# 21EES101T-ELECTRICAL AND ELECTRONICSENGINEERING UNIT 4

**Unit-4 –Transducers and Sensors**

Basic principles and classification of Instruments- Moving Coil instruments, Moving Iron instruments, Digital Multimeter, Digital storage Oscilloscope. Transducer-Classification- Capacitive and Inductive transducers, Linear Variable Differential Transformer (LVDT), Thermistors, Thermocouple, Piezoelectric transducer, Photoelectric transducer, Hall effect transducers, Introduction to Opto-electronics Devices, Light Dependent Resistor (LDR), Photodiodes, Phototransistors, Photovoltaic cells (solar cells), Opto-couplers, Liquid crystal display, Proximity sensor, IR sensor, Pressure sensor, Introduction to Bio sensor, Sensors for smart building.

# CLASSIFICATION OF INSTRUMENTS

Electrical measuring instruments are classified as follows:

I. Depending on the quantity measured e.g. Voltmeter, Ammeter, Wattmeter, Energymeter, Ohmmeter.

II. Depending on the different principles used for their working e.g. Moving Iron type, Moving coil type, Dynamometer type, Induction type.

III. Depending on how the quantity is measured? e.g. Deflecting type, Integrating type, Recording type.

## The different types of torques associated with measuring instruments

### 1.Deflecting Torque

This torque acts on the moving system of the instrument to give the required deflection. It exists as long as the instrument is connected to the supply.The deflecting torque shall ensure a deflection proportional to the magnitude of the quantity being measured.

## 2. Opposing Torque

This torque always opposes the deflecting torque. The moving system attains a steady deflected position when the opposing torque equals the deflecting torque. The components of the opposing torque are inertia torque, control torque and damping torque.

### 2 (a) Inertia Torque

This is due to the inertia of the moving system. The deflecting has to overcome this and make the moving system move from its rest position.

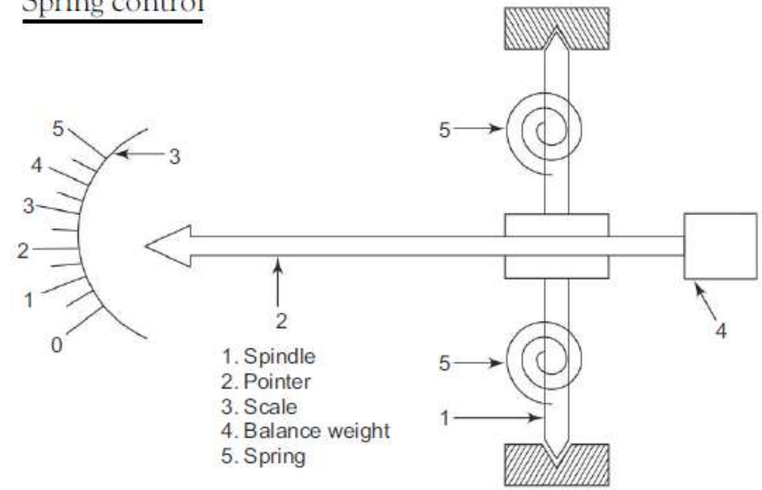
### 2 (b) Control Torque

This torque is always present in the instrument whether it is connected to the supply or not. The control torque increases with the deflection of the moving system. **It opposes the deflecting torque**. The moving system is brought to a steady deflected position when the control torque is balanced by the deflecting torque. The control torque is also essential to bring back the moving system to its initial or rest or zero position once the instrument is disconnected from the supply.

The control torque can be produced using spring or gravity:

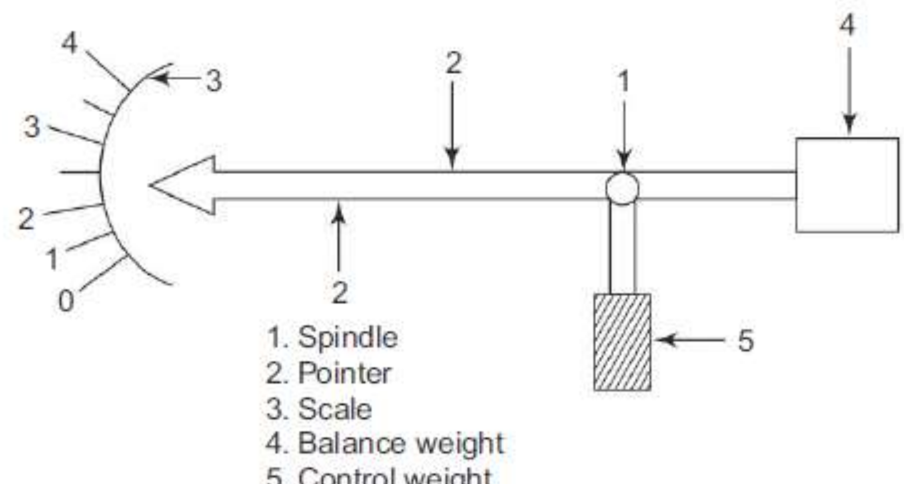
**2 (b) (i) Spring control** (Refer Fig.). Two helical springs of rectangular cross section are connected to the spindle of the moving system. With the movement of the pointer, the springs bet twisted in the opposite direction. Thus, the required amount of control is affected on the moving system. Also, once the instrument is disconnected from the supply, the pointer (moving system) is brought back to its initial position due to the twisted spring.

