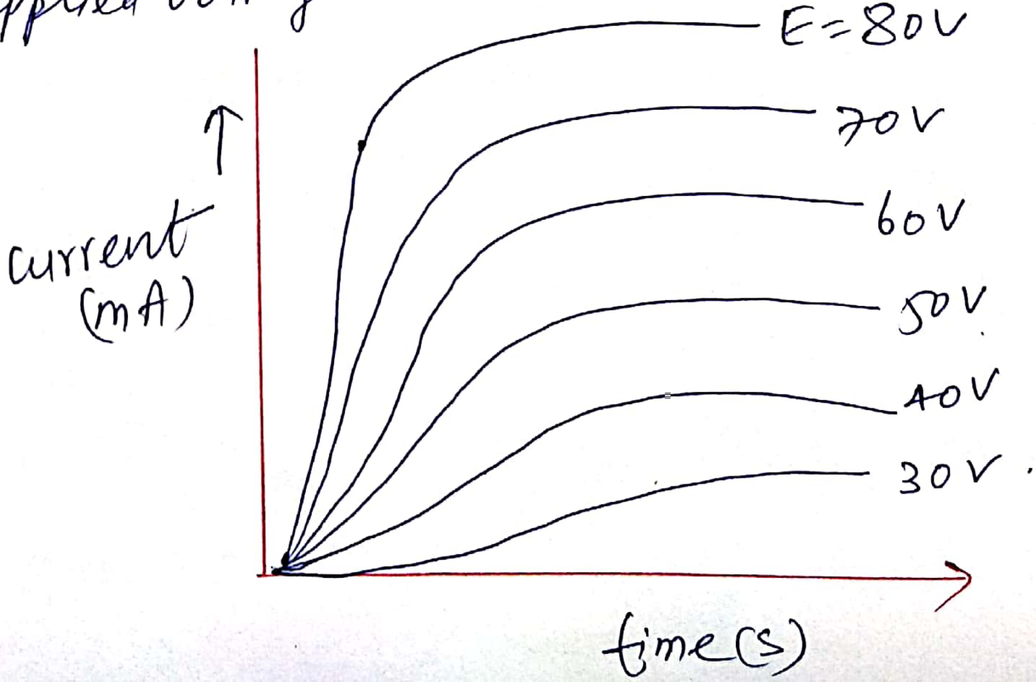
→ Voltage-current characteristics - (of NTC thermistor)

voltage drop across the thermistor increase with increasing current until it reaches a peak value (ie ambient temp), after peak value the voltage drop decreases with increase in current. (Negative resistance characteristics).



→ <u>current-time characteristics:</u>
(of NTC thermistor)

characteristics shows that the time delay to reach maximum current as a function of applied voltage.



Application of thermistor:

- ✓ Measurement of temperature
- ✓ control of temperature.
- ✓ Temperature compensation
- ✓ Measurement of power at high freq.
- ✓ Measurement of thermal conductivity.
- ✓ Measurement of level, flow, pressure.
- ✓ Provide the time delay.
- ✓ Health care & patient monitoring

Advantages of thermistor:

- ✓ The thermistor has fast response over narrow temperature range.
- ✓ It is small in size.
- ✓ Contact and lead resistance problem not occured due to large resistance
- ✓ It has good sensitivity in NTC region.
- ✓ cost is low.

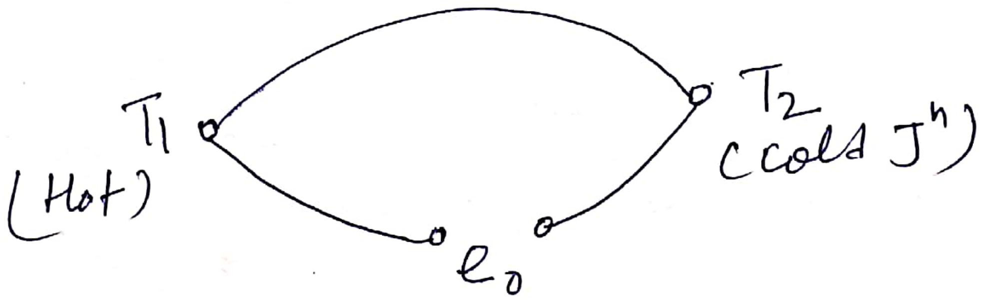
Disadvantages of thermistor:

- ✓ Thermistor need of shielding power line.
- ✓ The excitation current should be low to avoid self heating.
- ✓ It is not suitable for large temperature range
- ✓ The resistance temperature characteristics are nonlinear.

1.2: Thermocouple:

When two conductors made from dissimilar metals are connected forming two common junctions and the two junctions are exposed to two different temperatures, a net thermal emf is produced, the actual value being dependent on the materials used and the temperature difference between hot and cold junctions.

The thermal emf generated, in fact is due to the following three effects:
Peltier effect, seeback effect, Thomson effect.



$$e_0 = C_1(T_1 - T_2) + C_2(T_1^2 - T_2^2)\,\mu V$$

where, T_1 and T_2 are hot and cold junction temperature in K.
C_1 & C_2 are constants depending upon the materials.
ex. For copper: $C_1 = 62.1$ & $C_2 = 0.045$

$\therefore$ If C_1 is $\uparrow\uparrow\uparrow$ C_2 then,

$$e_0 = C_1(T_1 - T_2)$$

$\therefore$ $\boxed{\Delta T \propto e_0}$

Material of wire :

Iron – Constantan
Cromel – Constantan
Cromel – Alumal
Rhudium – Iridium
Tungston – Rhedium
Copper – Constantan.

each combination produce different value of emf

$$\boxed{e_0 \propto \Delta T}$$

Advantages of Thermocouple:

Thermocouple are extensively used for industrial measurement of temperature in situation. The major reason behind their popularity are :

- ✓ They are rugged and reading are constt.
- ✓ They can measure over wide range of temperature
- ✓ Their characteristics are almost linear. with an accuracy about 0.05%.

Disadvantages of thermocouple:

However, the major shortcoming of the thermocouple is :

- ✓ low sensitivity compared to other temperature measuring devices. (eg. RTD, Thermistor)

2: IR Detector:

Electromagnetic spectrum

Infrared Visible ultraviolet x-ray.

Infrared radiate thermal energy that cannot be seen by our eyes but can be sensed by skin or by sensor.

IR Detector

- Thermal or Uncooled
  - Pyroelectric
  - Bolometer
  - Thermopile
  - Low Sensitivity
  - Slow response
  - No cryogenic colling required
- Photon or Cooled.
  - photovoltaic
  - Photoconductive
  - photodiode
  - High Sensitivity
  - Fast response
  - Required crygenic cooling.

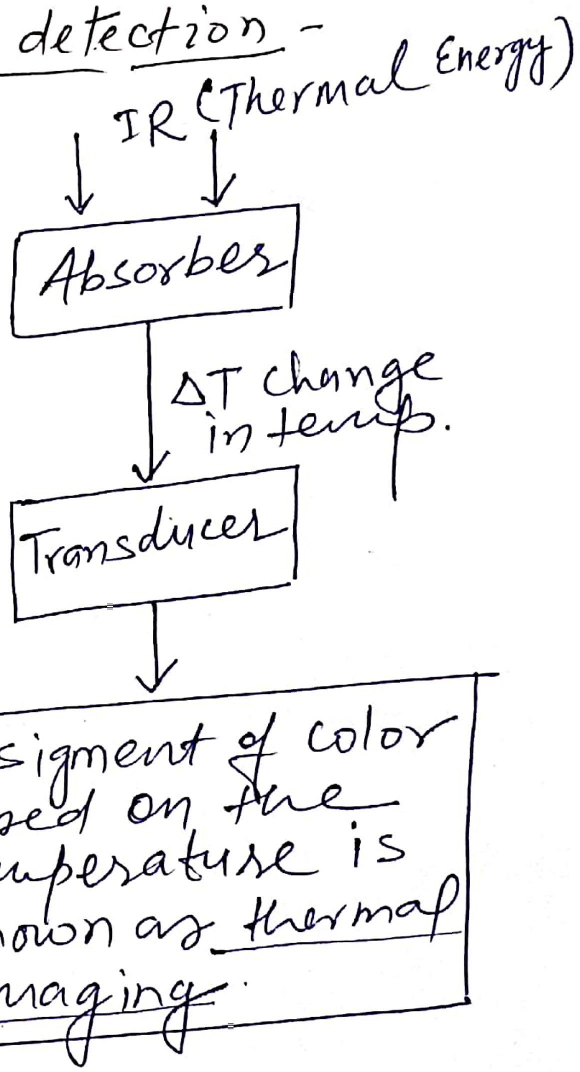
Thermal Imaging: Thermal imaging is use non contact detection and measurment of temperature difference and the assignment of colors based on temperature.

Thermopile – based on seeback effect

Pyroelectric – molecules having dipole moment shows pyroelectric effect.

Bolometer – change in resistance when change in temperature.

working principle for thermal detection –



Absorber absorb IR radiation & convert it into heat energy or temperature change.

Transducer sense temperature change and convert it into some measurable parameters.

