Module 6 – Physics of Sensors

Session 1 : Resistive Sensor - PT100

(Temperature and Humidity measurement)

Prerequisites:

A transducer is a device used to convert energy from one form to another. These devices deal with different types of energies such as mechanical, electrical energy, light energy, chemical energy, thermal energy, acoustic energy, electromagnetic energy, and so on.

There are a variety of transducer types like pressure transducer, piezoelectric transducer, ultrasonic transducer, temperature transducer etc.

Some transducer types like **active transducer** and **passive transducers** are based on whether a power source is required or not. **Active transducer** doesn't require any power source for their operations. These transducers work on the principle of energy conversion. They generate an electrical signal that is proportional to the input. The best example of this transducer is thermocouple. P**assive transducer** requires an external power source for their operation. They generate an output in the form of capacitance, resistance. Then that has to be converted to an equivalent voltage or current signal. The best example of a passive transducer is a photocell.

Piezoelectric Transducer
A piezoelectric transducer is a special kind of sensor which is used to convert mechanical energy into electrical energy. In the same way, electrical energy can be transformed into mechanical energy.

Pressure Transducer
A pressure transducer is a sensor that alters the pressure into electrical signals. These transducers are used in pressure indicators, manometers, piezometers, transmitters, and pressure sensors.

Temperature Transducer
Temperature transducer is a device that is used to convert the temperature of a device into another quantity like electrical energy or pressure or mechanical energy.

Ultrasonic Transducer
The main function of the ultrasound transducer is to convert electrical signals to ultrasound waves. This transducer can also be called as capacitive or piezoelectric transducers. This transducer can be used to measure the distance of the sound based on reflection.

Calibration

If we are using some device for measuring some physical quantity, we must be sure that the device is giving us correct readings. For this calibration is done.
calibration is the comparison of measurement values done by a device under test with those of a calibration standard of known accuracy. Over time, results and accuracy may 'drift' when using particular technologies or measuring particular parameters such as temperature and humidity. So, it is a need to maintain the calibration of the device throughout its lifetime for reliable, accurate and repeatable measurements.

The goal of calibration is to minimize any measurement uncertainty by ensuring the accuracy of test device. Calibration quantifies and controls errors or uncertainties within measurement processes to an acceptable level.

Resistive Sensors :

A resistive sensor is a transducer that converts a mechanical change such as displacement or heat or humidity into an electrical signal that can be monitored after conditioning.

Resistive sensors are among the most common in instrumentation. These Transducers do NOT generate electricity. Hence, they are called passive devices. The simplest resistive sensor is the potentiometer. Other resistive sensors include strain gauges, thermocouples, photo-resistors and thermistors.

Temperature measurement by PT100 and its calibration

A PT100 is a sensor used to measure temperature. It is one type of sensor which falls into a group called Resistance Temperature Detectors or RTD's.

The first part, Pt, is the chemical symbol for Platinum and this shows that the sensor is Platinum-based. The second part, 100, indicates resistance of the device in ohms at 0°C. There are other materials that can be used such as Nickel (Ni) and Copper (Cu) and different resistance values such as 50Ω, 500Ω and 1000Ω. This gives the possibility of sensors being identified as follows:- Cu100, Ni120, PT1000 etc.

The PT100 variant is the most commonly used. Sensors using Platinum are the most common group and are referred to as Platinum Resistance Thermometers or PRT's.

Why use Platinum in resistive sensors?

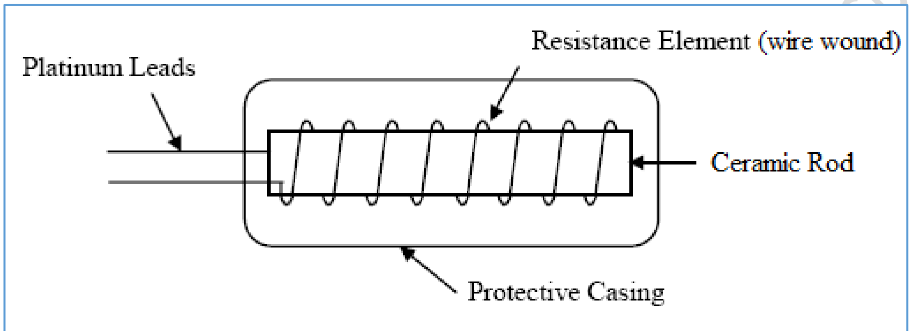
- Platinum gives the greatest linearity and stability as compared to any other material.
- It also has the benefit of being extremely resistant to corrosion and chemical attack.

- It is very stable at high temperatures.
- The mass of Platinum used in manufacturing the sensing elements is extremely small. So, even though platinum is very costly, the cost of the device is not much high.

Construction of PT100

Platinum temperature sensors can be divided into two categories - Temperature sensors with a solid wire winding in glass, ceramic or foil versions, and temperature sensors manufactured using the latest thin-film technology.

The classic platinum temperature sensor is based on the wirewound construction. One or two measurement windings are wound on a ceramic/glass rod, each in the form of a bifilar winding.



PT100 Construction

The winding is fused onto the ceramic and provided with connecting wires. The nominal resistance value is calibrated by altering the length of the winding. Afterwards, a protective case is pushed over the ceramic rod and the measurement winding, and the components are then fused together.

PT100 for Temperature Measurement and calibration

The resistance of the conductor changes when its temperature changes. This property can be utilized for measuring the temperature. The relationship between the temperature and resistance of conductor is given by –

$$R_T = R_0(1 + \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \cdots)$$

Where R_T is resistance of the conductor at temperature T^0C

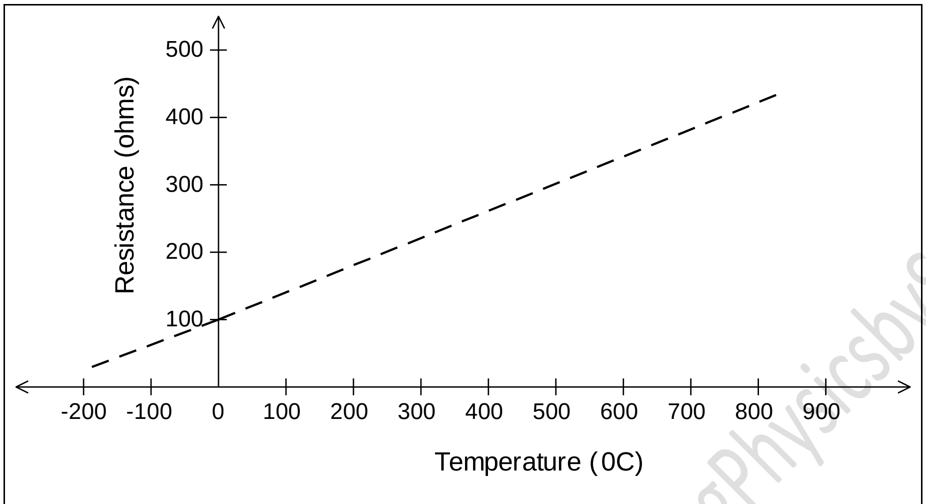
R_0 is resistance of the conductor at temperature 0^0C

$\alpha_1, \alpha_2, \alpha_3$ are temperature coefficients of resistance

PT100 measures temperature by using a change in resistance. For a PT100, the resistance at 0°C is 100Ω and at 100°C, it is 138.5Ω.

