Unit II
Transducers

Transducer

A transducer is a device that converts one form of energy to other form. It converts the measured to a usable electrical signal.

In other words it is a device which transforms a non-electrical physical quantity (i.e. temperature, sound or light) into an electrical signal (i.e. voltage, current, capacity…)

Instrumentation system

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.

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

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 resistance, capacitance, inductance or some other electrical parameter in response to the quantity to be measured.

Active and Passive transducers

Active Transducers

- Self-generating type.
- Energy for generating output is obtained from physical phenomenon.
  - Thermocouple
  - Piezoelectric transducer
  - Photovoltaic cell
  - Photoelectric (photoemission) cell

Passive Transducers

- Externally powered.
- Resistance type
  - Strain gauge
  - Potentiometric device
  - Thermistor
- Inductive type
  - LVDT
- Capacitive type
  - Hall effect transducer

Basic requirements of a transducer

- ***Linearity*** – characteristics between input and output.
- ***Ruggedness*** – ability to withstand overload and protection measures.
- ***Repeatability*** – ability to produce same output for same input at different times and environment.
- ***High stability & reliability*** – output should not be affected by temperature, vibration, other environmental conditions, with minimal error.
- ***Good dynamic response*** – ability to change output quickly for dynamic variation in input with respect to time.
- ***Convenient instrumentation*** – high analog output, high SNR, direct measurement or after amplification.
- ***Good mechanical characteristics*** – ability to withstand deformation and deterioration in performance caused by various mechanical strains.

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 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 m^2

ρ = resistivity of conductor material in Ω-m.

Capacitive Transducer

- In capacitive transduction transducers the measurand is converted to a change in the capacitance.
- The relationship between the capacitance and the size of capacitor plate, amount of plate separation, and the dielectric is given by

$$C = \varepsilon_0 \varepsilon_r A / d$$

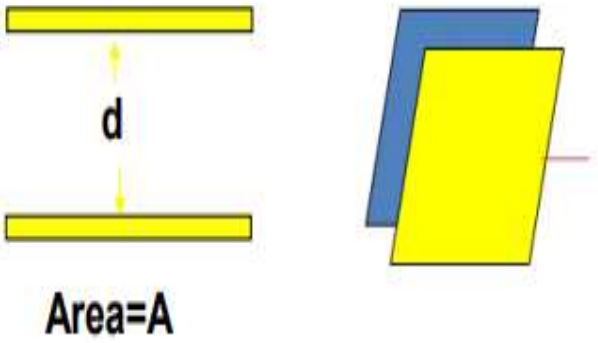
d is the separation distance of plates (m)

C is the capacitance (F, Farad)

ε_0 : absolute permittivity of vacuum

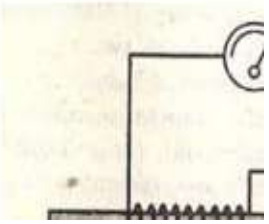
ε_r : relative permittivity

A is the effective (overlapping) area of capacitor plates (m2)



Inductive Transducer

- When a force is applied to the ferromagnetic armature, the air gap changes, varying the reluctance of the magnetic circuit.
- Applied force is measure as change of inductance in the coil.
- Can measure both static and dynamic changes.
- *Drawback* → Limited frequency response.



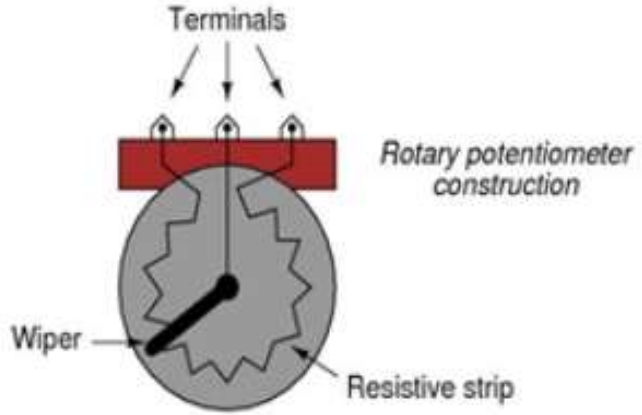
RESISTIVE TRANSDUCER

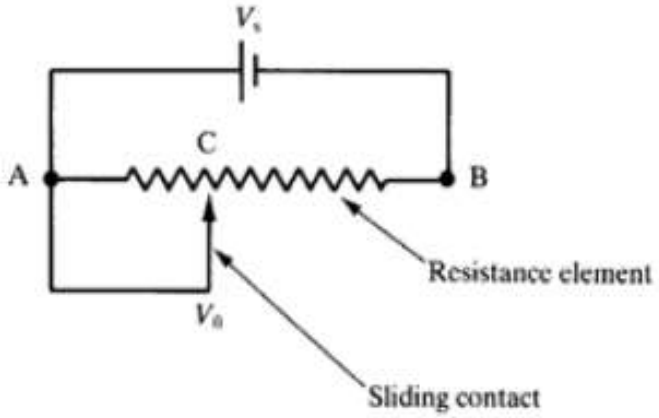
There are 4 type of resistive transducers.

1. Potentiometers (POT)
2. Strain gauge
3. Thermistors
4. Resistance thermometer

POTENTIOMETER

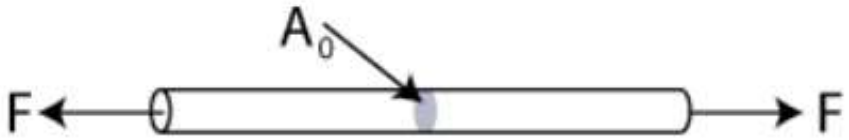
- The potentiometer are used for voltage division. They consist of a resistive element provided with a sliding contact. The sliding contact is called as wiper.
- The contact motion may be linear or rotational or combination of the two. The combinational potentiometer have their resistive element in helix form and are called helipots.
- Fig shows a linear pot and a rotary pot.





Strain Gauge

- The resistance of a **strain gauge** changes when force is applied and this change will give a different electrical output.
- Strain gauges use this method to measure pressure, force, weight and tension.
- A strain is the amount of deformation of a body due to an applied force
- Strain can be positive(tensile)– when conductor is stretched
- Negative(compressive)– when conductor is compressed

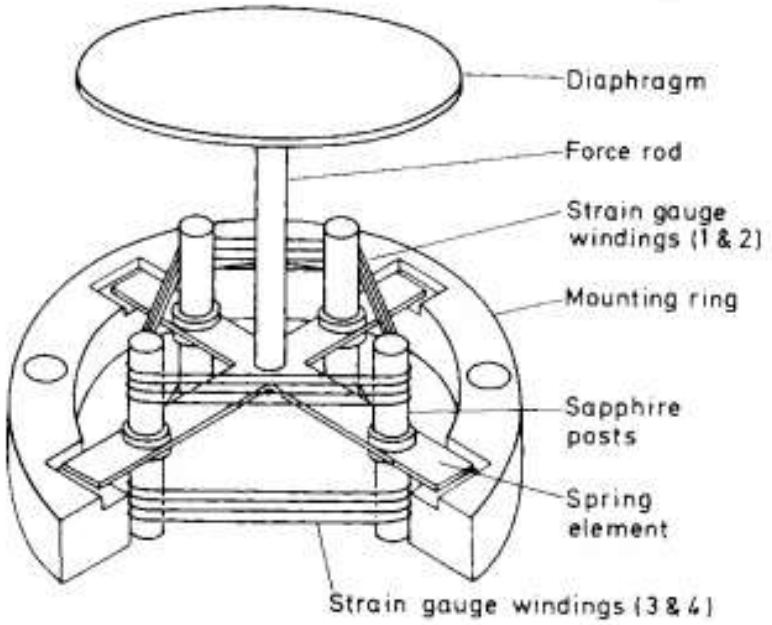


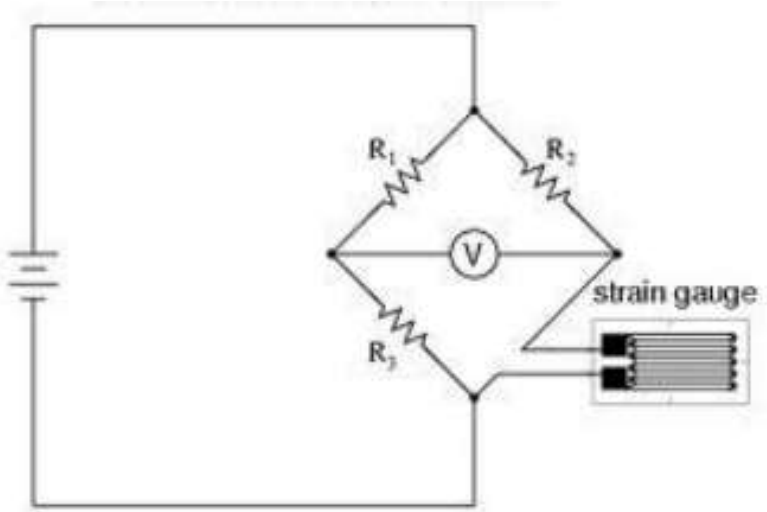
$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$