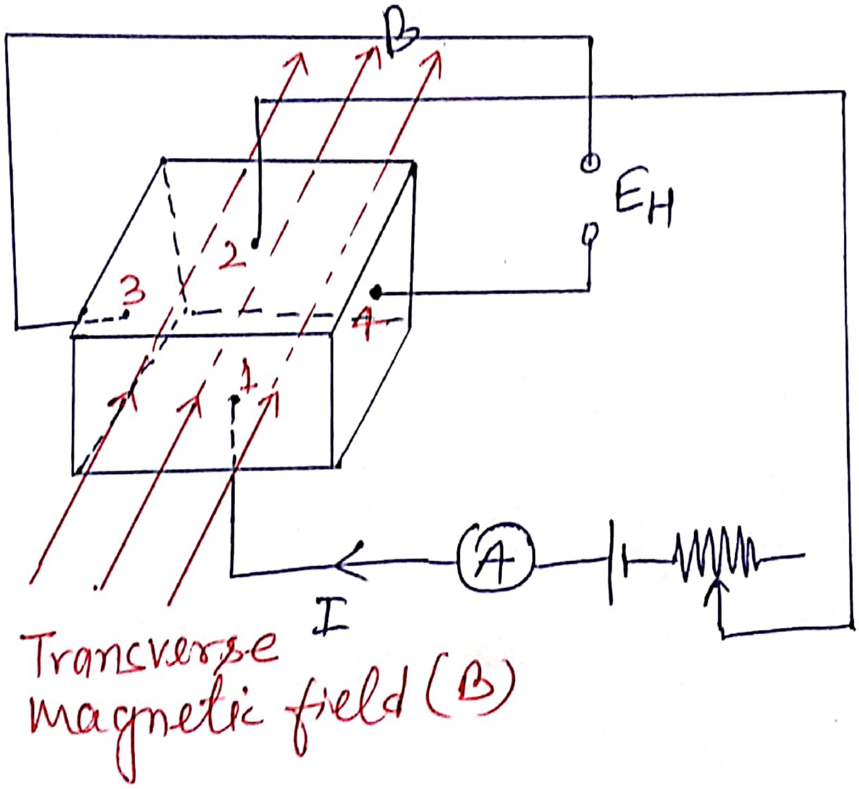
3: Measurement of position using Hall effect & proximity sensor (inductance & capacitive):

3.1 Hall effect sensor:

If a strip of conducting material carries a current in the presence of transverse magnetic field, a diffence of potential produce b/w the opposite edge of the conductor.

The magnitude of voltage depends upon the current, the strength of magnetic field and the property ~~call~~ of conductor called Hall effect.

Hall effect can be in conductor & semiconductor in varying amount and will depends upon the densities and mobility of carriers.



$$\boxed{E_H = K_H I B / t}$$

K_H - Hall effect Coefficient $\frac{V-m}{A-Wb\,m^{-2}}$

t - thikness of Strip, m

I - A

B - Wb/m^2

Application of Hall effect sensor:

The following are some of the applications of the Hall effect sensor.

1- Magnetic to Electric transducer
2- Measurement of displacement
3- Measurement of current
4- Measurement of power.

7.

Measurement of displacement using Hall effect:

The Hall effect element can be used for the measurement of the location or displacement of a structural element i.e, it can serve as an indirect acting position displacement or a proximity transducer in case where a change of geometry of a magnetic structure causes a change of magnetic field strength.

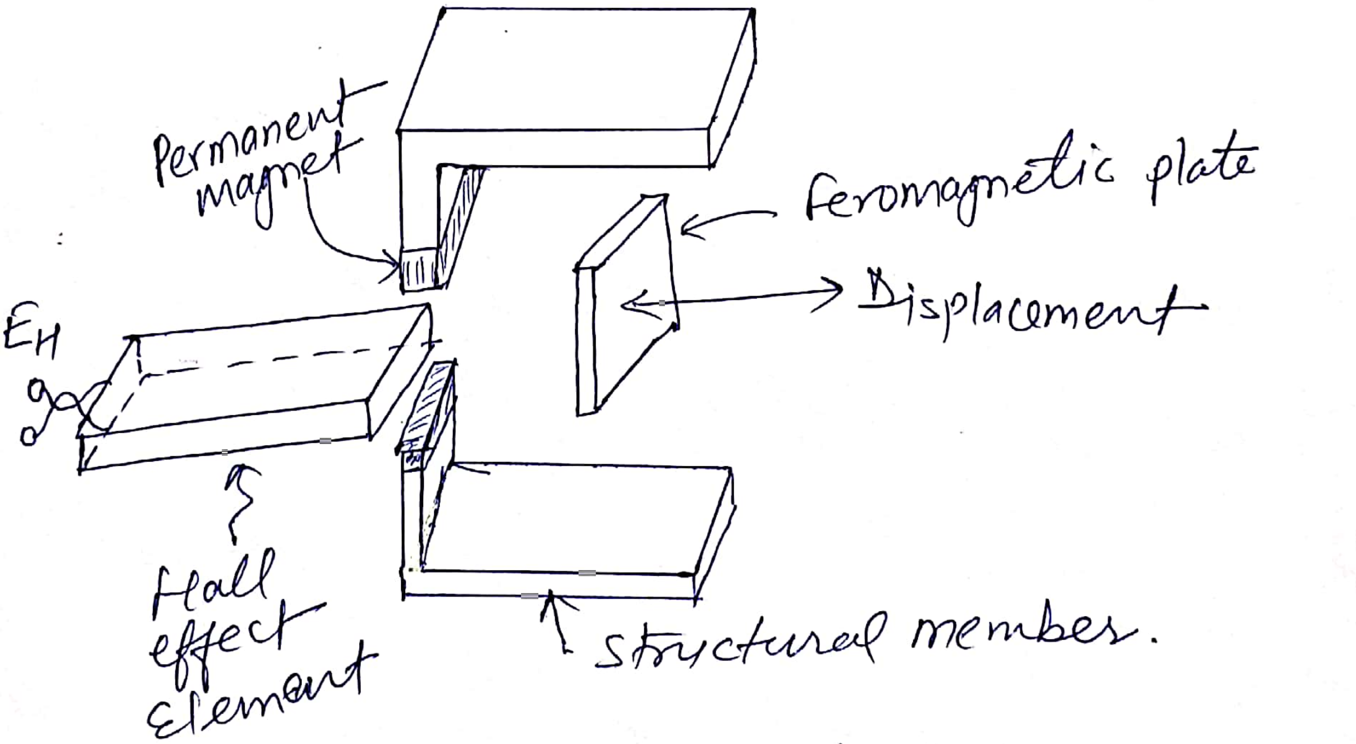


Fig: measurement of displacement Using Hall effect transducer.

The field strength produced by the permanent magnet in the gap, where the hall effect element is located, is varied by changing the position of a feromagnetic plate.

$$\boxed{E_H \propto \underset{\text{(in gap)}}{\text{Magnetic field}} \propto \text{Displacement}}$$

Scanned with CamScanner

3.2 Proximity sensor:

A proximity is a sensor able to detect the presence ~~of~~ of nearby objects without any physical contact.

So, "proximity" means closeness (nearness) of some object.

Type of proximity sensor:

(a) Inductive (proximity sensor)
(b) Capacitive (proximity sensor)
(c) Photoelectric (proximity sensor)
(d) Magnetic (proximity sensor).
(e) ultrasonic (proximity sensor)
(f) optical (proximity sensor)
(g) Radar & sonar (proximity sensor)
(h) Hall effect (proximity sensor)
(i) Doppler's effect (proximity sensor)

etc.

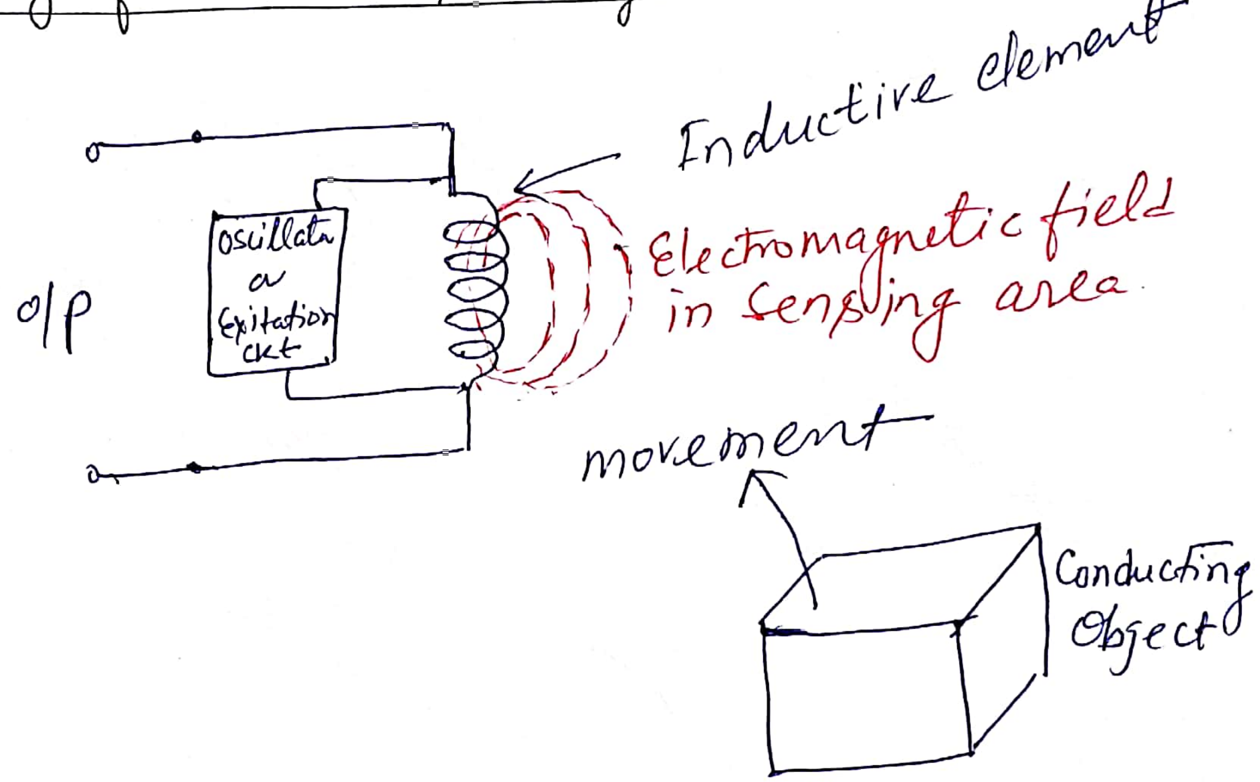
(a) Inductive (proximity sensor):-

Inductors are devices that oppose any change in the current flowing through them, the inductance of coil is given by: $L = \frac{N^2 \mu A}{d}$.