For platinum sensors in the range from 0 ^{0}C to 100 ^{0}C, the relationship is almost linear and we can write –

$$R_T = R_0(1 + \alpha T)$$



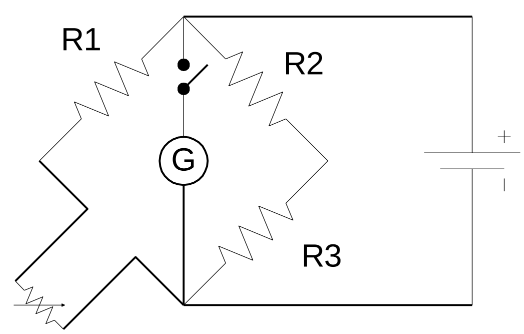
Resistance vs Temperature PT100

If R_0 and R_{100} are the resistance values for the temperatures 0 °C and 100 °C respectively, then the mean temperature coefficient between 0 °C and 100 °C is given by –

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100℃} = \frac{138.5 - 100}{100 \times 100℃} = 0.00385\ /℃$$

Therefore, the change in resistance for each degree Celsius change is 0.00385Ω. It represents the average change in resistance, referred to the reference value at 0 °C

For calibration, a Wheatstone's bridge can be used as shown below-



Rs (PT100)

R1, R2, R3 are constant resistances for the given temperature range. The sensing element (Rs-PT100) is placed in one arm of the bridge. As temperature changes, Rs will change and galvanometer will show deflection. This deflection can be calibrated to give a suitable temperature scale.

Advantages of PT100 in temperature measurement

1. The measurement is accurate.
2. The response time of the sensor is very less.
3. Sensor can be used for a long period of time.
4. Size of sensing element is very small (around 6-12 mm in diameter and 12-75 m in length)

Disadvantages

1. Cost is comparatively high
2. Being a passive device, needs power source.
3. Self-heating may occur

Humidity measurement using resistive sensors

Humidity is the measure of the amount of water vapor (moisture) present in the air. Humidity Sensors are the low cost-sensitive electronic devices used to measure the humidity of the air. These are also known as Hygrometers. Humidity can be measured as Relative humidity, Absolute humidity, and Specific humidity.

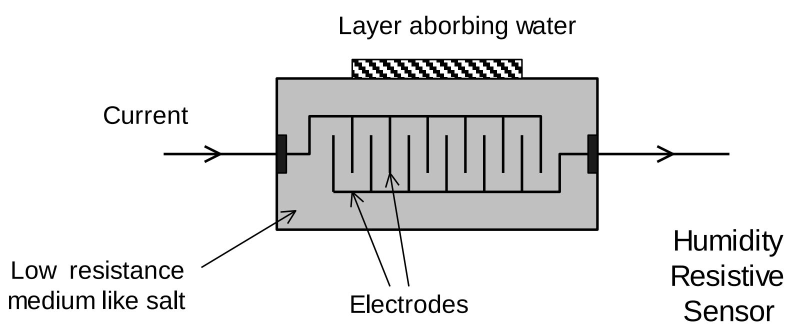
A humidity sensor (or hygrometer) senses, measures and reports both moisture and air temperature. The ratio of moisture in the air to the highest amount of moisture at a particular air temperature is called relative humidity.

Humidity sensors work by detecting changes that alter electrical currents or temperature in the air.

There are three basic types of humidity sensors:

- Capacitive
- Resistive
- Thermal

For constructing a Resistive sensor, a low resistivity materials are used. This low resistive material is placed on top of two electrodes. Salt, solid electrolytes and conductive polymers are the examples of resistive material used in Resistive humidity sensor. When water is absorbed by the absorbing layer, resistivity between the electrodes changes. Change in the resistivity is measured by noting the variation in current passed through the terminals.



Humidity measurement doesn't measure humidity directly. Digital sensors are used to measure the changes in resistivity values to calculate the humidity.

These sensors output the digital values which makes them easy to interface and use with microcontrollers such as Arduino, Raspberry Pi boards.

Advantages and Applications of Humidity sensors (Hygrometers)

- These humidity sensors are very useful for the safety of sensitive electronic equipment which is less tolerable to the environmental changes.
- Due to their low cost and small size, resistive sensors are used in residential, industrial and domestic applications.
- For people with illnesses affected by humidity, monitoring and preventive measure in homes can be employed humidity sensors.
- A humidity sensor is also found as part of home heating, ventilating and air conditioning systems.
- These are also used in offices, cars, humidors, museums, industrial spaces and greenhouses.
- Humidity sensors are also used in meteorology stations to report and predict the weather.

1. A platinum RTD, PT100 measures 100Ω at 0℃ and 138.5Ω at 100℃. Calculate resistance of RTD at 50℃.

Soln: Given : T = 50℃, $R_0 = 100\ \Omega$, $R_{100} = 138.5\ \Omega$

The mean temperature coefficient of RTD between 0 °C and 100 °C is given by –

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100℃} = \frac{138.5 - 100}{100 \times 100℃} = 0.00385\ /℃$$

Resistance of RTD at temperature T is given by –

$$R_T = R_0(1 + \alpha T)$$

$$\therefore R_{50} = 100(1 + 0.00385 \times 50) = 119.25\ \Omega$$

2. A platinum RTD, PT100 measures 100Ω at 0℃ and 138.5Ω at 100℃. Calculate temperature when resistance is 110Ω.

Given : $R_0 = 100\ \mathbf{\Omega}$, $R_{100} = 138.5\ \mathbf{\Omega}$, $R_T = 110\ \mathbf{\Omega}$ T = ?