Types of Strain Gauges

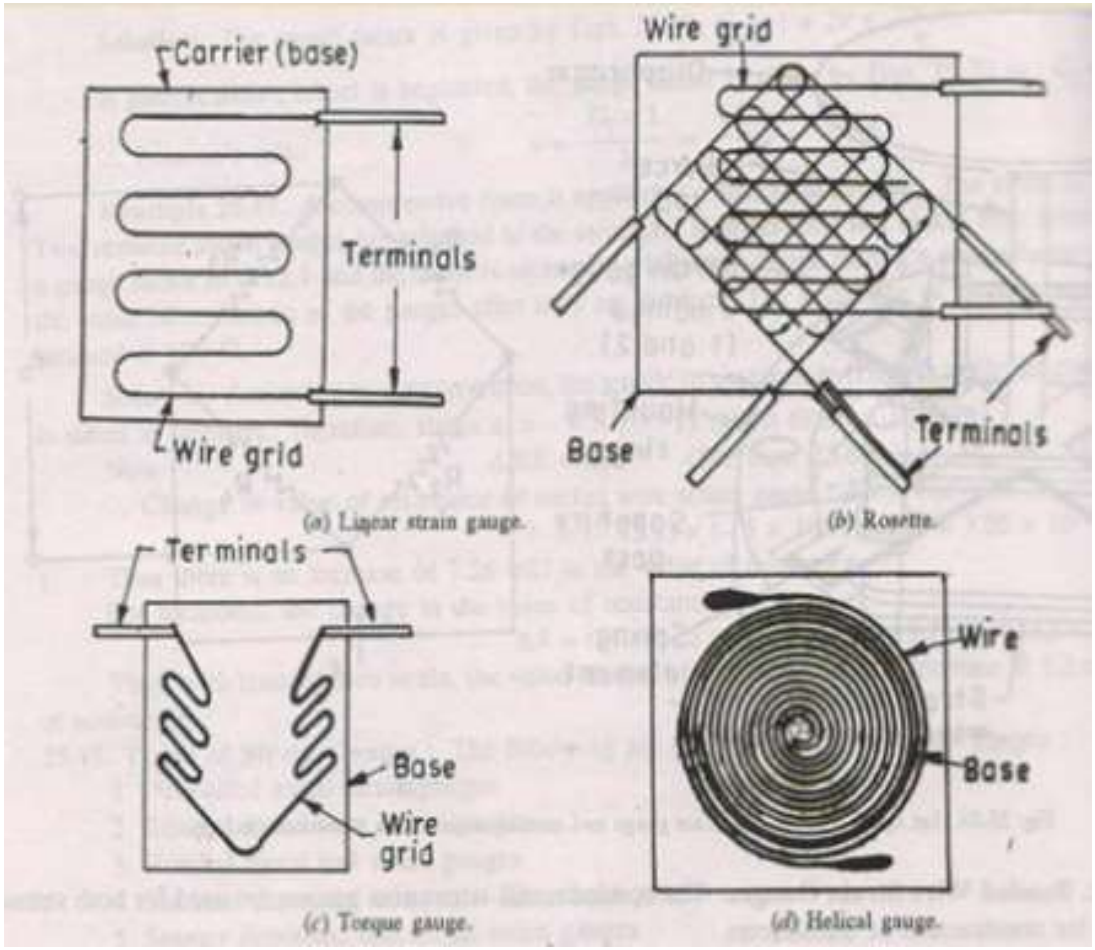
1. Wire Strain Gauge
    a. Unbonded Strain Gauge
    b. Bonded Strain Gauge
2. Foil Strain Gauge
3. Semiconductor Strain Gauge

Unbonded Strain Gauge





Bonded Strain Gauge



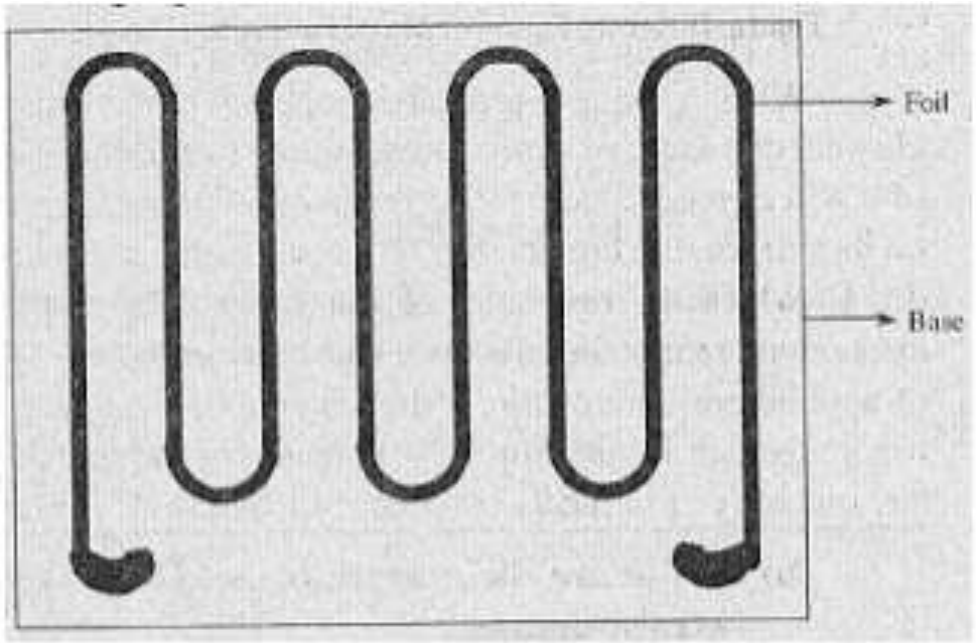
Gauge Factor: Sensitivity of strain gauge is called Gauge Factor(K)

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

$\Delta R/R$ = Change in resistance due to strain

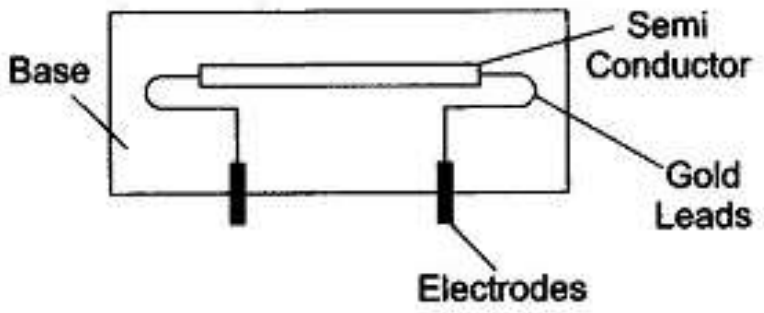
$\Delta L/L$ = Change in length due to strain