(An inductance that will produce an emf 1V when the current through the inductance changes at the rate 1A/s.)

Inductive sensor widely used in industry in many applications. They are robust and compact and less affected by environmental factors.

working of inductive proximity sensor -



Inductive sensors are based on the principle of magnetic circuits. They can be classified as.

- self Generating type
  - electromagnetic
  - Electrodynamic
  - Edy current
- Passive type

self generating type utilize an electrical generator principle; i.e, when there is relative motion b/w a conductor and magnetic field, a voltage is induced in conductor or a varying magnetic field linking a stationary conductor produces voltage in conductor.

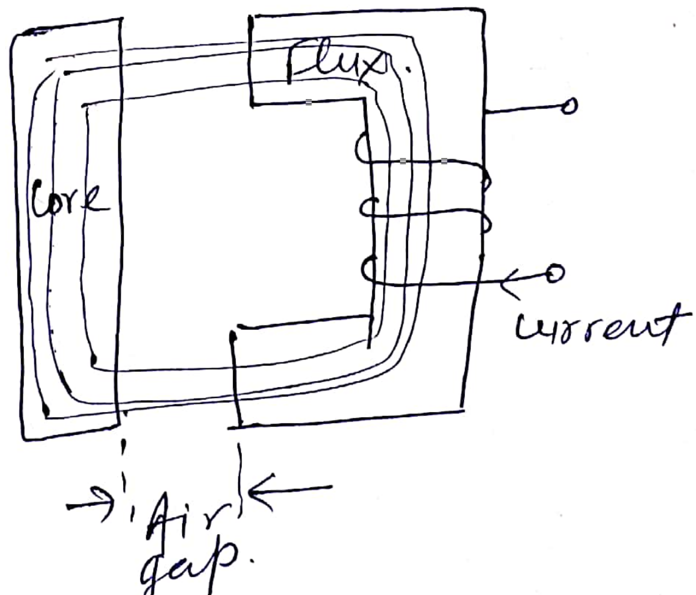
In passive type the motion of an object results in change in the inductance of the coil of the transducers.

Inductive displacement sensor can be divided into two major type.

(i) Air Core sensor

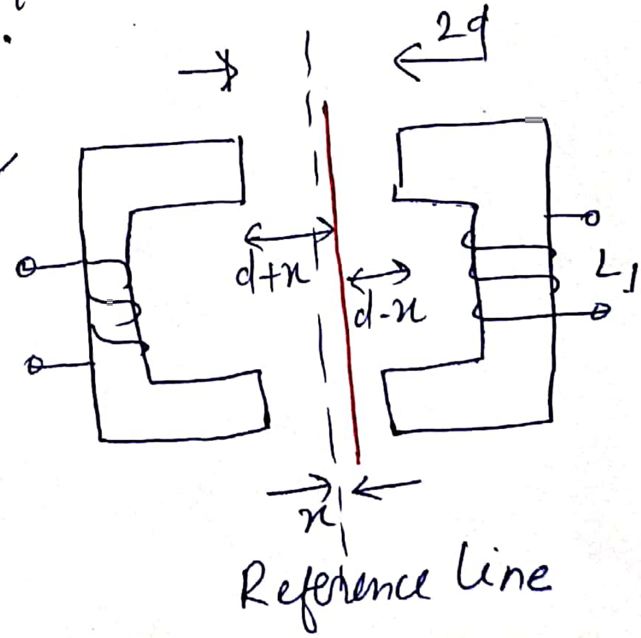
(ii) Magnetic Core sensor.

(*)



small change in air gap result in measurable change in inductance.

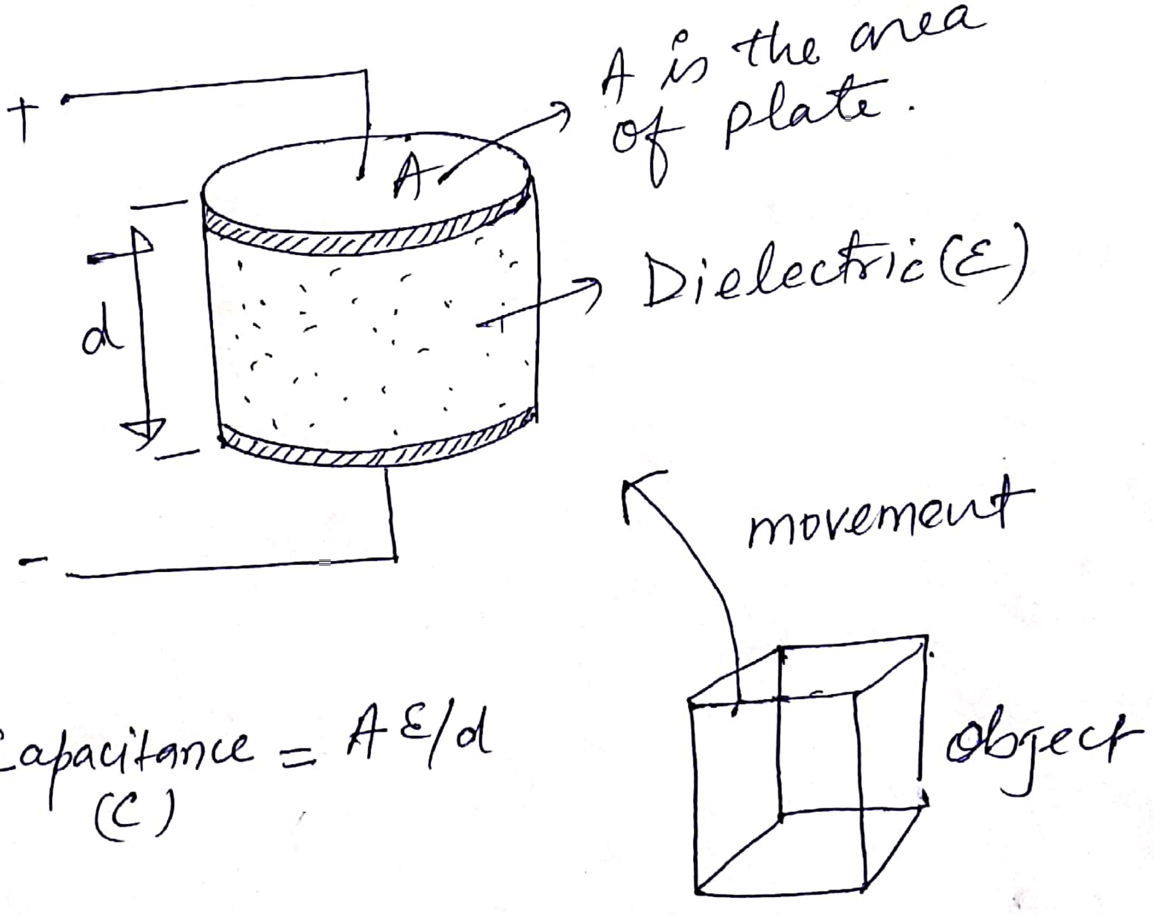
(ii) Armature move in the air gap. This movement alter the reluctance of coil 1 & 2, thus altering their inductive properties.



b: capacitive (proximaty sensor) :-

Change in capacitance is due to closeness of object.

This arrangement can be used for detecting the metalic and non-metalic object like liquid, plastic, wood etc.



$$\text{Capacitance } (C) = A\varepsilon/d$$

when an object ~~with~~ will move close to capacitance. The capacitance will change.

Change in capacitance will reflect the closeness of the object.

B1

Capacitive Sensor :—

There are based on changes in capacitance to physical variations.
These sensors find many diverse applications like humidity, moisture measurements to displacement sensing.
The displacement is basically the vector representing a change in position of a body or point with respect to a refrence point.

Capacitive displacement / position sensor.

The basic sensing element of a typical displacement sensor consist of two simple electrodes ~~of a~~ with a capacitance 'C'.
The capacitance is a function of the distance d (cm) between electrodes of a structure, the surface area (A) → cm^2 of the electrodes, and the permitivity ε ($8.85 \times 10^{-12}\ Fm^{-1}$ for air) of the dielectric between the electrodes,
therefore:

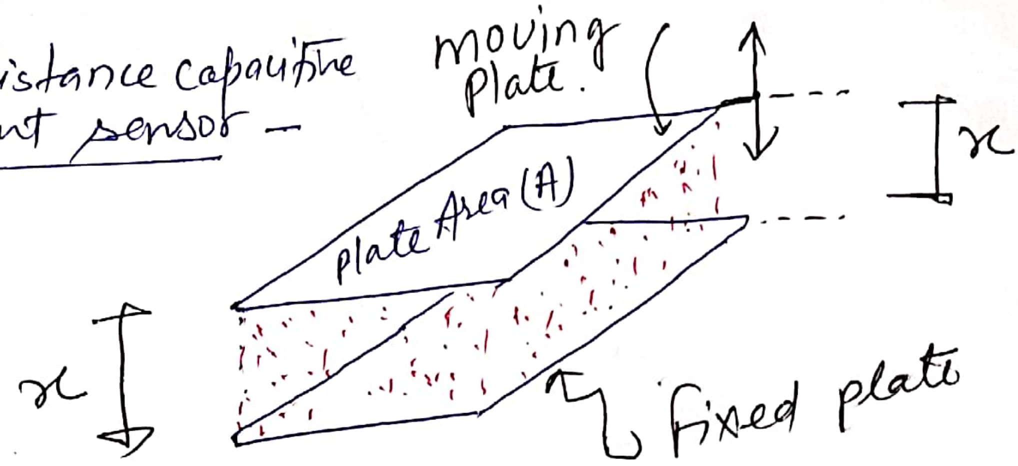
$$\boxed{C = f(d, A, \varepsilon)}$$

So, capacitive displacement sensor can be realized by varying d, A or ε.