The mean temperature coefficient of RTD between 0 °C and 100 °C is given by –

$$\alpha = \frac{R_{100} - R_0}{R_0 \times 100℃} = \frac{138.5 - 100}{100 \times 100℃} = 0.00385\ /℃$$

Resistance of RTD at temperature T is given by –

$$R_T = R_0(1 + \alpha T)$$

So, the temperature can be calculated using –

$$T = \frac{R_T - R_0}{R_0 \times \alpha} = \frac{110 - 100}{100 \times 0.00385} = 25.97\ ℃$$

Module 6 – Physics of Sensors

Session 2 : Pressure Sensors

(Capacitive method, flex and inductive method)

Pressure Sensor

Pressure is defined as the physical force exerted on an object. The force applied is perpendicular to the surface of objects per unit area. The basic formula for pressure is F/A (Force per unit area).

A **pressure sensor** is a device used for pressure measurement of gases or liquids. A pressure sensor acts as a transducer, converting the pressure in some sort of electrical signal. Pressure sensors are used for control and monitoring in thousands of everyday applications in which we need to measure and control fluid/gas flow, speed, water level and altitude.

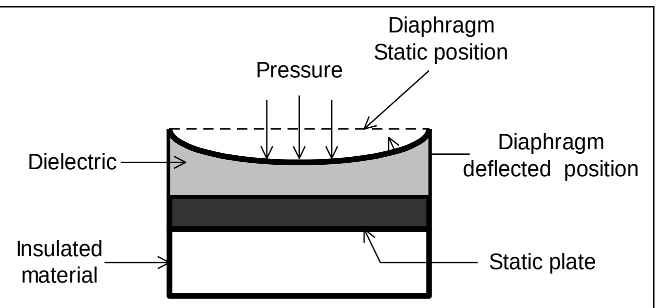
Pressure sensing by capacitive method

A capacitor consists of two parallel conducting plates separated by a small gap. The capacitance is defined by:

$$C = \epsilon_0 \epsilon_r \frac{A}{d} = \epsilon \frac{A}{d}$$

Where, A is area of plates, d is distance between the plates, $\epsilon_0 = 8.85 \times 10^{12} F/m$ is permittivity of free space and ϵ_r is relative permittivity or dielectric constant of the material between the plates. ϵ is called permittivity of the material.

From the above equation, the capacitance changes when the distance between the two plates is changed. A capacitive pressure sensor is built typically with one plate as a pressure sensitive diaphragm and the other plate is fixed. This capacitive pressure transducer is enclosed in air tight container. An example of a capacitive pressure sensor is shown in the following figure-



Capacitive Pressure Transducer (sensor)

When pressure is applied to the metallic diaphragm, it is deflected and the value of 'd' i.e. distance between the plates change. This causes change in capacitance. The variation in capacitance can be calibrated in terms of pressure.

Capacitive pressure sensors are often used to measure gas or liquid pressures in jet engines, car tyres, the human body and many other places.

Advantages of Capacitive Pressure Sensors

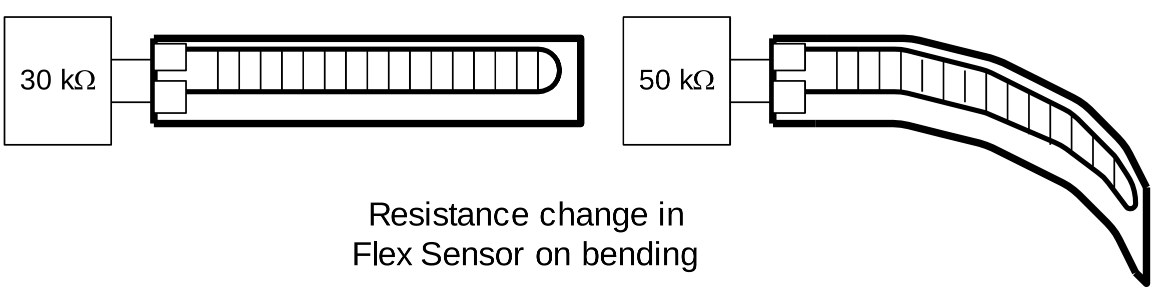
- Capacitive pressure sensors have very low power consumption because there is no DC current through the sensor element. Current only flows when a signal is passed through the circuit to measure the capacitance.
- The sensors are mechanically simple and suitable for use in harsh environments.
- Capacitive sensors can tolerate temporary over-pressure conditions.

Disadvantages

- Capacitive sensors have non-linear output.
- Careful circuit design is required for the interface electronics because of the high output impedance of the sensor.

Pressure sensing by Flex

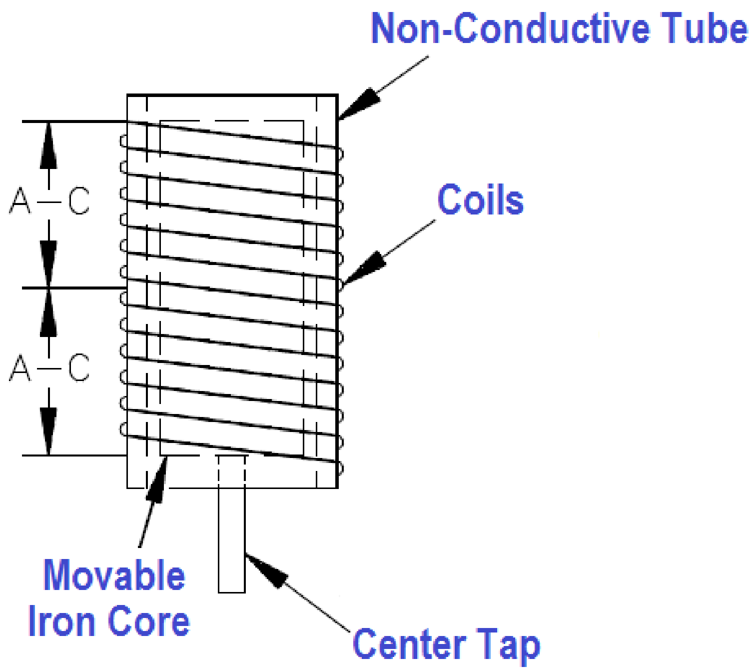
A flex sensor is a long strip used for measuring amount of bending. This flex sensor is a variable resistor. The resistance of the flex sensor increases as the body of the component bends. One side of the flex is printed with a polymer ink that have conductive particles embedded in it.



When it is flat, this sensor will look like a 30kΩ resistor. As it bends, the resistance between the two terminals increases depending on the angle of bending. It may increase to as much as 70kΩ at a 90° angle. By noting the resistance change, the pressure responsible for bending can be measured.

Pressure sensing by inductive method

The inductance-type transducer consists of three parts: a coil, a movable magnetic core, and a pressure sensing element. The pressure sensing element is attached to the core. As pressure changes, the element causes the core to move inside the coil. As the core moves, the inductance of the coil changes. As the inductance changes, the current through the coil will change. For increased sensitivity, the coil can be separated into two coils by utilizing a center tap, as shown in Figure. As the core moves within the coils, the inductance of one coil will increase, while the other will decrease.