Foil Strain Gauge



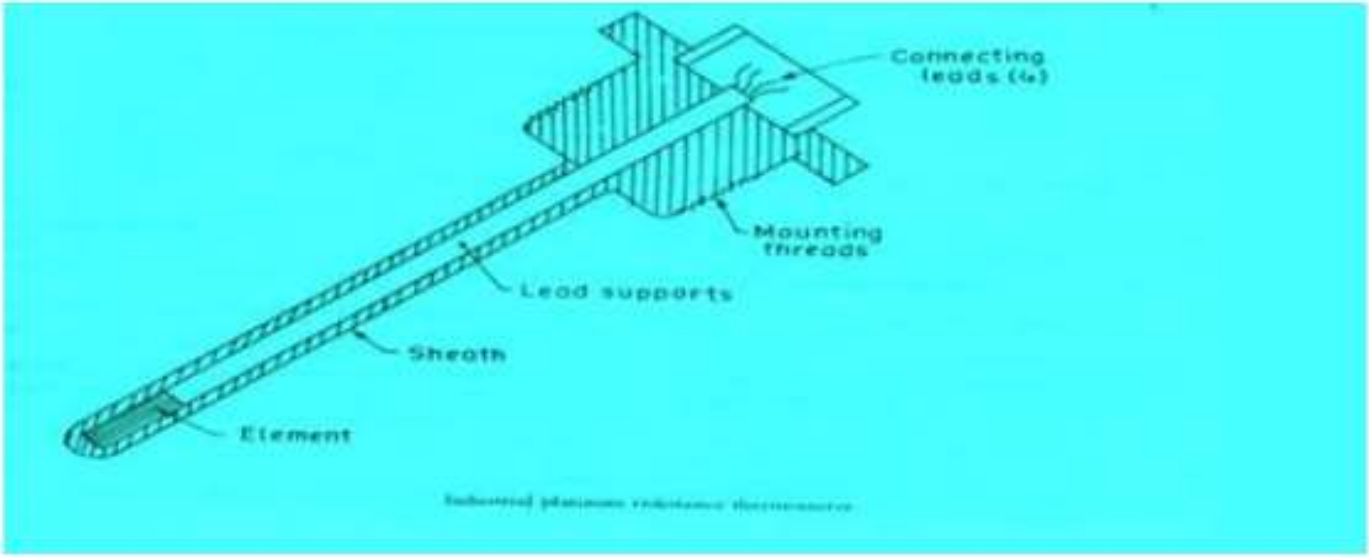
Semiconductor Strain Gauge

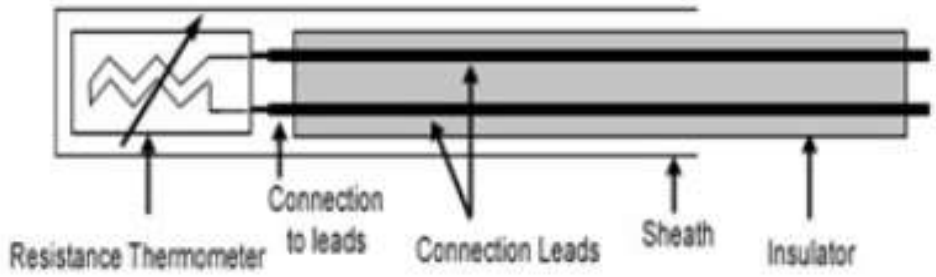
- To achieve a high sensitivity a high value of gauge factor is desirable
- These are used when a very high gauge factor is required



RESISTANCE THERMOMETER

- Resistance of metal increase with increases in temperature. Therefore metals are said to have a positive temperature coefficient of resistivity.
- Fig shows the simplest type of open wire construction of platinum résistance thermometer. The platinum wire is wound in the form of spirals on an insulating material such as mica or ceramic.
- This assembly is then placed at the tip of probe
- This wire is in direct contact with the gas or liquid whose temperature is to be measured.


Connecting leads (4)
Mounting threads
Lead supports
Sheath
Element


Resistance Thermometer
Connection to leads
Connection Leads
Sheath
Insulator

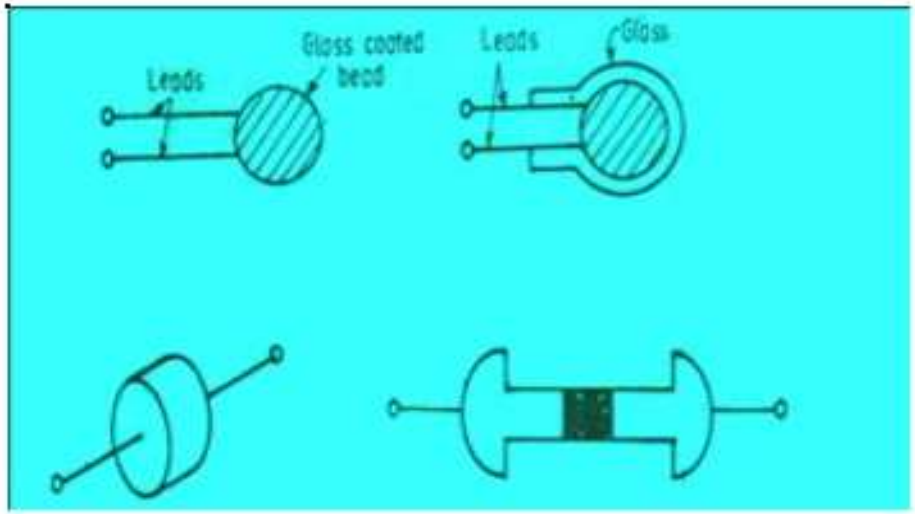
- The resistance of the platinum wire changes with the change in temperature of the gas or liquid
- This type of sensor have a positive temperature coefficient of resistivity as they are made from metals they are also known as resistance temperature detector
- Resistance thermometer are generally of probe type for immersion in medium whose temperature is to be measured or controlled.

THERMISTOR

- Thermistor is a contraction of a term "thermal resistor".
- Thermistor are temperature dependent resistors. They are made of semiconductor material which have negative temperature coefficient of resistivity i.e. their resistance decreases with increase of temperature.
- Thermistor are widely used in application which involve measurement in the range of 0-60° Thermistor are composed of sintered mixture of metallic oxides such as magnese, nickle, cobalt, copper, iron and uranium

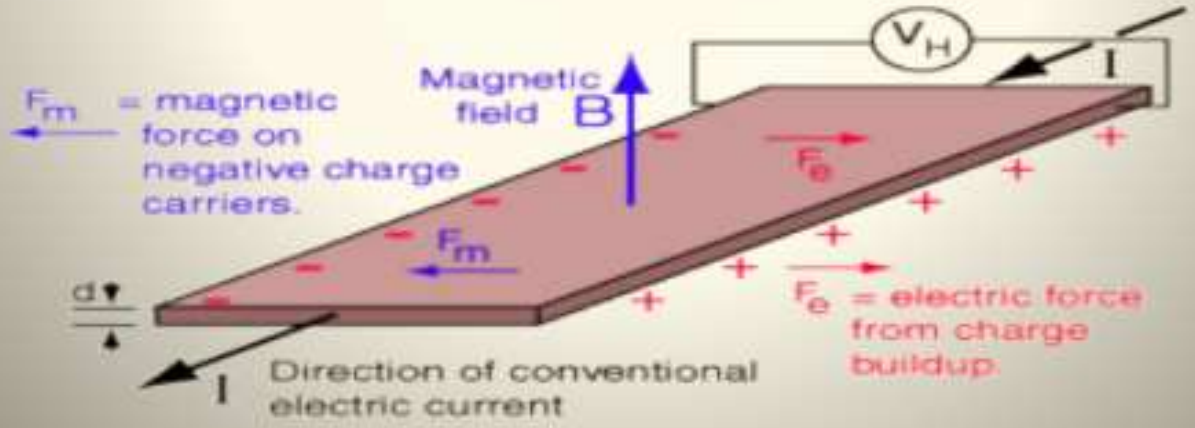
Contd.

- The thermistor may be in the form of beads, rods and discs.
- The thermistor provide a large change in resistance for small change in temperature. In some cases the resistance of themistor at room temperature may decreases as much as 6% for each 1°C rise in temperature.



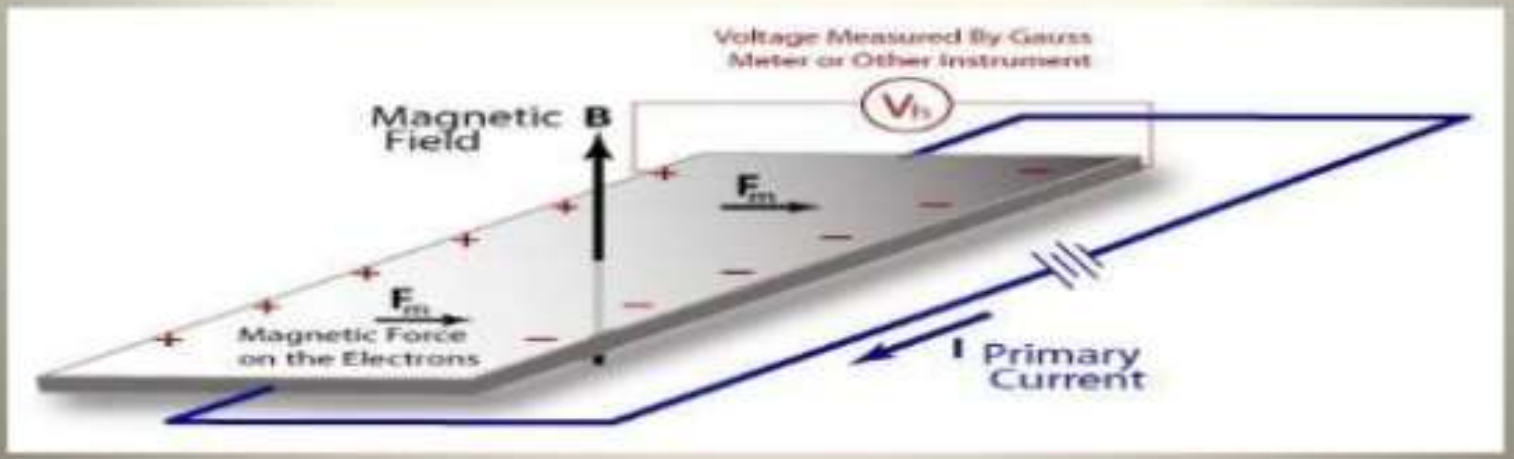
What is Hall Effect?