(a) Variable distance displacement sensor.
(b) Variable area displacement sensor
(c) Variable dielectric displacement sensor.

BV

Variable distance capacitive displacement sensor –



$$\boxed{C(x) = \varepsilon A/x = \varepsilon_r \varepsilon_0 A/x}$$

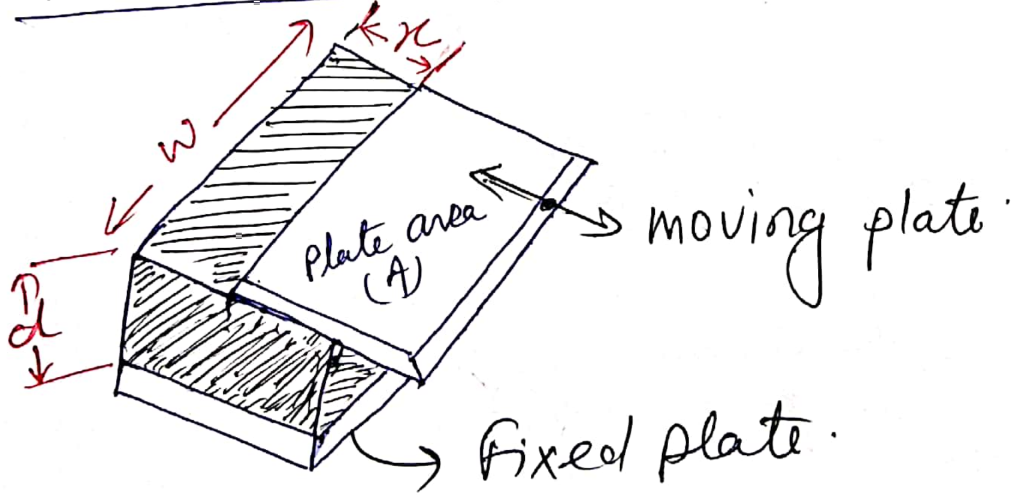
x in, m
A in, m^2

$$\boxed{\frac{dc}{c} = -\frac{dx}{x}}$$

$\boxed{\text{\% change in } C \propto \text{\% change in } x}$

This type of measuring small increamental displacement.

Variable area displacement sensor.

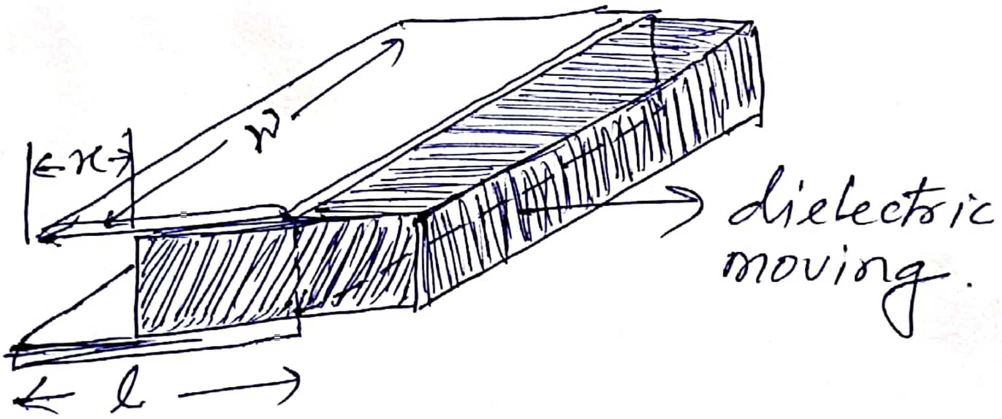


The displacements may be sensed by varying the surface area of the electrodes of a plate capacitor, as shown in fig.

$$\boxed{C = \varepsilon_r \varepsilon_0 (A - wx)/d}$$

Where, w – width
wx – reduction in area due to movement of the plate.

Variable dielectric displacement sensor –



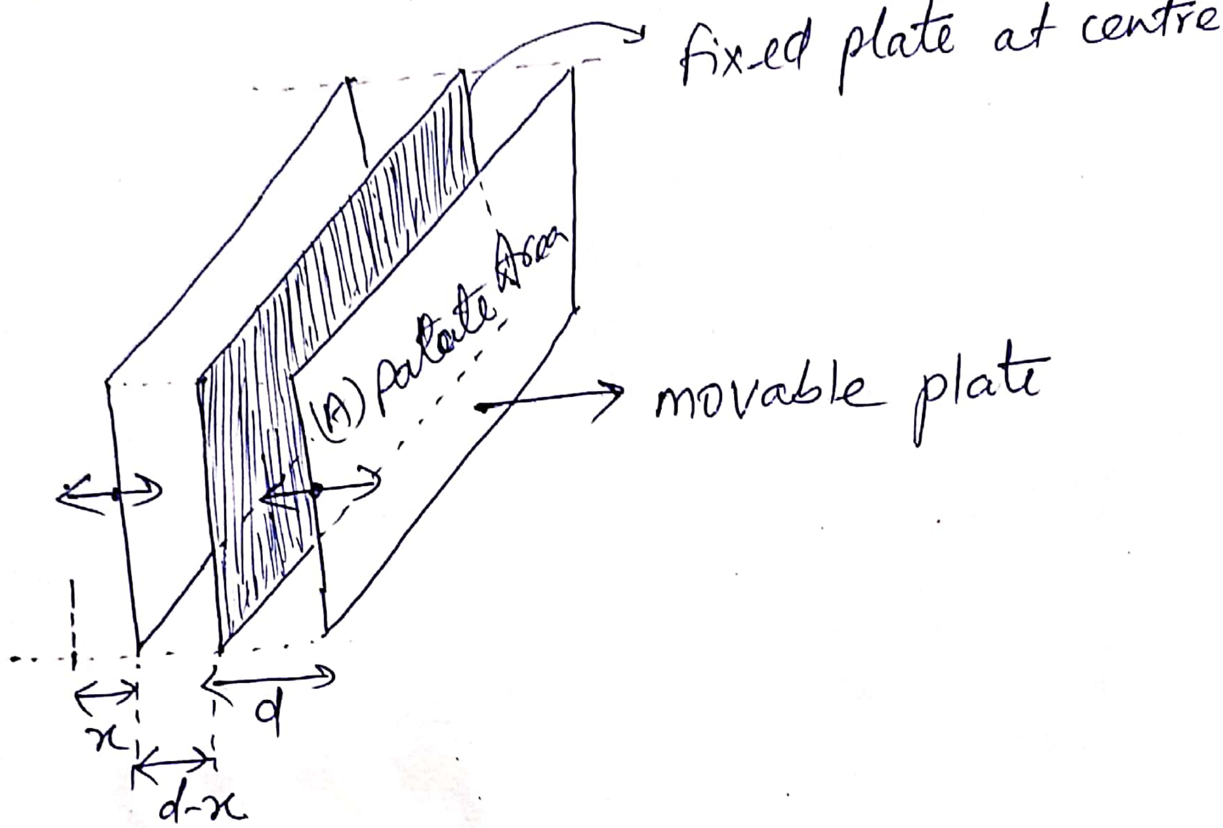
displacement may be sensed by the relative movement of the dielectric material between the plates, as shown in fig.

$$C = \varepsilon_0 w \left[\varepsilon_2 l - (\varepsilon_2 - \varepsilon_1) x \right]$$

ε_1 – relative permitivity of the dielectric.
ε_2 – relative permitivity of displacing material.

b/x

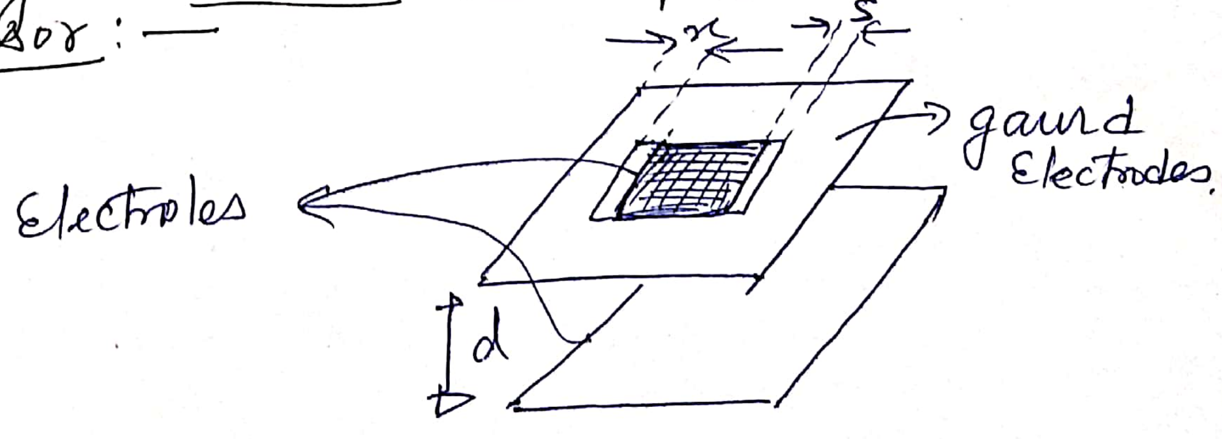
Differential capacitive sensor :-



nonlinearity in capacitive sensor can be eliminated using differential capacitive arrangement.

o/p from the centre plate is zero at the central position and increases as it moves left or right.