Analog Pressure Sensor

A pressure sensor works by converting pressure into an analogue electrical signal.
There are two basic categories of analog pressure sensors –

Force collector types pressure sensors
These types of electronic pressure sensors generally use a force collector (such a diaphragm, piston, bourdon tube, or bellows) to measure strain (or deflection) due to applied force over an area (pressure). E.g. Capacitive pressure sensor, Piezoelectric pressure sensor.

Other types of electronic pressure sensors use other properties (such as density) to infer pressure of a gas, or liquid.
e.g.

- **Thermal Sensors** that use changes in thermal conductivity of a gas due to density changes to measure pressure. A common example of this type is the Pirani gauge.
- **Ionization sensors** that measure the flow of charged gas particles (ions) which varies due to density changes to measure pressure. Common examples are the Hot and Cold Cathode gauges.

Module 6 – Physics of Sensors

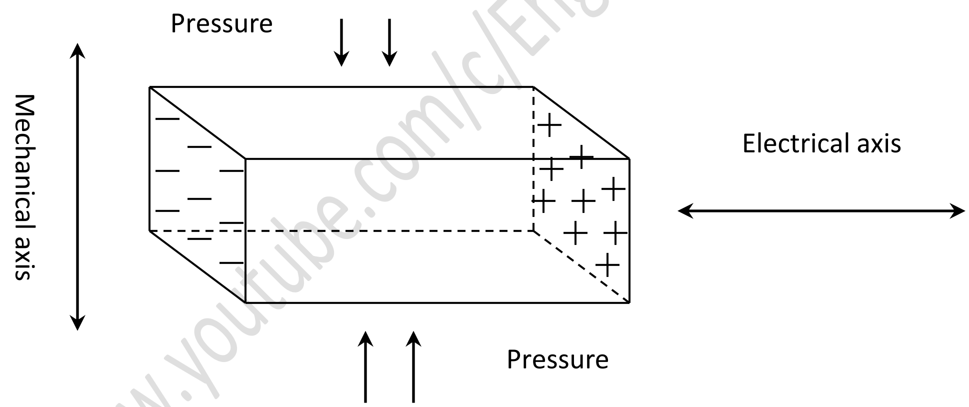
Session 3 : Piezoelectric Transducer

(Ultrasonic transducer and its applications)

Piezoelectric Transducer

Piezoelectric transducer uses piezoelectric effect to covert pressure into electric signal.
It was discovered in 1880 by Curie Brothers. Certain crystals like quartz, Rochelle salt, Ceramics exhibit piezo-electric effect. According to this effect, if we apply pressure along certain axis (known as mechanical axis) of the crystal, then equal and opposite charges are developed along the perpendicular axis (known as electrical axis) of the crystal. Magnitude of these charges is directly proportional to the pressure.

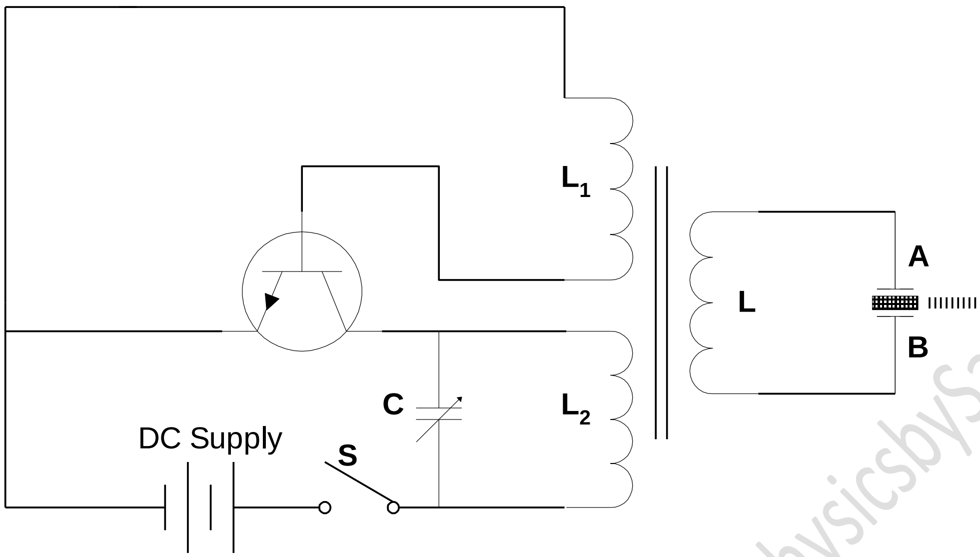
The converse of piezo-electric effect is also true. i.e. If a potential difference is applied across two faces of the crystal along electrical axis, the change in dimension of the crystal (expansion or contraction) is observed along the mechanical axis.



Piezo electric Transducer as Ultrasonic Generator :

If we apply alternating voltage across the slice of the piezoelectric crystal (quartz), it will alternatively contract and expand and thus start vibrating. If adjusted to be equal to one of the modes of vibration of the crystal, resonance occurs i.e. crystal vibrates with maximum amplitude and sets surrounding medium into longitudinal vibrations, thus producing ultrasonic waves.

The schematic circuit of the ultrasonic wave generator using piezoelectric effect is shown in following figure.



Piezoelectric oscillator

The coil L_2 is inductively coupled to coil L. The capacitor C and L_2 form a LC tank circuit used to generate an ac signal of precise frequency. When the circuit is switched on, the starts functioning as an oscillator producing oscillations at the frequency given by –

$$f = \frac{1}{2\pi\sqrt{L_2 C}}$$

The frequency of oscillations can be controlled by varying the capacitor C.

When the frequency of is very high, the inductive reactance of the coil $X_L = 2\pi f L$ increases. Due to this current level reduces. In order to amplify the signal, a transistor is used. With the help of a transistor, electrical oscillations produced are maintained continuously.