- The Hall effect is the production of a voltage difference (the Hall voltage) across a current carrying conductor (in presence of magnetic field), perpendicular to both current and the magnetic field.



Working

- When a current-carrying conductor is placed into a magnetic field, a voltage will be generated perpendicular to both the current and the field.
- When a perpendicular magnetic field is present. A Lorentz force is exerted on the electron. Due to which Electron moves in perpendicular direction to both current and Magnetic Field. And develop a Potential difference across the conductor or semiconductor.

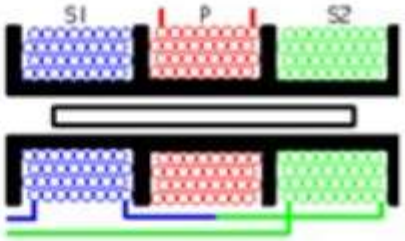


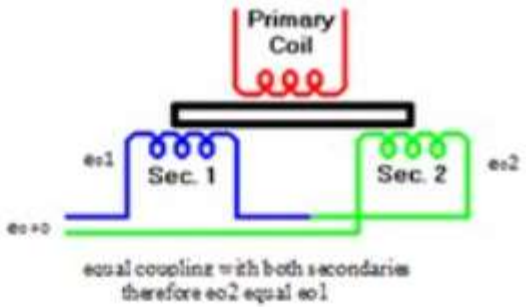
Application

- Used as Magnetometers, i.e. to measure magnetic field.
- **Hall effect sensor is also used as Current Sensor.**
- **Magnetic Position Sensing in Brushless DC Electric Motors**
- Automotive fuel level indicator.
- Spacecraft propulsion.

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER(LVDT)

- AN LVDT transducer comprises a coil former on to which three coils are wound.
- The primary coil is excited with an AC current, the secondary coils are wound such that when a ferrite core is in the central linear position, an equal voltage is induced in to each coil.
- The secondary are connected in opposite so that in the central position the outputs of the secondary cancels each other out.





LVDT contd…

- The excitation is applied to the primary winding and the armature assists the induction of current in to secondary coils.
- When the core is exactly at the center of the coil then the flux linked to both the secondary winding will be equal. Due to equal flux linkage the secondary induced voltages (eo1 & eo2) are equal but they have opposite polarities. Output voltage eo is therefore zero. This position is called "null position"

- Now if the core is displaced from its null position toward sec1 then flux linked to sec1 increases and flux linked to sec2 decreases. Therefore $e_{o1} > e_{o2}$ and the output voltage of LVDT e_o will be positive
- Similarly if the core is displaced toward sec2 then the $e_{o2} > e_{o1}$ and the output voltage of LVDT e_o will be negative.

Advantages and Disadvantages

Advantages of LVDT

- The transducers possess a high sensitivity.
- The transducers have low hysteresis and hence repeatability is excellent under all conditions.
- They have infinite resolution.
- They are simple, light in weight and easy to maintain.

Disadvantages of LVDT

- They are sensitive to stray magnetic fields but shielding is possible.
- They are inherently low in power output.
- Temperature affects the perfomance of transducer.

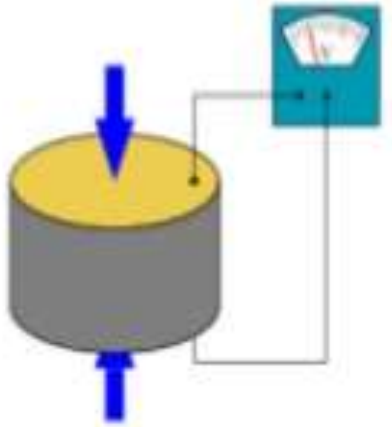
Applications

- The LVDT can be used in all applications where displacements ranging from fraction of a mm to a few cm have to be measured.

- Acting as a secondary transducer it can be used as a device to measure force, weight and pressure.

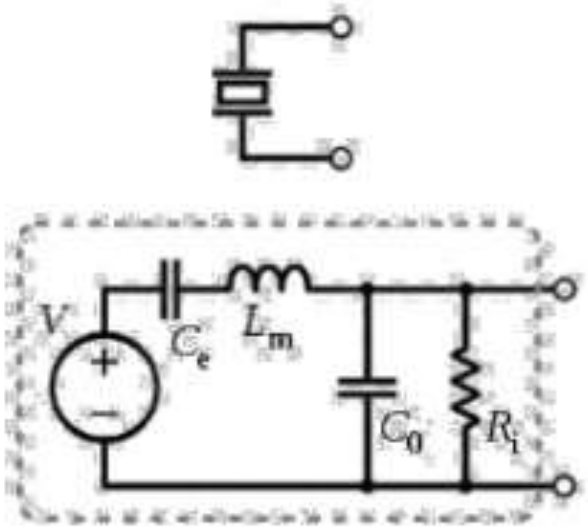
PIEZOELECTRIC TRANSDUCERS

- The piezoelectric transducers work on the principle of PIEZOELECTRIC EFFECT. When mechanical stress or forces are applied to some materials along certain planes, they produce electric voltage. This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force.

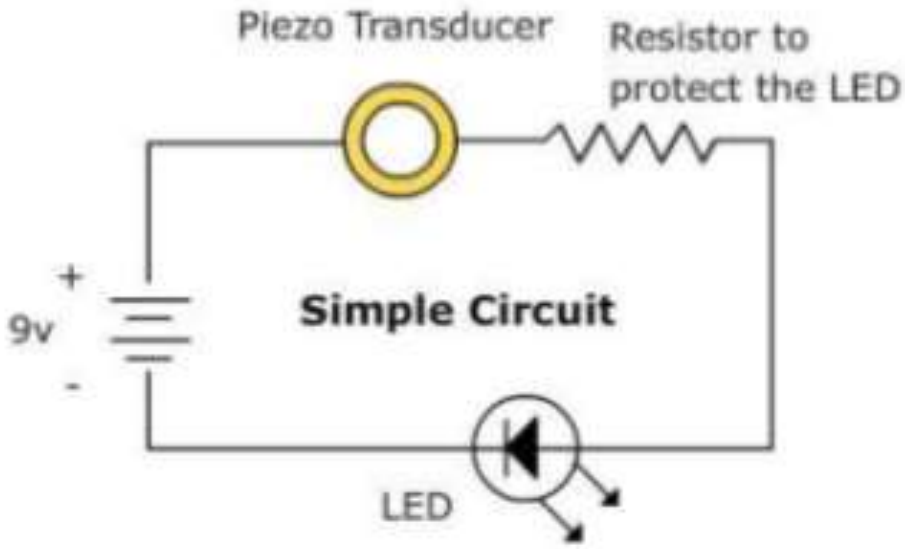


A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated)

- The voltage output obtained from the materials due to piezoelectric effect is very small and it has high impedance. To measure the output some amplifiers, auxiliary circuit and the connecting cables are required.

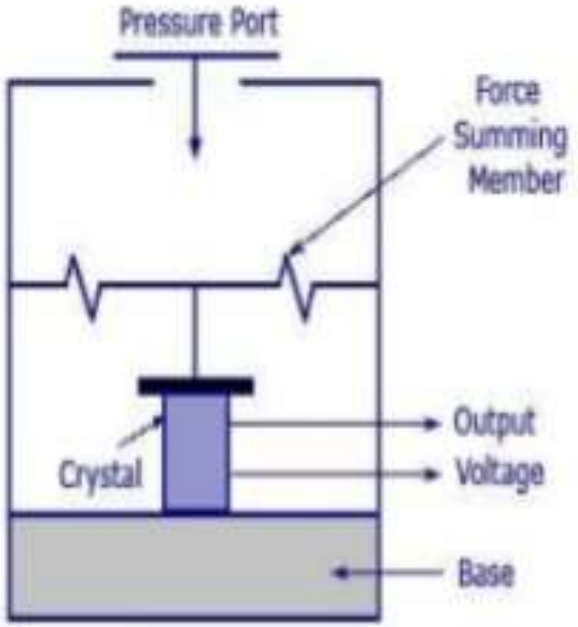


symbol



CONSTRUCTION and WORKING

- The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member.
- If a force is applied on the pressure port, the same force will fall on the force summing member.
- Thus a potential difference will be generated on the crystal due to its property. The voltage produced will be proportional to the magnitude of the applied force.