Integrated circuit smart capacitive position sensor :-



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4: Use of proximity sensor as

4.1 – Accelerometer

4.2 – Vibration sensor

4.1 Accelerometer:

Acceleration is the rate of change in velocity (v) & v is the rate of change in distance.

As explained capacitive devices are commonly used in displacement measurements, and hence, they can be configured for acceleration measurement too.

Capacitive-type micromachined accelerometers, as illustrated in fig below, are commonly used.

These accelerometers are arranged such that a proof mass forms one of the plates of the capacitor and the other plate fixed as the base. When the sensor is accelerated, the proof mass moves altering the distance between itself and the base plate; thus, the capacitance changes. This change in capacitance corresponds to the applied acceleration.

Let $F(x)$ be the positive force in the direction in which x increases.

Neglecting all the losses (due to friction, resistance etc)

If the supply voltage across capacitor is constt, then the coulomb force is given by

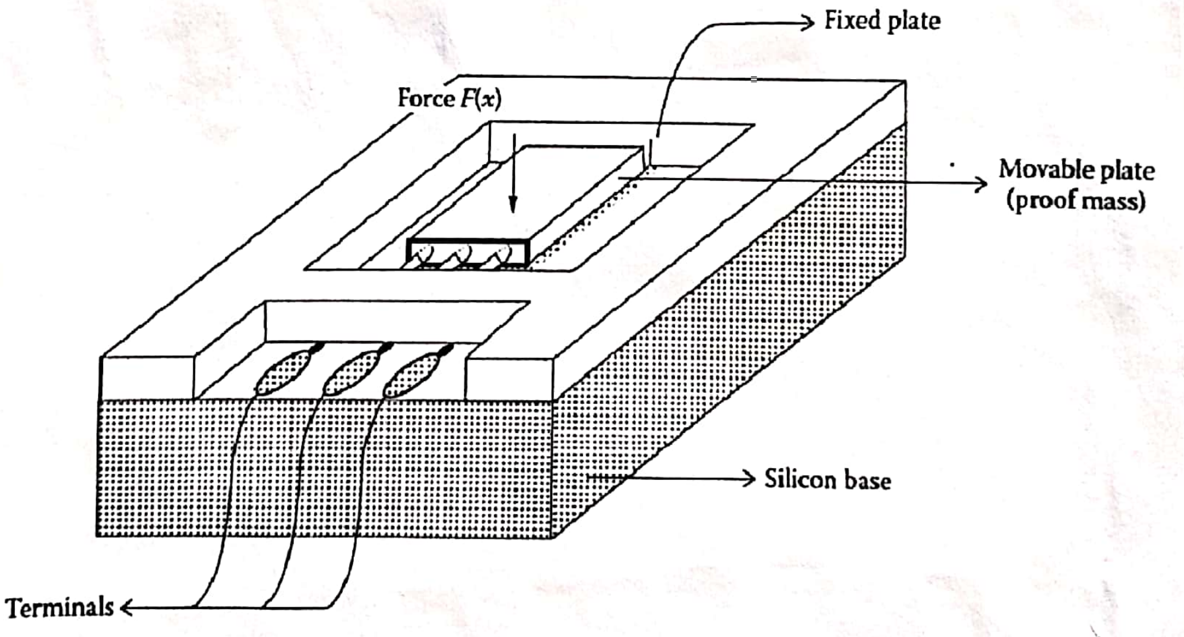
$$\boxed{F(x) = -V^2 \frac{dC(x)}{dx}}$$

Thus, if the movable electrodes has complete dr

freedom of motion, it will have assumed a position in which the capacitance is maximal; also, if C is linear function of x, the force F(x) becomes independent of x.

Capacitive silicon accelerometers are available in wide range of specifications.

A typical light weight sensor will have a frequency range of 0-1000Hz and a dynamic range of acceleration of $\pm 2g$ to $\pm 500g$.



A typical capacitive micromachined accelerometer

Other types:

Types of Accelerometers -

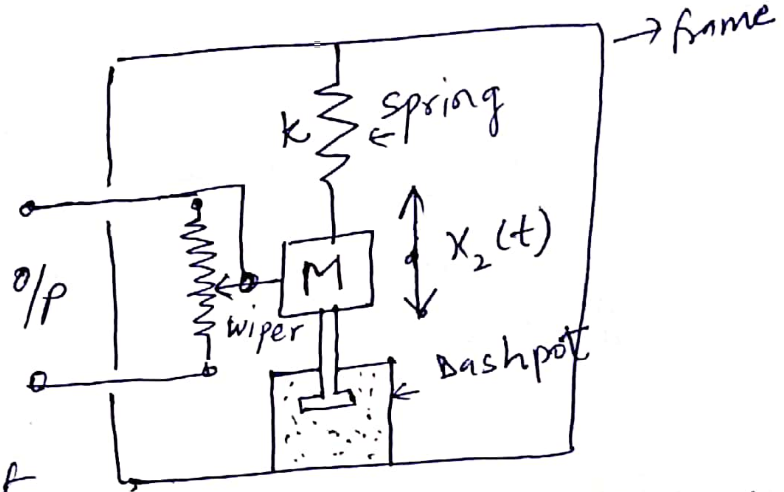
The variety of accelerometers used results from different applications with varied requirement of range of natural frequency and damping.

✓(i) potentiometric type Accelerometer

✓(ii) LVDT Accelerometer.

✓(iii) Piezo electric Accelerometer.

(i)

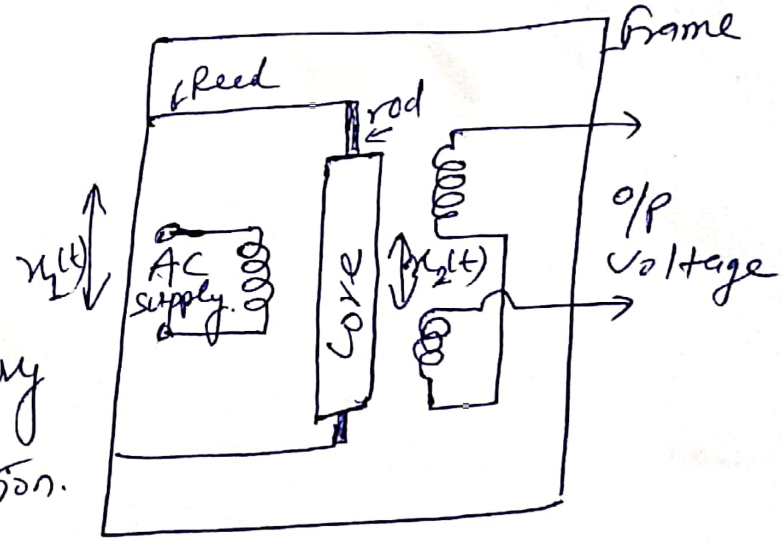


seismic mass is attached to the wiper arm or resistance potentiometer. The relative motion of the mass with respect to the transducer frame is sended either a change in resistance or as a change in voltage output (if the potentiometer is used as potential divider). Dashpot is used to provide proper damping.

(potentiometric Accelerometer)

(ii)

The reed are attached to housing, which is subjected to vibrations. The above arrangement is necessary in order to maintain the core at null position.

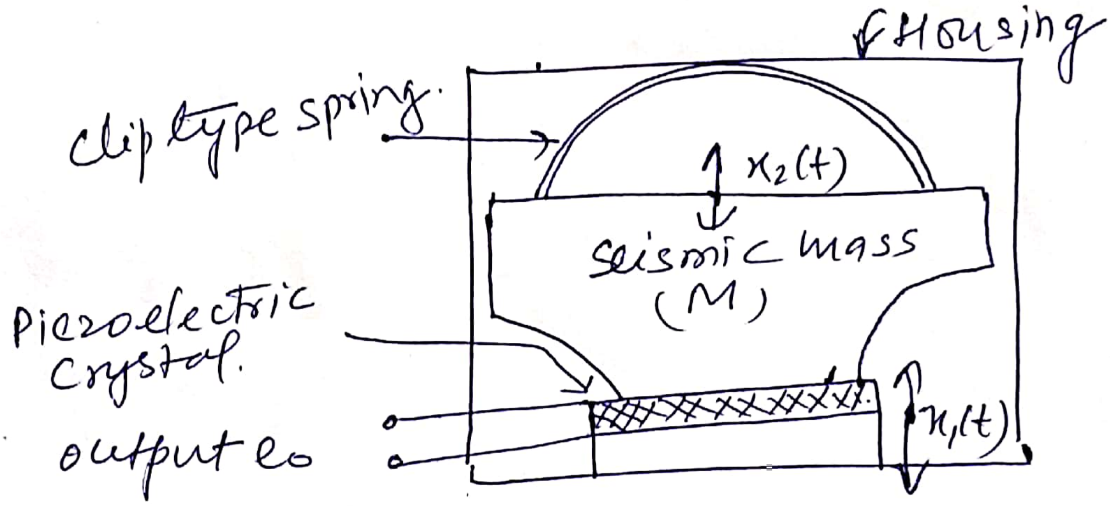


As the sensor moves up and down on account of vibration, the LVDT secondaries gives an a.c output voltage. The magnitude of this o/p signal depends upon the amplitude of vibrations.

Advantage of LVDT –

- ✓ contact less device, free from problem of friction
- ✓ offer low resistance & more resolution
- ✓ LVDT has much smaller mass.