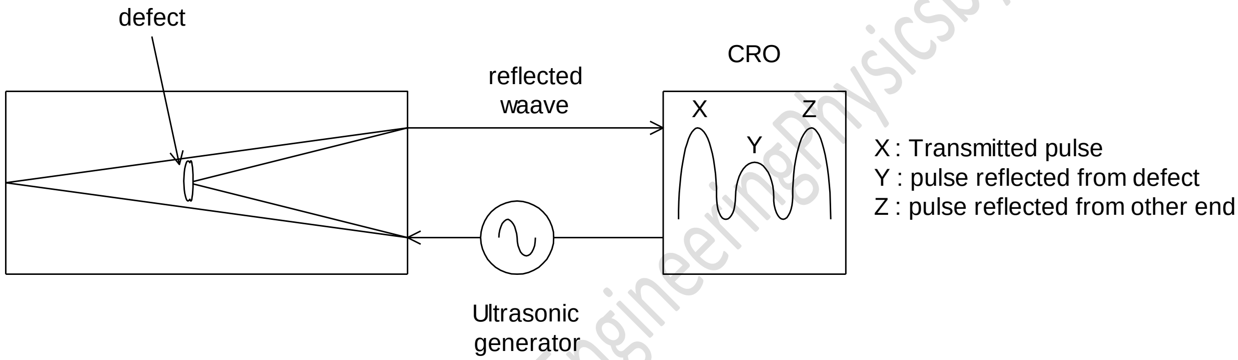
By transformer action, an e.m.f. is induced in coil L which in parallel to the crystal. The capacitance is varied till the frequency of oscillations matches with the natural frequency of the piezoelectric crystal. The crystal subjected to the ac voltage produces ultrasonic waves in the surrounding air.

Application of ultrasonic sound in distance measurement

Echo sounding is used to measure distance using ultrasonic sound. In Echo sounding ultrasonic beam is transmitted towards the object, it strikes the object and gets reflected from the object. The reflected beam is received. Using time taken by the beam to travel towards the object and return back, the distance of the object can be determined.

1) Detection of flaws in metals (Non Destructive Testing):

Ultrasonic waves can be used to detect flaws in metal. We know that a flaw in a metal produces a change in the medium due to which reflection of ultrasonic waves takes place. Hence, when ultrasonic waves pass through metal having some hole or crack inside it, an appreciable reflection occurs. The reflection also takes place at the back surface of the metal. The reflected pluses are picked by the receiver and are suitably amplified. These pulses are now applied to one set of plates of cathode ray oscilloscope. The transmitted signal and reflected signal from the flaw and the back surface of the metal produce a peak each. The position of the second peak on the time base of oscilloscope gives distance of the flaw from the surface.



Non Destructive Testing

2) SONAR (Sound Navigation and Ranging) :

It is possible to determine the presence of submerged submarines or an enemy aircraft by a system known as SONAR. SONAR is a device which stands for Sound Navigation and Ranging. In this system, a sharp ultrasonic beam is directed in various directions into the sea. These are picked on their return after reflection. The reflection of waves from any direction shows the presence of some reflecting body in the sea in that direction. The time interval between the generation of ultrasonic waves and their return after reflection gives the distance of the body. The change in frequency of the echo signal due to Doppler effect helps to determine the velocity of the body and its direction.

3) To find the depth of the sea :

We know that ultrasonic waves are highly energetic and show a little diffraction effect. They can be used to find the depth of the sea. The time interval between sending the wave and receiving the reflected wave from the seabed is recorded. Velocity of ultrasonic sound in seawater is found out and using it, depth of the sea is estimated using relation -

$$\text{depth of the sea} = \frac{v\,t}{2}$$

where, v is velocity of sound in sea water and t is the time taken by sound wave to return from seabed.

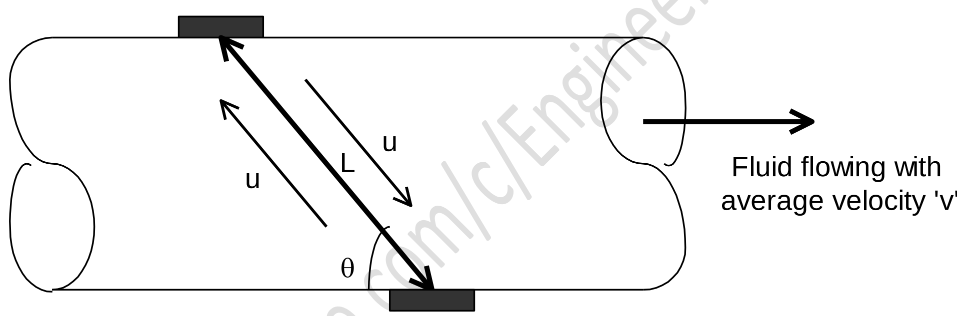
Velocity of sound in sea water is given by

$$v = v_0 + 1.14\,S + 4.21\,T - 0.037\,T^2$$

where v_0 is velocity of sound in pure water at 0 ^{0}C, Sis salinity in gm/lit and T is temperature in ^{0}C.

Application of ultrasonic Transducer to measure velocity of Liquid or Gas

An **ultrasonic flow meter** measures the velocity of a fluid (liquid of gas) with ultrasonic sound to calculate volume flow. Using ultrasonic transducers, the flow meter can measure the average velocity along the path of an emitted beam of ultrasound. Ultrasonic flow meters measure the difference between the transit time of ultrasonic pulses propagating with and against the flow direction.



Ultrasonic Flowmeter

Let us consider a pipe carrying fluid at velocity ‘v’. Ultrasonic transducers T1 and T2 transmit ultrasonic waves in the fluid at velocity ‘u’ at an angle θ. After covering distance L, the wave is collected by the other transducer.

Let the time taken by transducer T1 to reach the transducer T2 be t_1.

$$\therefore t_1 = \frac{L}{u+v\cos\theta} \rightarrow u + v\cos\theta = \frac{L}{t_1} \quad \text{---- (1)}$$

Let the time taken by transducer T2 to reach the transducer T1 be t_2.

$$\therefore t_2 = \frac{L}{u-v\cos\theta} \rightarrow u - v\cos\theta = \frac{L}{t_2} \quad \text{----(2)}$$

(1)-(2) gives

$$2v\cos\theta = \frac{L}{t_1} - \frac{L}{t_2}$$
$$\therefore v = \frac{L}{2\cos\theta}\left(\frac{t_2 - t_1}{t_1 t_2}\right)$$

Using this expression and measuring the required parameters, velocity of fluid can be calculated. Ultrasonic flowmeters are often inexpensive and easy to maintain because they do not use moving parts, unlike mechanical flow meters.

1. Find the natural frequency of a piezoelectric crystal of thickness 1.5 mm. Given that Young's modulus 8 x 10^{10} N/m^2 and density 2650 kg/m^3.

Soln :

$$f = \frac{1}{2l}\sqrt{\frac{Y}{\rho}}$$
$$= \frac{1}{2 \times 1.5\times10^{-3}}\sqrt{\frac{8 \times 10^{10}}{2650}}$$
$$= 1.83\times10^{6}\ \text{Hz} = 1.83\,\text{MHz}$$

2. Find the natural frequency of vibrations of a quartz plate of thickness 1.8 mm. Given : Young's modulus for quartz 8 x 10^{10} N/m^2 and density 2650 kg/m^3. Calculate the change in the thickness required if the same plate is to be used to produce ultrasonic waves of frequency 2 MHz.