Piezo-Electric Transducer

Advantages of Piezoelectric Transducers

- **High frequency response:** They offer very high frequency response that means the parameter changing at very high speeds can be sensed easily.
- **High transient response:** The piezoelectric transducers can detect the events of microseconds and also give the linear output.
- The piezoelectric transducers are **small in size** and have rugged construction.

Thermocouple

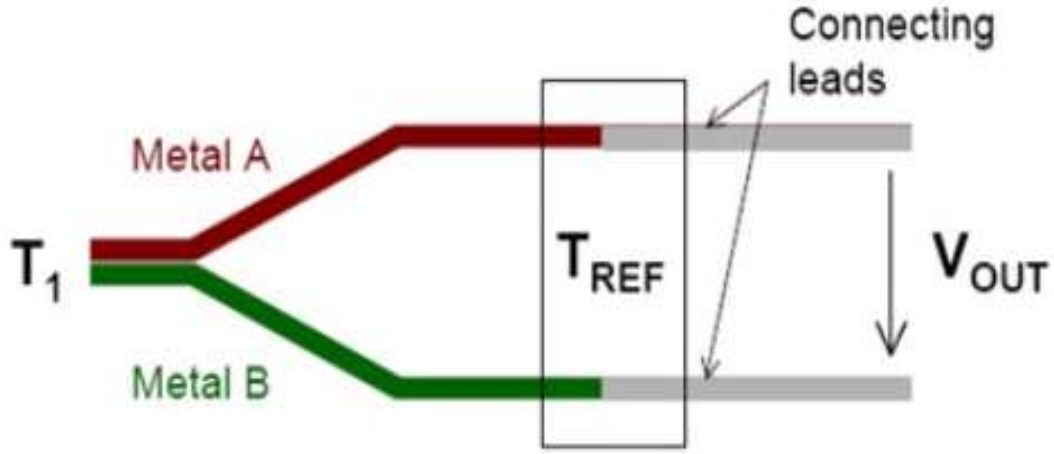
- A thermoelectric transducer that converts heat directly into electricity, according to the Seebeck effect.
- This can be used to generate electricity, measure temperature difference or change the temperature of objects.

Thermocouples

See beck Effect

When a pair of dissimilar metals are joined at one end, and there is a temperature difference between the joined ends and the open ends, thermal emf is generated, which can be measured in the open ends.

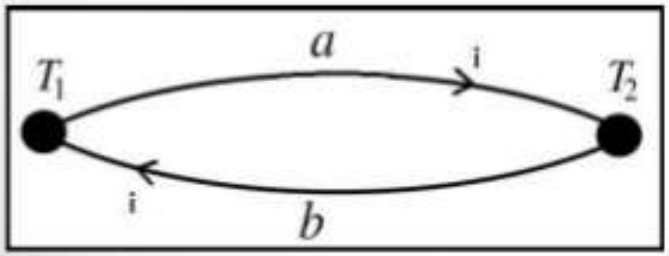
This forms the basis of thermocouples.



The Seebeck Effect

temperature difference between two junctions

voltage difference between them which drives the current

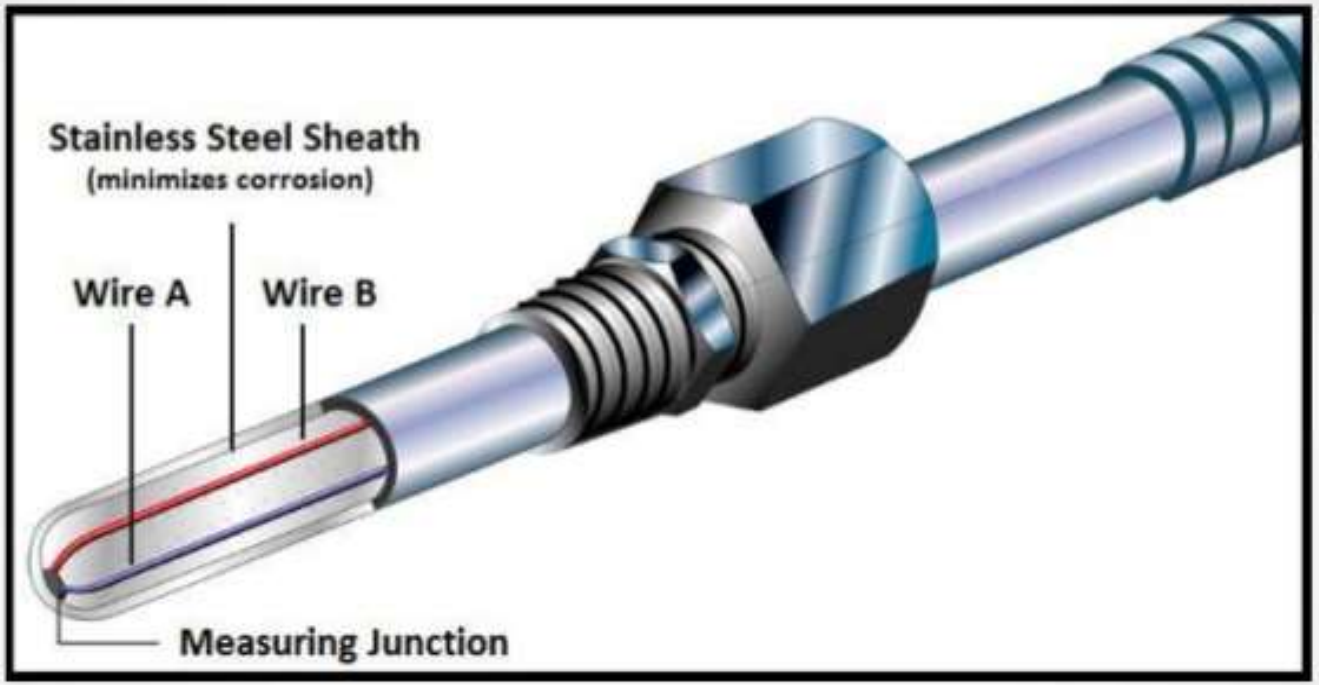


$$E_{emf} = - S \nabla T$$

where, S is the Seebeck coefficient

$\nabla T = T_1 - T_2$

How it looks like ?



Its construction consists of two conductors, welded together at the measuring point and insulated from each other along the length, inside an outer protection sheath.

- Thus Thermocouple consists of two dissimilar wires insulated from each other but joined at one end.
- The net emf and the current in the circuit is a function of difference in temperature between hot and cold junctions.

Applications

- Temperature Measurement
- Power Generation
- Radiation Sensors
- Gas Safety Equipments
- Manufacturing Industry

Difference between Sensor & Transducer

No.	Differential Matters	Sensor	Transducer
01.	Definition	A sensor is a device which detects one form of energy and converts the data to electrical energy	A transducer is a device which converts one form of energy into another. So sensors are, in fact, a type of transducer
02.	Function	A sensor is a device which detects a physical quantity and produces an electric signal based on the strength of the quantity measured.	A transducer is a device which converts one form of energy into anther form.
03.	Sensing Element	Sensing element itself	Sensing element plus any associated circuitry
04.	Feedback	A sensor merely measures a quantity and cannot, by itself, give feedback to the system.	A transducers can convert between any forms of energy, they can be used to provide feedback to the system.

Ultrasonic Sensors

- **Ultrasonic transducers** and **ultrasonic sensors** are devices that generate or sense ultrasound energy.

Ultrasonic Sensor

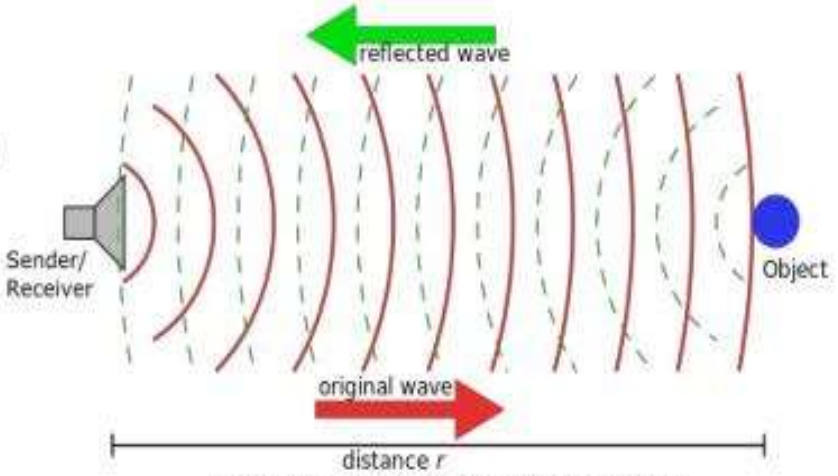
- An ultrasonic sensor has two parts:
  - A transmitter that sends out a signal that humans cannot hear
  - A receiver that receives the signal after it has bounced off nearby objects
- The sensor sends out its signal and determines how long the signal takes to come back.
  - If the object is very close to the sensor, the signal comes back quickly
  - If the object is far away from the sensor, the signal takes longer to come back
  - If objects are too far away from the sensor, the signal takes so long to come back (or is very weak when it comes back) that the receiver cannot detect it
- The sensor sends a message back to the computer brick telling it the time taken for the signal to return. Then the brick uses this info to compute how far away the object is.