Spring control




**2 (b) (ii) Gravity control**

(Refer Fig.). In this method, adjustable small weights are added to some part of the moving system. When the pointer deflects, this weight also takes a deflected position. The gravitational force acting on the moving weight produces the required control torque



**2 (c)** ***Damping Torque*** This torque is produced only when the instrument is in operation. This ensures that the moving system takes just the required time to reach its final deflected position.

**Electrical measuring instruments**

- MOVING COIL INSTRUMENTS
  - PERMANENT MAGNET TYPE
  - DYNAMOMETER TYPE
- MOVING IRON INSTRUMENTS
  - ATTRACTION TYPE
  - REPULSION TYPE

# 1 MOVING COIL INSTRUMENTS

## 1 A. PERMANENT MAGNET MOVING COIL INSTRUMENT [PMMC]

***Principle*** A current carrying coil is placed in a magnetic field, a force is exerted. It tends to act on the coil and moves it away from the field. This movement of the coil is used to measure current or voltage.

***Construction*** (Refer Figs. 7.9 and 7.10). N and S refer to the pole pieces of a permanent magnet. A soft iron core in the form of a cylinder is placed in the space between the poles ($C$). In the permanent magnetic field is placed a rectangular coil of many turns ($MC$) wound on a former (AF). The former is made of aluminium or copper. To the moving coil is attached the spindle ($S_p$). Two helical springs ($S_g$) are connected to the spindle to give the necessary control torque. A pointer ($p$) attached to the spindle is made to move over a calibrated scale.

***Working*** A magnetic field of sufficient density is produced by the permanent magnet. The moving coil carries the current or a current proportional to the voltage to be measured. Hence, an electromagnetic force is produced which tends to act on the moving coil and moves it away from the field. This movement makes the spindle move and so the pointer gives a proportionate deflection.