Soln :

$$f_1 = \frac{1}{2t_1}\sqrt{\frac{Y}{\rho}} = \frac{1}{2 \times 1.8\times10^{-3}}\sqrt{\frac{8 \times 10^{10}}{2650}}$$
$$= 1.53\times10^{6}\ \text{Hz} = 1.53\,\text{MHz}$$
$$f_2 = \frac{1}{2t_2}\sqrt{\frac{Y}{\rho}}$$
$$\therefore\ t_2 = \frac{1}{2f_2}\sqrt{\frac{Y}{\rho}} = \frac{1}{2 \times 2\times10^{6}}\sqrt{\frac{8 \times 10^{10}}{2650}} = 1.37\times 10^{-3}\ \text{m}$$

Difference in thickness = $t_2 - t_1$ = 1.8 - 1.37 = 0.43 mm

3. Velocity of ultrasound waves in mild steel is 5.9 x 10^3 m/sec. The velocity of ultrasound wave in brass is 4.8 x 10^3 m/sec. If thickness of brass plate measured by the ultrasound gauge meter, calibrated for mild steel, is 12.8 cm, what is the real thickness?

Soln : The gauge is calibrated for mild steel.

Let 'x' be the real thickness and 'd' be the measured thickness. d = 12.8 x 10^{-2} m.

Velocity of sound in mild steel = v_{ms} = 5.9 x 10^3 m/sec.

Velocity of sound in brass = v_b = 4.8 x 10^3 m/sec.

Thickness of brass plate is measured using velocity of mild steel i.e. 5.9 x 10^3 m/sec and it gives value 12.8 cm.

If the same thickness of the brass is measured using correct velocity of brass i.e. 4.8 x 10^3 m/sec, we will get real thick ness.

$$\text{Real thickness} = \frac{v_b \times d}{v_{ms}} = \frac{4.8 \times 10^3 \times 12.8 \times 10^{-2}}{5.9 \times 10^3}$$
$$= 10.41 \times 10^{-2} \text{ m} = 10.41 \text{cm}$$

4. An ultrasonic beam of 1 cm wavelength is sent by a ship, returns from the sea-bed after 2 seconds. If velocity of ultrasonic beam in sea-water is 1510 m/s at 0 ^{0}C, its salinity at 30 ^{0}C is 29 gm/lit, calculate the depth of sea-bed at 30 ^{0}C and frequency of ultrasonic beam.

Soln : Velocity of water in sea water is given by -

$$v = v_0 + 1.14 S + 4.21 T - 0.037 T^2$$
$$= 1510 + 1.14 \times 29 + 4.21 \times 30 - 0.037 \times 30^2$$
$$= 1636.06 \text{ m/s}$$

Depth of the sea is -

$$\text{depth} = \frac{v\,t}{2} = \frac{1636.06 \times 2}{2} = 1636.06 \text{ m}$$

Frequency of ultrasonic beam is -

$$f = \frac{v}{\lambda} = \frac{1636.06}{1 \times 10^{-2}} = 163.60 \text{ kHz}$$

5. Two ships are anchored at certain distance between them. An ultrasonic signal of 50 kHz is sent from one ship to another by two routes – (i) through water and (ii) through atmosphere. The difference between time intervals for receiving the signal at the other ship is 2 seconds. If velocities of sound in the atmosphere and in sea water are 348 m/s and 1392 m/s respectively, find the distance between the ships. Also find time taken by the signal to travel trough water.

Soln : Let 'd' be the distance between the two ships.

Given that $t_{atmosphere} - t_{water} = 2$ sec

$$d = v_{water}\, t_{water} = 1392\, t_{water}$$

$$d = v_{atmosphere}\, t_{atmosphere} = 348\,(2 + t_{water})$$

$$= 696 + 348\, t_{water} = 1392\, t_{water}$$

$$\therefore (1392 - 348)\, t_{water} = 696$$

$$\therefore \quad t_{water} = \frac{696}{(1392-348)} = 0.667 \text{ sec}$$

Distance between the ships -

$$d = v_{water}\, t_{water} = 1392 \times 0.667 = 928.46 \text{ m}$$

6. Find the echo time of ultrasonic pulse travelling with velocity 5.9 x 10^3 m/sec in a mild steel whose thickness displayed by gauge is 18 mm.

Soln :

$$\text{thickness} = \frac{v\,t}{2}$$

$$\text{echo time} \quad t = \frac{2 \times \text{thickness}}{v} = \frac{2 \times 18 \times 10^{-3}}{5.9 \times 10^{3}} = 6.10 \times 10^{-6} \text{ m}$$

Module 6 – Physics of Sensors

Session 4 : Optical Sensor and Pyro electric Sensor

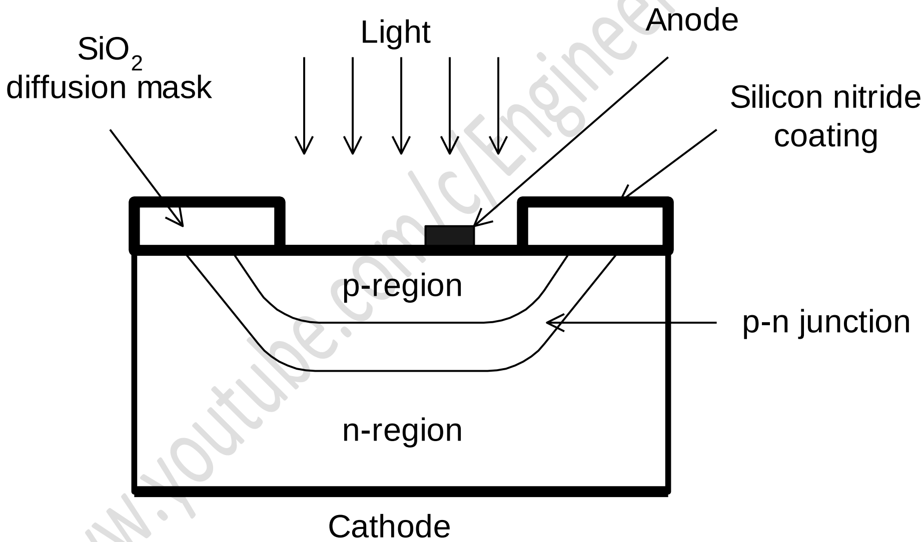
Optical Sensor

An optical sensor converts light rays into electronic signals. Commonly used optical sensor is a photodiode.