Can you name a similar sensing performed by a bird that works like this?

How Can We Measure Distance?

The ultrasonic sensor sends out sound from one side and receives sound reflected from an object on the other side.

The sensor uses the time it takes for the sound to come back from the object in front to determine the distance of an object.



Bats use the same principle!

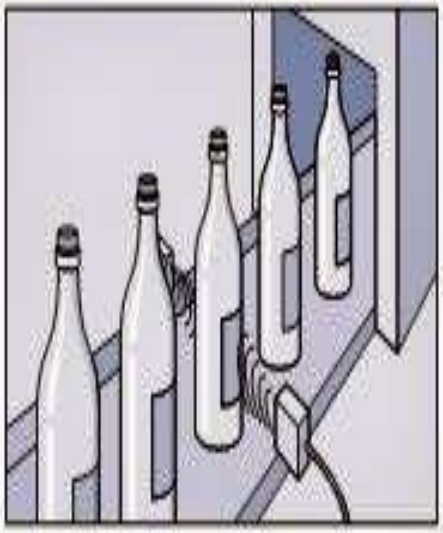
- The "sonic" in ultrasonic refers to sound, and "ultra" means that humans cannot hear it (but bats and dogs can hear those sounds).
- The ultrasonic sensor can measure distances in centimeters and inches. It can measure from 0 to 2.5 meters, with a precision of 3 cm.
- It works very well and provides good readings in sensing large-sized objects with hard surfaces. But, reflections from soft fabrics, curved objects (such as balls) or very thin and small objects can be difficult for the sensor to read.
- Note: Two ultrasonic sensors in the same room may interfere with each other's readings.

HC-SR04 Pinout

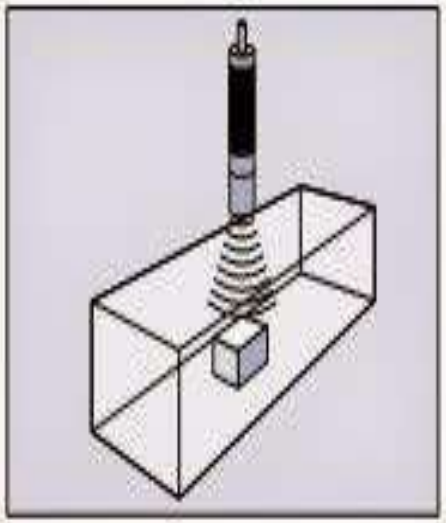
Applications

- Ultrasonic sensor is used in oil, chemical, milk or water tanks for level measurements or for liquid level control.
- This sensor is used in car parking system where car entry is controlled through barrier system, the barrier must not be lowered when there is beneath a vehicle. This whole process is controlled through ultrasonic sensor.

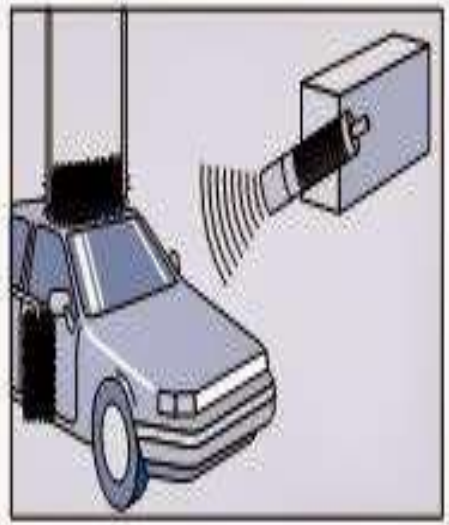
- This sensor is used with bottle cutting and drink filling machines, where bottle is detecting at serval points and for this continuous monitoring the ultrasonic sensor is used.
- This sensor is used in transporting printed circuit boards (PCBs) industry where smart phones, computer mother boards and home appliances circuit boards are designed and print.
- This sensor is used in car manufacturing industry for manufacturing or assemble the car automatically.
- This sensor is used in car washing system for detecting and washing the car automatically.
- This sensor is used for detecting the speed of motor or generator.
- This sensor is also used in presence detection system



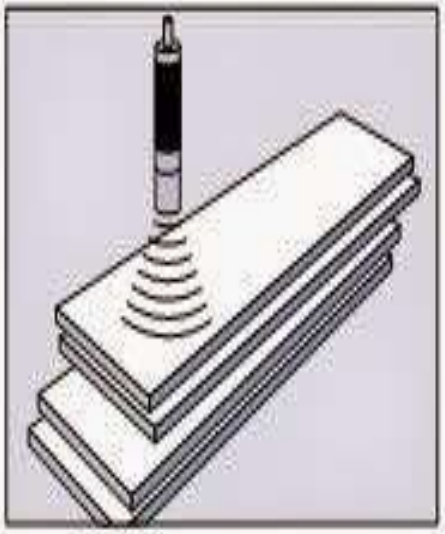
Application
Bottle Counting



Application
Object Sensing

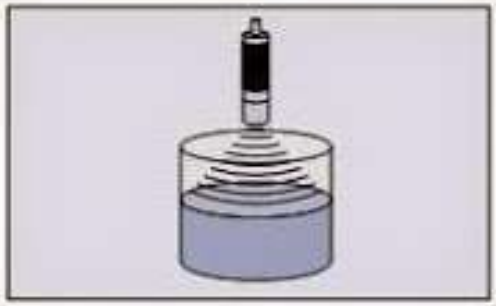


Application
Vehicle Sensing and
Positioning

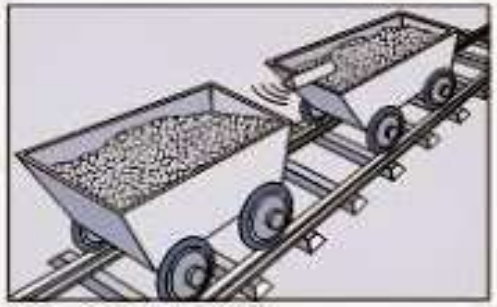


Application
Stack Height Sensing

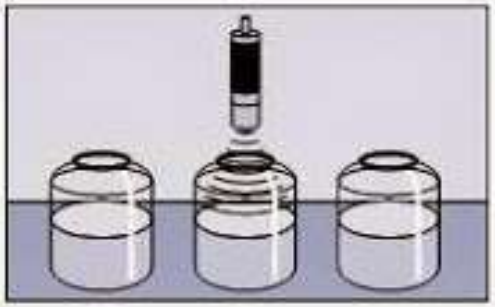
Ultrasonic Sensors Application



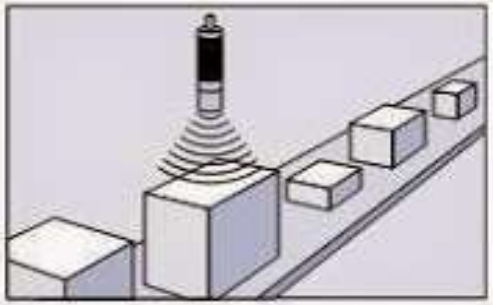
Application
Level Measurement in Large Vessels (Tanks, Silos)