# PMMC

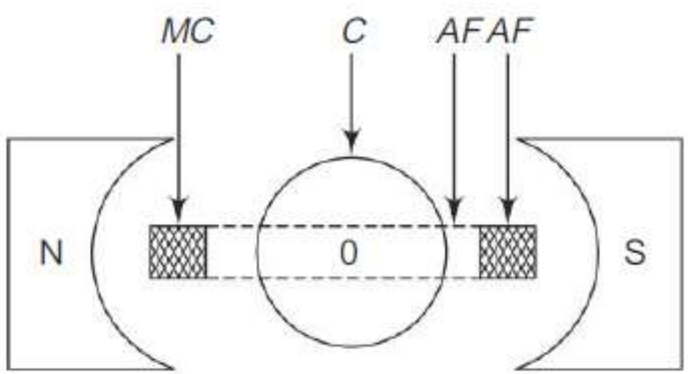



Fig. 7.9

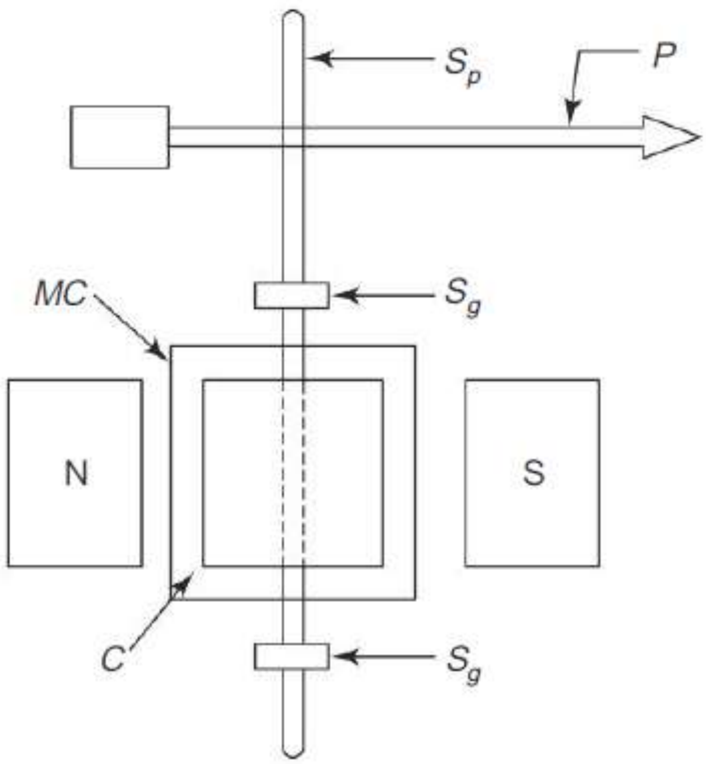



Fig. 7.10

| | |
|---|---|
| Deflecting torque | ... It is directly proportional to the current or the voltage to be measured. So, the instrument can be used to measure direct current and dc voltage. |
| Control torque | ... Spring control |
| Damping torque | ... Eddy current damping. When the moving coil made of aluminium former is moved due to the force exerted on it, it cuts the magnetic flux lines produced by the permanent magnet. Hence, eddy currents are induced in the former. |

As per Lenz's law, these eddy currents produce the required damping torque opposing the motion of the moving coil.

# 1 B DYNAMOMETER TYPE MOVING COIL INSTRUMENT

***Principle*** Working principle of this type of instrument is same as that of permanent magnet moving coil type. But, the difference is that there is no permanent magnet in this instrument. Both the operating fields are produced by the current and/or the voltage to be measured.

***Construction*** (Refer Fig. 7.11). The fixed coil (*FC*) is made in two sections. In the space between these two sections, a moving coil (*MC*) is placed. The moving coil is attached to the spindle to which is attached a pointer. The pointer is allowed to move over a calibrated scale. Two helical springs are attached to the spindle to give the required control torque. A piston attached to the spindle is arranged to move inside an air chamber.

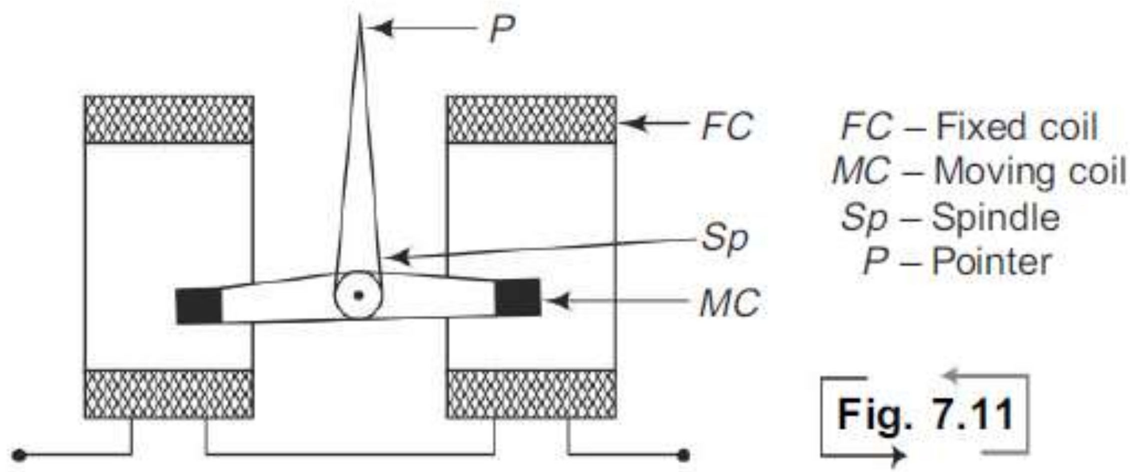



**Fig. 7.11**

***Working*** The fixed coil and the moving coil carry currents. Thus, two magnetic field are produced. Hence, an electromagnetic force tends to act on the moving coil and makes it move. This makes the pointer give a proportionate deflection.

### *Deflecting Torque*

(a) *As voltmeter* The two coils are electrically in series. They carry a current proportional to the voltage to be measured. The deflecting torque is proportional to $(\text{voltage})^2$. Hence, the instrument can be used for measuring dc and ac voltages.

(b) *As ammeter* The two coils are electrically in series. They carry the current to be measured. The deflecting torque is proportional to $(\text{current})^2$. Hence, the instrument can be used for measuring dc and ac.