Photodiode: Construction and use of photodiode as Ambient light measurement and flux measurement

A special type of PN junction device that generates current when exposed to light is known as Photodiode. It is also known as photodetector or photosensor. It operates in reverse biased mode and **converts light energy into electrical energy**.

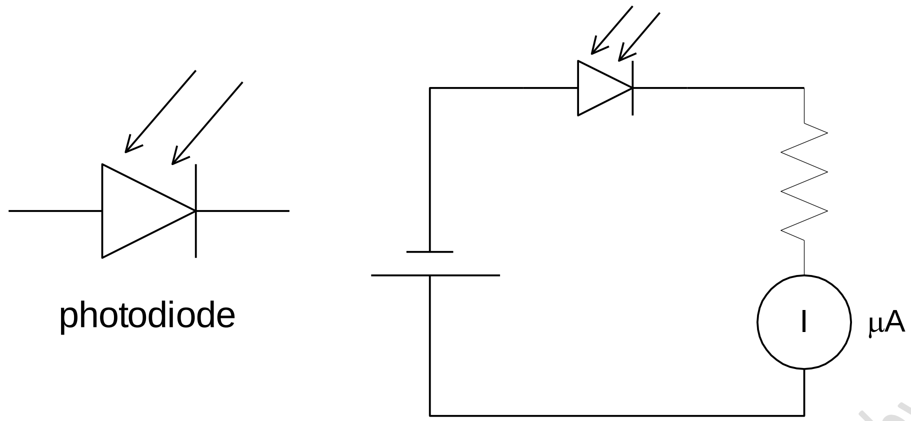
Its construction is shown below-



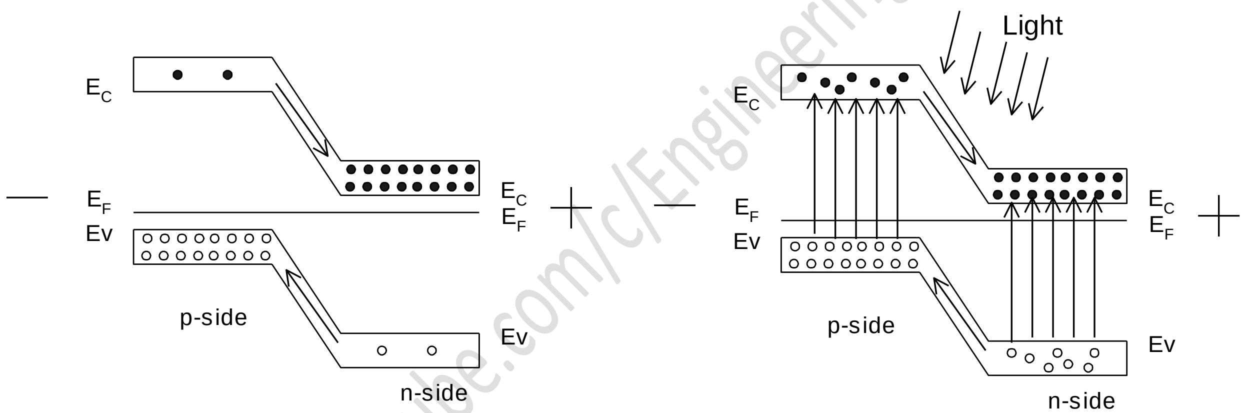
Construction of photodiode

The PN junction of the device placed inside a glass material. This is done to order to allow the light energy to pass through it. As only the junction is exposed to radiation, thus, the other portion of the glass material is painted black or is metallized.

Working of a Photodiode is based on the phenomenon called electron-hole pair generation. In a photodiode, when light is made incident on reverse biased p-n junction, more electron-hole pairs are generated. This increases the reverse current. Photodiode is used only in reverse bias mode.



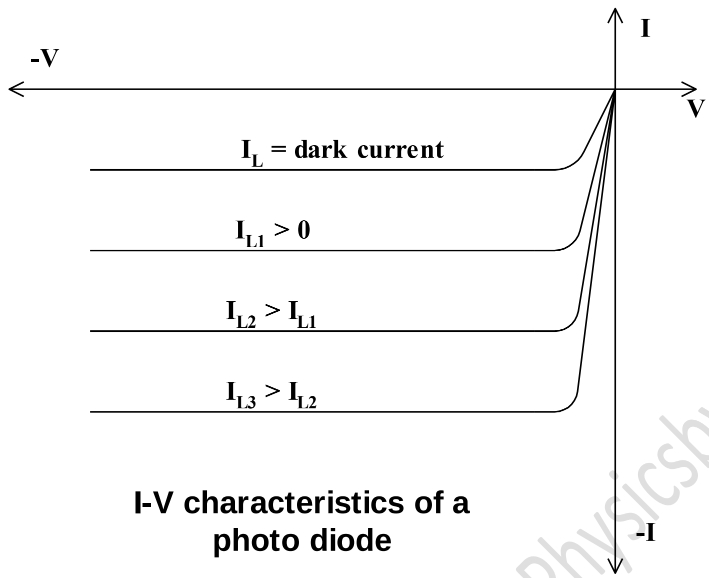
When there is no light falling on the photo diode, the reverse saturation current is normally limited to a few microamperes. It is solely due to thermally generated minority carriers in n-type and p-type material. It is call as dark current.



Energy Bands of photodiode when no light falls

Energy Bands of photodiode when light falling

Application of light to the junction will result in more number of electrons jumping from valence band to conduction band utilizing the light energy. Due to this, more number of electrons in p-side conduction band and more number of holes in n-side valence band are created. This increase in number of minority carriers result in increased level of reverse saturation current. Following figure shows photodiode characteristics-



I-V characteristics of a photo diode

I_L is intensity of light. For increasing intensity $I_{L3} > I_{L2} > I_{L1}$. As the reverse current is proportional to the intensity of light incident on the photo diode, it can be used for the measurement of intensity of ambient light. This can be used in many applications such as smartphones, laptops where we need to sense the ambient light intensity to adjust the bright ness of the screen.

Luminous flux is a measure of the total amount of visible light emitted by a lamp. It's different from the radiant flux. Radiation flux is the measurement of all electromagnetic radiation emitted (including infrared, ultraviolet and visible), which is the total amount of objective light. Luminous flux is the amount of light that the human eye senses. It reflects the sensitivity of the human eye by weighting each wavelength with a luminosity function. So that it is the weighted sum of all wavelengths of power in the visible light band, excluding infrared and ultraviolet.