(iii)

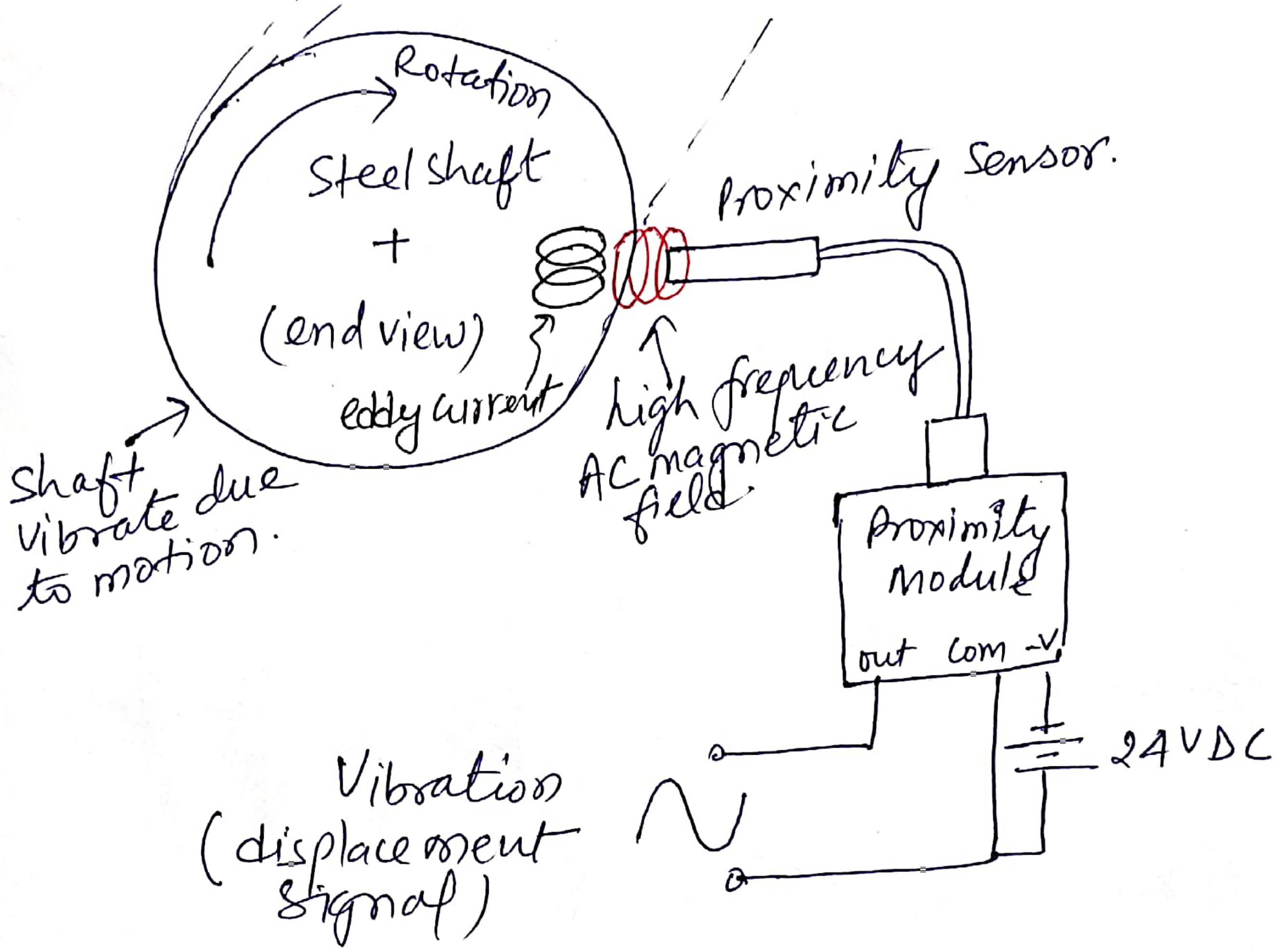


A typical piezoelectric accelerometer is shown in fig with sismic mass in contact with the crystal. when subjected to an acceleration, the seismic mass stresses the crystal to a force $F = Ma$, resulting a voltage generated across the crystal.

This force, generates a output voltage which is proportional to the acceleration.

$$\boxed{e_o = \frac{dF}{C} = \frac{Q}{C} = \frac{dMa}{C}}$$

4.2 Vibration Sensor:



A design of displacement sensor uses electromagnetic eddy current technology to sense the distance between the probe tip and the rotating shaft.

The magnetic field produced by the coil induced eddy currents in the metal shaft of the machine

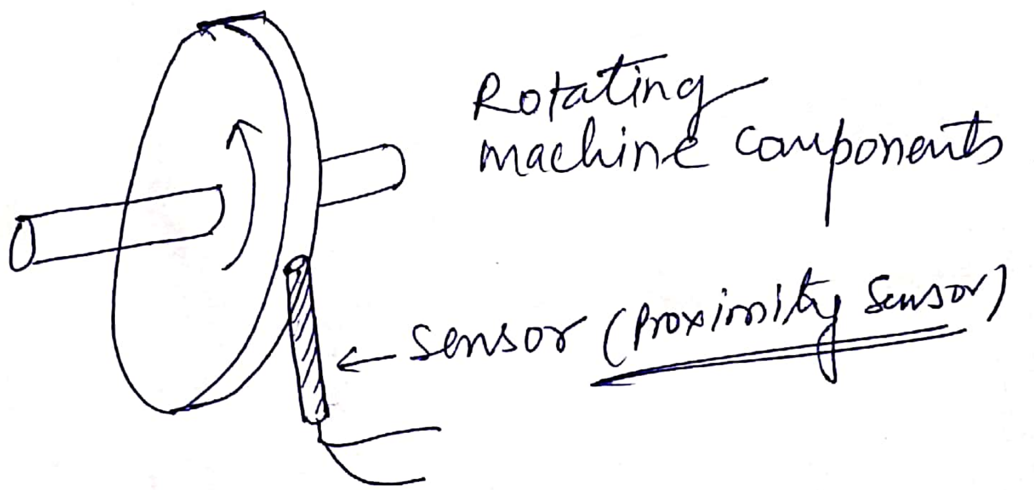
The closer the shaft moves towards the sensor tip, the tighter the magnetic coupling between the shaft and sensor coil, and the strong the eddy currents.

~~Therefore, the oscillator's load becomes~~ a dr

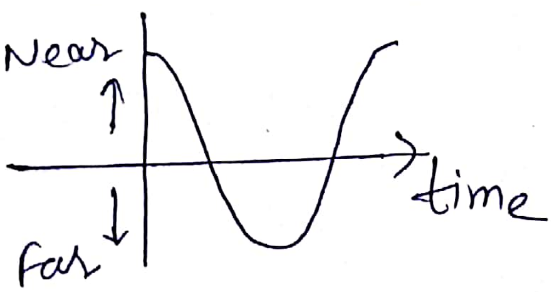
The high frequency oscillator circuit providing the sensor coil's ~~exit~~ excitation signal becomes loaded by the induced eddy currents.

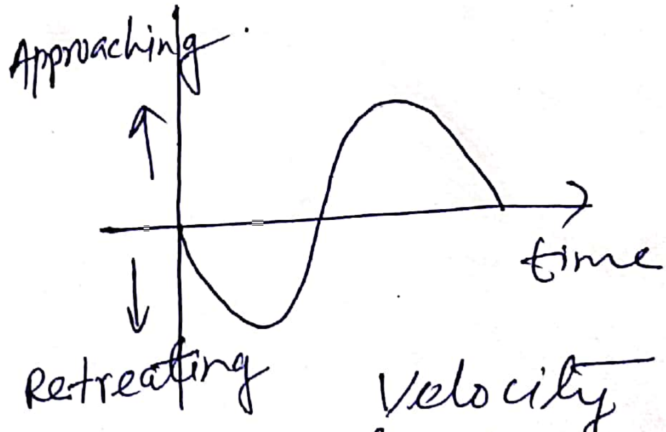
Therefore, the oscillator's load becomes a direct indication of how close the probe tip is to the metal shaft.

An oscilloscope connected to this o/p signal will show a direct representation of shaft vibration.

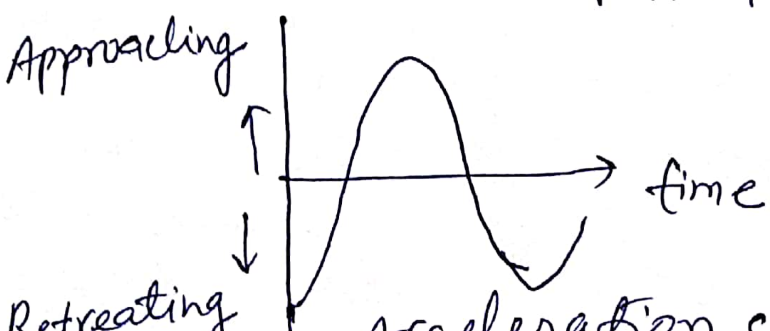


Displacement signal





Velocity sensor signal.



Acceleration sensor signal.

5: Flow sensor:

5.1: Ultrasonic flow sensor / flow meter:

For many years, differential pressure types of flowmeters have been the most widely used as flow measuring device for fluid flow in pipes and open channels that required accurate measurement at reasonable cost.

However flow must be measured without any head losses or any pressure drop. This means there is no moving part, no secondary devices, nor any restrictions allowed.

Two type of flow meters presently fulfill this requirement electromagnetic & ultrasonic

Ultrasonic flowmeter - applied nearly for any kind of flowing liquid.

Electromagnetic flowmeter - require a minimum electric conductivity of the liquid for operation.