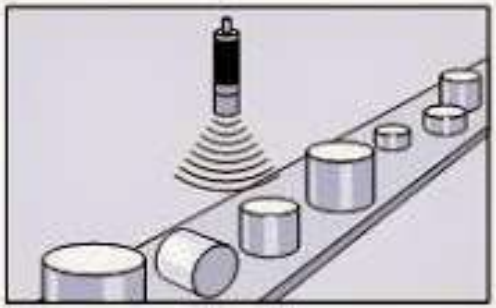
Application
Anti-Collision



Application
Level Measurement in Small Bottles

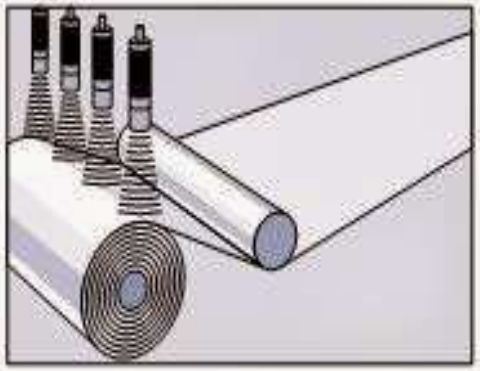


Application
Height Sensing

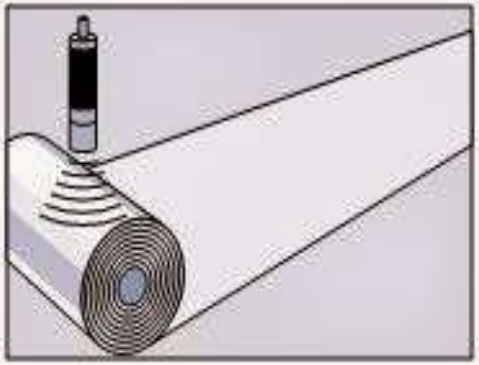


Application
Quality Control

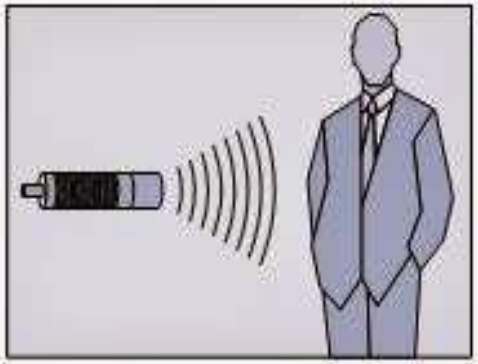
Application
Breakage Sensing



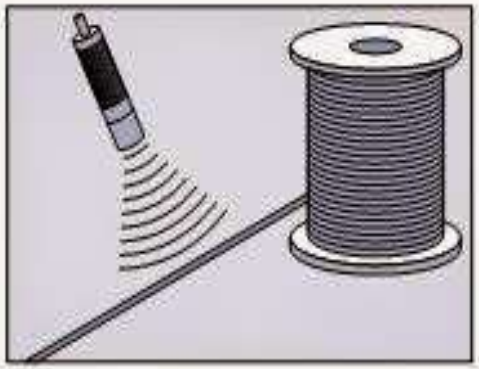
Application
Contour Recognition



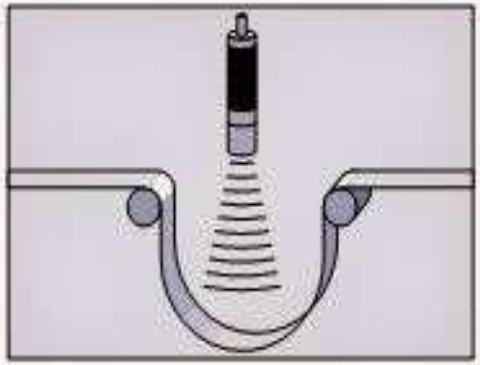
Application
Diameter Sensing and
Strip Speed Control



Application
People Sensing



Application
Wire and Rope
Breakage Monitoring



Application
Loop Control

PIR Sensor

- **Passive Infrared Sensor (PIR Sensor)** is an electronic sensor that measures infrared(IR) light radiating from objects in its field of view. They are most often used in PIR-based motion detectors.
- PIR sensors detect general movement, but do not give information on who or what moved. For that purpose, an imaging IR sensor is required.

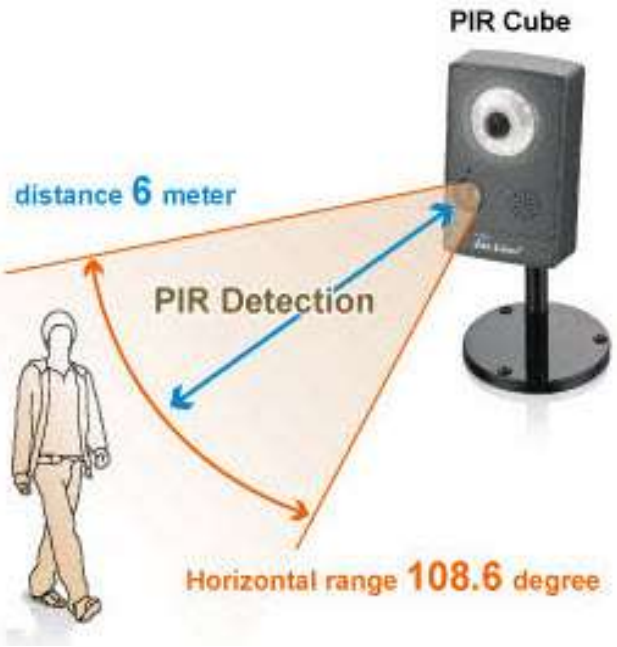
- PIR sensors are commonly called simply "PIR", or sometimes "PID", for "passive infrared detector". The term passive refers to the fact that PIR devices do not radiate energy for detection purposes. They work entirely by detecting infrared radiation(radiant heat) emitted by or reflected from objects.
- A PIR-based motion detector is used to sense movement of people, animals, or other objects. They are commonly used in burglar alarms and automatically activated lighting systems.

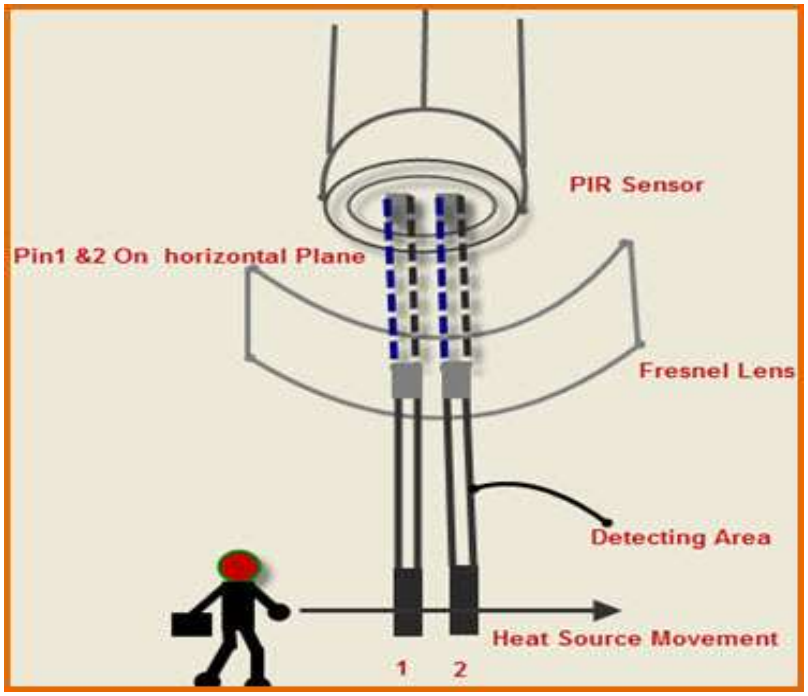
Operation:

- A PIR sensor can detect changes in the amount of infrared radiation impinging upon it, which varies depending on the temperature and surface characteristics of the objects in front of the sensor.
- When an object, such as a person, passes in front of the background, such as a wall, the temperature at that point in the sensor's field of view will rise from room temperature to body temperature, and then back again. The sensor converts the resulting change in the incoming infrared radiation into a change in the output voltage, and this triggers the detection.
- Objects of similar temperature but different surface characteristics may also have a different infrared emission pattern, and thus moving them with respect to the background may trigger the detector as well.