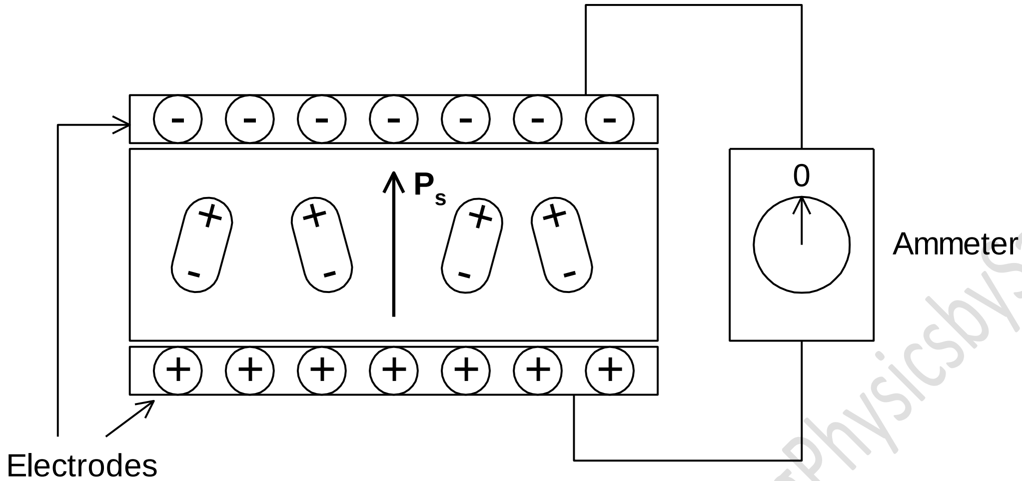
Luminous flux (in lumens) is a measure of the total amount of light a lamp puts out. The luminous intensity (in candelas) is a measure of how bright the beam in a particular direction is.

To measure, luminous flux, a source of light is kept in a light proof box along with the photodiode at highly precise locations.

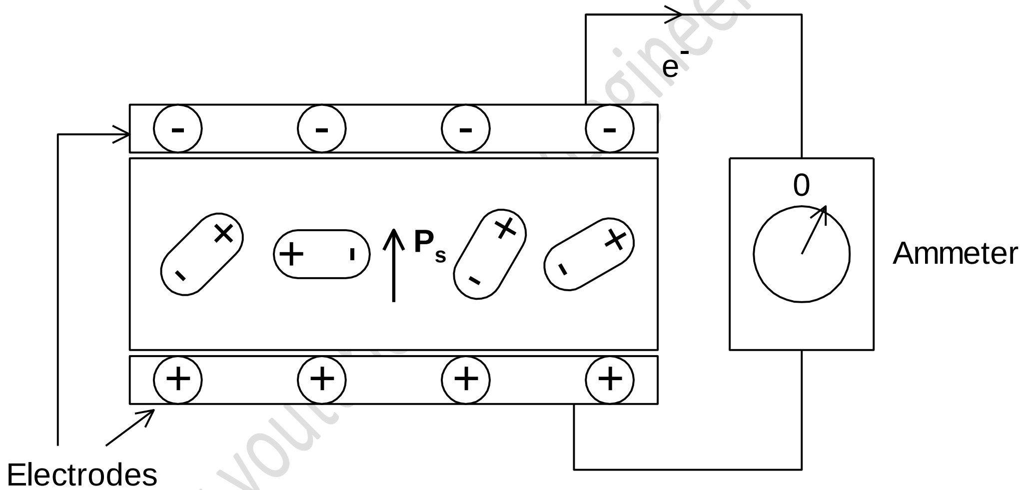
Pyroelectric Sensor : Construction and Working

Pyro-electricity is the ability of certain materials to generate an electrical potential when they are heated or cooled. Pyroelectric materials are characterized by a permanent polarization which varies with the temperature. This results in polarization charges to flow in an external circuit. Since this polarization response time is very short (in the picoseconds range), this effect can be utilized for very fast detection of power fluxes.

Pyroelectric sensors are thermal detectors. When subjected to small temperature fluctuations, they can give rise to a temporary voltage. The change in temperature modifies the positions of the atoms slightly within the crystal structure and the polarization of the material changes. This leads to the development of temporary voltage across the crystal.



Pyroelectric crystal: No current when temperature is constant



Pyroelectric crystal: current introduced when temperature changes

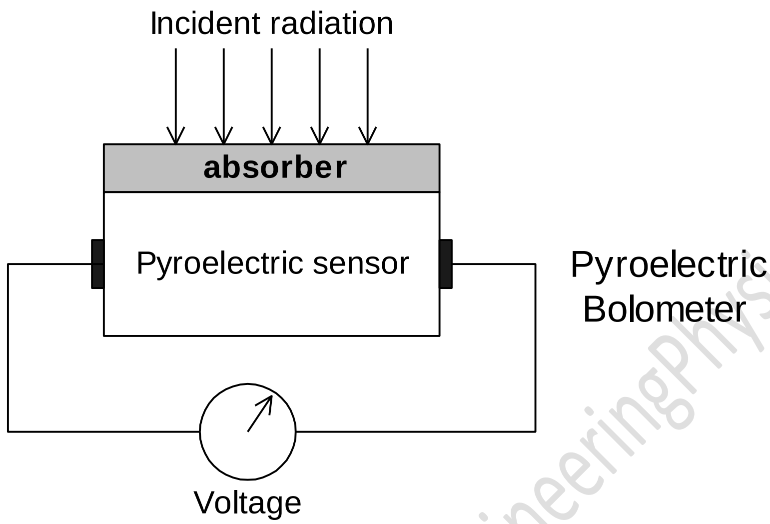
This temperature gradient can be created by the absorption of light. A Pyroelectric sensor is an infrared sensitive optoelectronic component which are specifically used for detecting electromagnetic radiation in a wavelength range from (2 to 14) µm.

Why pyroelectric crystals and piezoelectric crystals cannot be used for generation of electricity?

Pyro-electricity, like piezoelectricity, is shown by crystals which have high resistivity. So even though the voltage generated is not negligible, if we draw any current, which we need to do to have useful work, all the voltage will be lost across this internal resistance. It is fine for sensors, but not for meaningful generation.

Application of Pyroelectric sensor as Bolometer

The bolometer is a device used for detecting and measuring power of incident electromagnetic radiation. It uses the temperature sensitive resistive element whose resistance changes with the temperature. Pyroelectric sensor can be used as a temperature sensor element.



In Pyroelectric bolometer, the radiation is made incident on pyroelectric sensor. As it absorbs the radiation, heat is generated and its temperature changes. This change in temperature gives rise to temporary voltage across the pyroelectric sensor. This voltage change can be calibrated to measure the power of incident radiation.

Since the response time of pyroelectric sensor is very short (in the picoseconds range), pyroelectric bolometers can be utilized for very fast detection of power fluxes.