Note: In addition, the cost of ultrasonic flow-meter is nearly independent of pipe diameter, whereas the price of electromagnetic flowmeter increases drastically with pipe diameter.

Types of ultrasonic flowmeter -

1. Transit time
2. Dopler
3. cross correlation
4. Phase
5. Drift.

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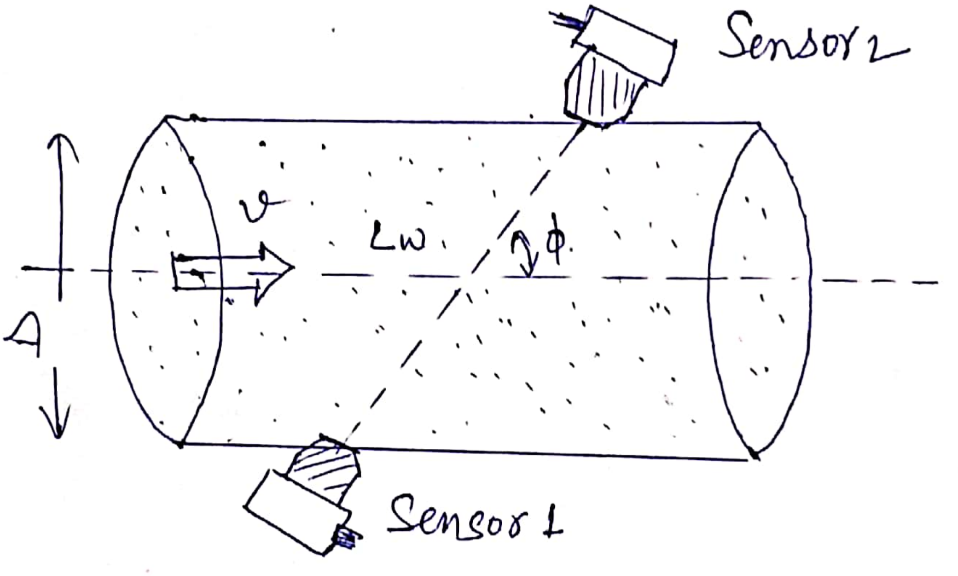
Ultrasonic flowmeter based on transit time

This type of flowmeter measure the differences in transit time between ultrasonic pulse transmitted ie upstream pulse t_{21} and the downstream pulse t_{12} across the flow. as shown below.



the two transmitt times of pulses are given by

$$t_{12} = \frac{L_w}{c + v_a \cos\phi} \quad \& \quad t_{21} = \frac{L_w}{c - v_a \cos\phi}.$$

Since, the transducer used both transmitter & receiver, the difference in travel time can be determined with the same pair of transducers. Thus the mean axial velocity $\bar{v}_a$ alon the path is given by.

$$\boxed{\bar{v}_a = \frac{L_w}{2\cos\phi}\left(\frac{1}{t_{21}} - \frac{1}{t_{12}}\right) = \frac{D}{2\cos\phi \sin\phi}\left(\frac{1}{t_{21}} - \frac{1}{t_{12}}\right)}$$

Where,

L_w – is the distance in the fluid between the two transducers.

c – is the speed of sound at the operating conditions.

ϕ – is the angle between the axis of the axis and acoustic path.

$\bar{V}_a$ – is the axil low velocity averaged along the distance L_w.

5.2 Laser flow meter / Laser anemometry / Laser Velocimetry:

This the technique that uses lasers to measure velocity.

There are three most common methods:

✓ LDV (Laser Doppler velocimetry) or LDA (Laser Doppler anemometry)

✓ L2F (Laser transit velocimetry)
  ↳ Laser to focus.

✓ Particle image velocity (PIV)

The noninvasive nature of LDV technique and its ability to make accurate velocity measurements with high spatial and temporal resolution, even in highly turbulent flows, have led to the wide spread use of LDV for flow measurement. Flow velocity ranging from micrometers per second to hypersonic speed have been measured using LDV systems.

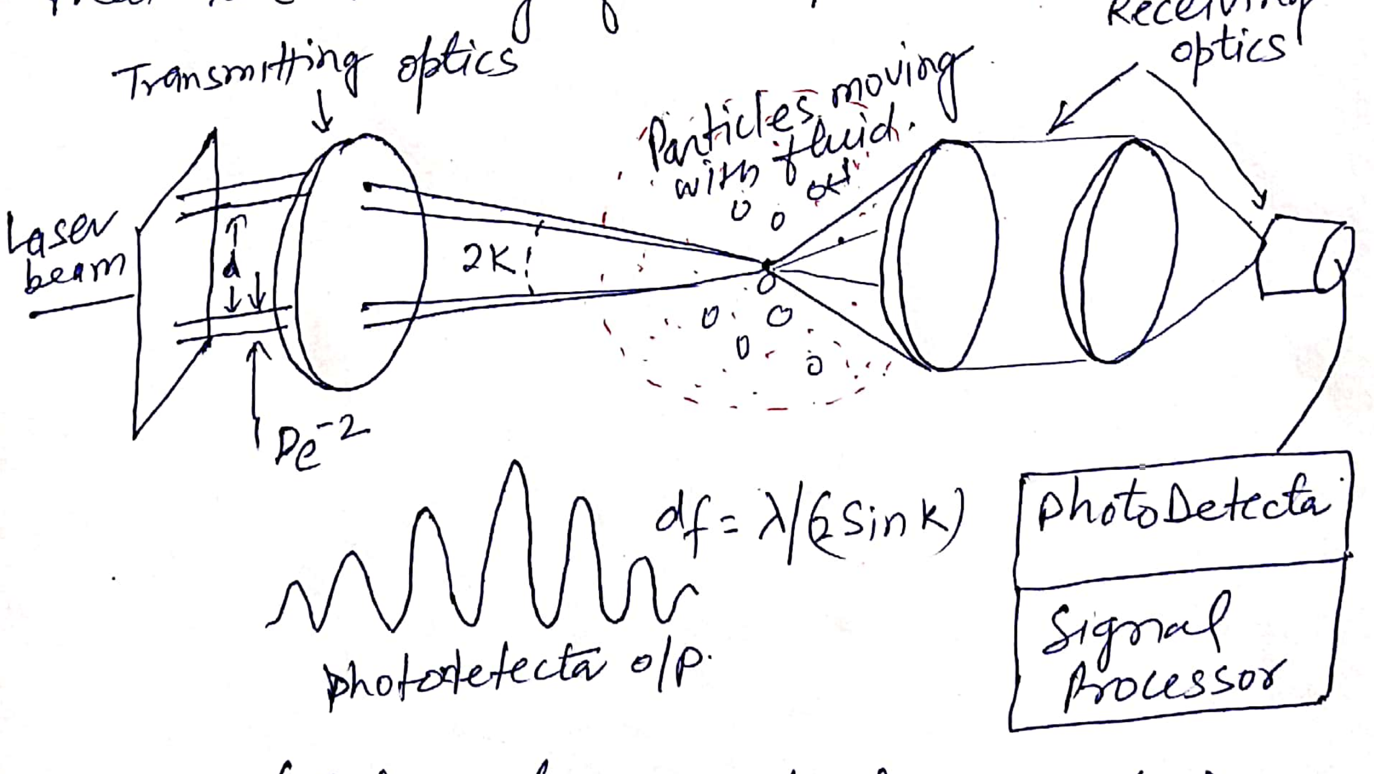
CK

The versatility and the widespread use of the LDV approach to measure flow accurately have resulted in referring to this technique as laser velocimetry or laser anemometry

LDV technique relies on the light scattered by scattering centers in the fluid to measure flow velocity.

The particle whose velocity are measured, must be small enough (micrometer range) to follow the flow variations and large enough to provide signal strength adequate for the signal processor to give velocity measurement.

The scattered light signal is processed to obtain the Doppler shift frequency and from that the velocity of the particle



(Schamatic of a dual-beam Systam)