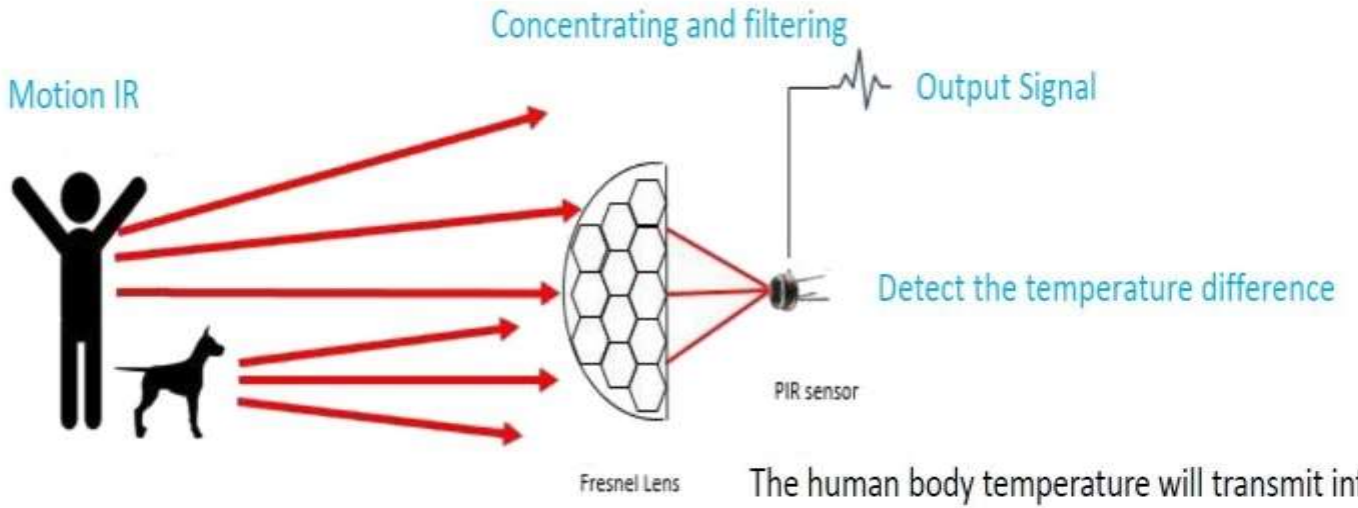
- PIRs come in many configurations for a wide variety of applications. The most common models have numerous Fresnel lenses or mirror segments, an effective range of about 10 meters (30 feet), and a field of view less than 180°.
- Models with wider fields of view, including 360°, are available, typically designed to mount on a ceiling. Some larger PIRs are made with single segment mirrors and can sense changes in infrared energy over 30 meters (100 feet) from the PIR. There are also PIRs designed with reversible orientation mirrors which allow either broad coverage (110° wide) or very narrow "curtain" coverage, or with individually selectable segments to "shape" the coverage.

PIR Sensor Detection Area and PIR Sensor Working





Passive Infrared Sensing Principle (PIR)



The human body temperature will transmit infrared with a wavelength of 10um. The infrared are enhanced by a Fresnel filter and concentrated on the PIR sensor . When the pyroelectric element receives the infrared temperature change of the human body, it will lose the electric charge balance and release the electric charge, subsequent circuits can generate the signals after detection the electric charge.

DHT Sensor

- DHT11 is a low-cost digital sensor for sensing temperature and humidity. This sensor can be easily interfaced with any micro-controller such as Arduino, Raspberry Pi etc… to measure humidity and temperature instantaneously.
- DHT11 humidity and temperature sensor is available as a sensor and as a module. The difference between this sensor and module is the pull-up resistor and a power-on LED. DHT11 is a relative humidity sensor.
- To measure the surrounding air this sensor uses a thermistor and a capacitive humidity sensor.

Working Principle of Digital Temperature and Humidity Sensor

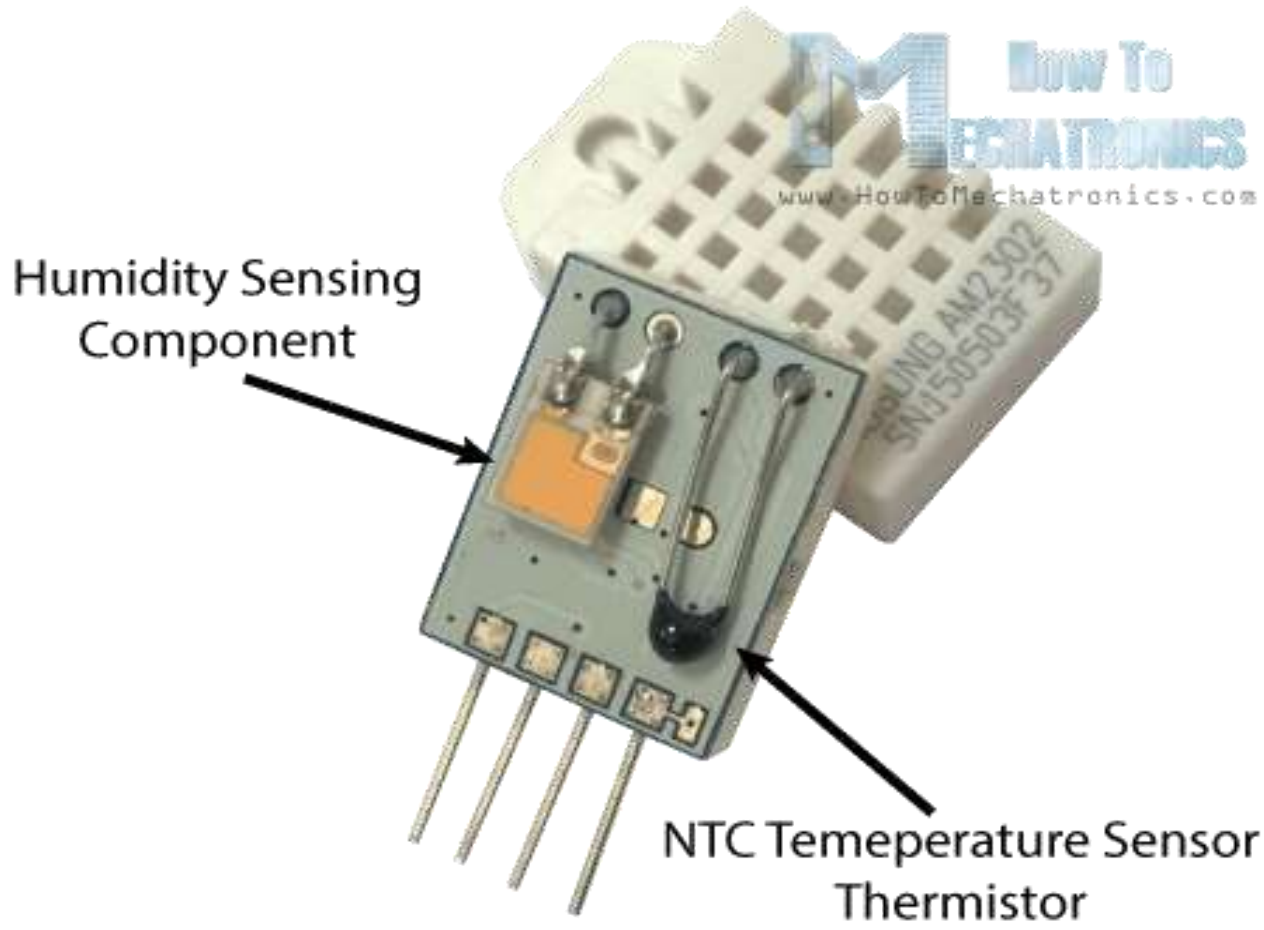
- **DHT11** is a commonly used **Temperature and humidity sensor.** DHT11 sensor consists of a capacitive humidity sensing element and a thermistor for sensing temperature.
- The humidity sensing capacitor has two electrodes with a moisture holding substrate as a dielectric between them.
- Change in the capacitance value occurs with the change in humidity levels. The IC measure, process this changed resistance values and change them into digital form.
- For measuring temperature this sensor uses a Negative Temperature coefficient thermistor, which causes a decrease in its resistance value with increase in temperature.

- To get larger resistance value even for the smallest change in temperature, this sensor is usually made up of semiconductor ceramics or polymers.
- The temperature range of DHT11 is from 0 to 50 degree Celsius with a 2-degree accuracy. Humidity range of this sensor is from 20 to 80% with 5% accuracy. The sampling rate of this sensor is 1Hz .i.e. it gives one reading for every second. DHT11 is small in size with operating voltage from 3 to 5 volts. The maximum current used while measuring is 2.5mA.

DHT11 sensor has four pins- VCC, GND, Data Pin and a not connected pin. A pull-up resistor of 5k to 10k ohms is provided for communication between sensor and micro-controller.

Applications

- This sensor is used in various applications such as measuring humidity and temperature values in heating, ventilation and air conditioning systems. Weather stations also use these sensors to predict weather conditions.
- The humidity sensor is used as a preventive measure in homes where people are affected by humidity. Offices, cars, museums, greenhouses and industries use this sensor for measuring humidity values and as a safety measure.


Humidity Sensing
Component
NTC Temeperature Sensor
Thermistor
www.HowToMechatronics.com

- For measuring humidity they use the humidity sensing component which has two electrodes with moisture holding substrate between them. So as the humidity changes
- The conductivity of the substrate changes or the resistance between these electrodes changes. This change in resistance is measured and processed by the IC which makes it ready to be read by a microcontroller.

- A thermistor is actually a variable resistor that changes its resistance with change of the temperature. These sensors are made by sintering of semiconductive materials such as ceramics or polymers in order to provide larger changes in the resistance with just small changes in temperature.
- The term “NTC” means “Negative Temperature Coefficient”, which means that the resistance decreases with increase of the temperature.