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6: Level Sensor —

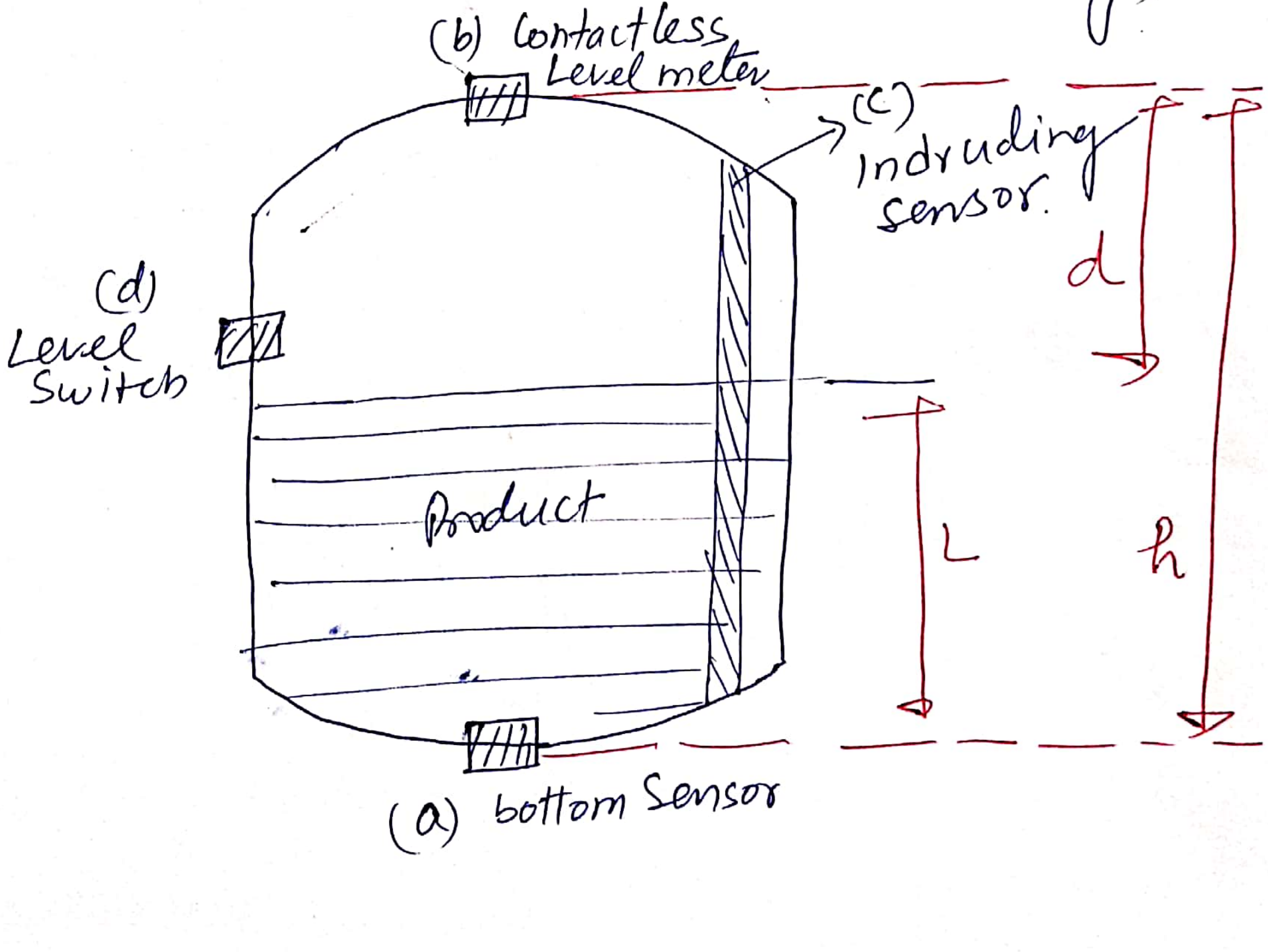
Level is defined as the filling height of a liquid or bulk material, For example, in a tank or reservoir. Generally, the position of the surface is measured relative to a reference plane, usually the tank bottom.

Various classic method exist and modern method exist to measure product level in process and storage tanks in the chemical, petrochemical, petroleum, pharmaceutical, water, and food industries. etc. Typical tank ~~Size~~ heights are approximately between 0.5 and 40 m.

Two different task can be distinguished.

✓ continous level measurement (Level indication, LI)

✓ Level Switch (LS_s) – (prevent overfilling)



6.1: Ultrasonic Level measurement -

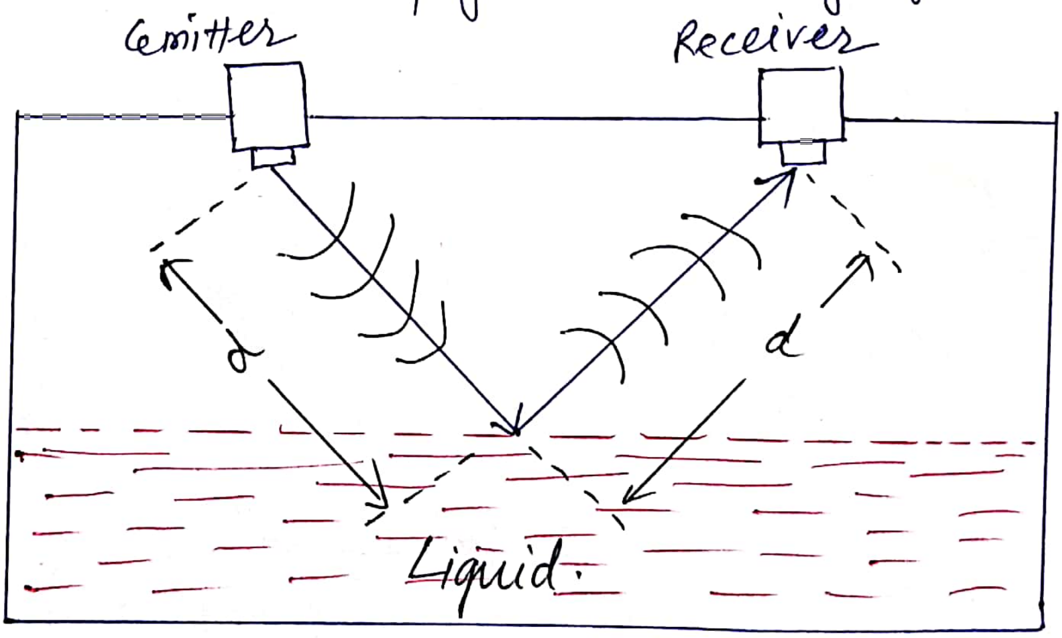
An indirect measurement of level is evaluating the time of flight of a wave propagation through the atmosphere above the liquid or solid.

This is primarily a distance measurement; the level then can calculating accordingly. Although different types of physical waves (acoustic or electromagnetic) are applied, the principle of all these methods is the same: a modulated signal is emitted as a wave toward the product, reflected its surface and received by sensor, which in many cases is the same (eg the ultrasonic piezoelectric transducer or the RADAR antenna).

The measuring system evaluates the time of flight (t) of the signal

$$\boxed{t = \frac{2d}{v}}$$

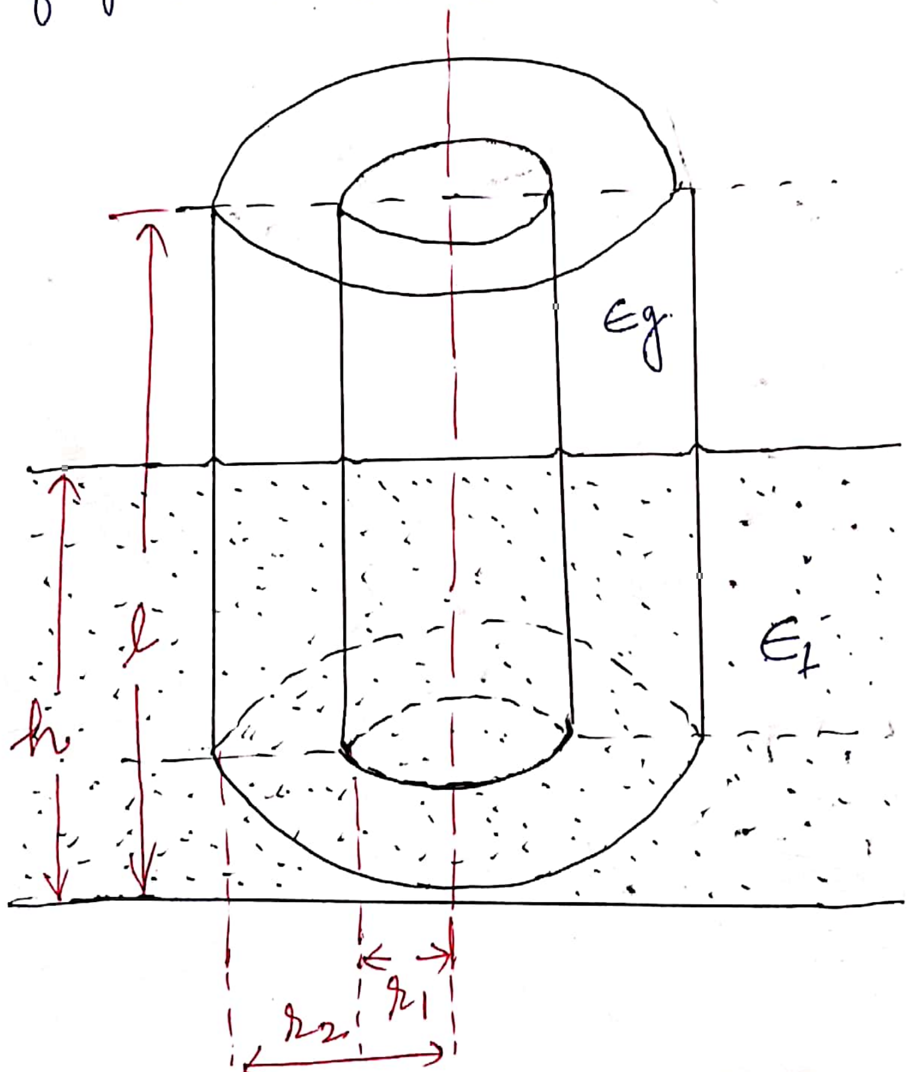
where v is the propagation velocity of the wave.



(Representation of time of flight measurement)

6.2: Capacitive Liquid Level Measurement;

The level of noncondučting liquid can be determined by capacitive techniques.
The method is generally based on difference between the dielectric constant of the liquid and that of gas or air above it.



The height of liquid, h, is measured relative to the total height, l,.
The usual operational condition dictate that the spacing between the electrodes, $s = r_2 - r_1$, should be much less than the radius of inner electrode, r_1,. Futhermore, the tank height should be much greater than, r_2,

A_2

when these conditions apply, the capacitance is approximated by:

$$\boxed{C = \frac{\varepsilon_1 (l) + \varepsilon_g (h-l)}{4.6 \log [1-(s/r)}}$$

where,

ε_1 and ε_g are diectric constant of the liquid and gas (or air).

→ ✓ A typical application is the measurement of the amount of gasoline in a tank in airplanes. The dielectric constant for gasoline is approximately equal to 2, while that of air is approximately equal to 1. A linear change in capacitance with gasoline level is expected for this situation.

✓ Quite high accuracy can be achieved if the denominator is kept quite small.

✓ These sensors often incorporate an ac deflection bridge.