(c) *As wattmeter* Fixed coils carry the system current. Moving coil carrys a current proportional to the system voltage. The design is such that the deflecting torque is proportional to VI cos $\phi$, i.e power to be measured.

Control torque: Spring Control

Damping torque: Air damping

# 2 MOVING IRON INSTRUMENTS

## 2A ATTRACTION TYPE

Moving Iron Instruments are used mainly to measure voltage or current.

***Principle*** It is well known that a soft iron piece gets magnetised when it is brought into a magnetic field produced by a permanent magnet. The same phenomenon happens when the soft iron piece is brought near either of the ends of a coil carrying current. The iron piece is attracted towards that portion where the magnetic flux density is more. This movement of the soft iron piece is used to measure the current or voltage which produces the magnetic field.

***Construction*** (Refer Fig. 7.7). The instrument consists of a working coil. It carries the current to be measured or a current proportional to the voltage to be measured. A soft iron disc is attached to the spindle. To the spindle, a pointer is also attached. The pointer is made to move over a calibrated scale. The moving iron (soft iron disc) is pivoted such that it is attracted towards the centre of the coil where the magnetic field is maximum.

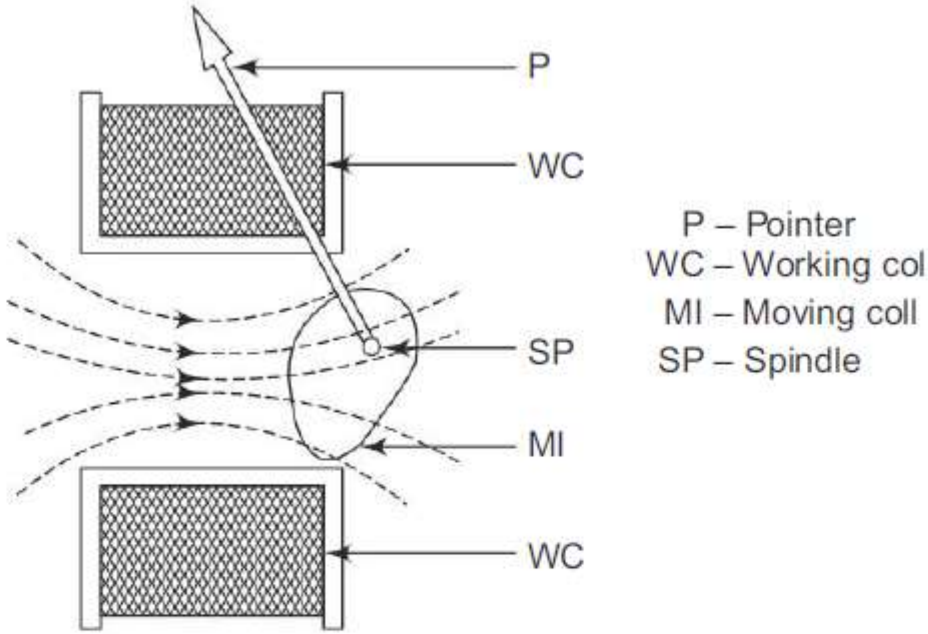



**Fig. 7.7**

***Working*** The working coil carries a current which produces a magnetic field. The moving disc is attracted towards the centre of the coil where the flux density is maximum. The spindle is, therefore, moved. Thus, the pointer, attached to the spindle gives a proportional deflection.

***Deflecting Torque*** Produced by the current or the voltage to be measured. It is proportional to the square of the current or voltage. Hence, the instrument can be used to measure d.c. or a.c scale is non-uniform.

Control torque: Spring or gravity

Damping: Air friction damping

## 2B REPULSION TYPE MOVING IRON INSTRUMENT

***Principle*** Two iron pieces kept with close proximity in a magnetic field get magnetized to the same polarity. Hence, a repulsive force is produced. If one of the two pieces is made movable, the repulsive force will act on it and move it on to one side. This movement is used to measure the current or voltage which produces the magnetic field.

***Construction*** (Refer Fig. 7.8). The instrument consists of a working coil which carries a current proportional to voltage or the current to be measured. There are two iron pieces-fixed and moving. The moving iron is connected to the spindle to which is attached a pointer. It is made to move over a calibrated scale.

***Working*** When the operating coil carries current, a magnetic field is produced. This field magnetises similarly both the soft iron pieces. Thus, a repulsive force is produced which acts on the moving iron and pushes it away from its rest position. Thus, the spindle moves and hence the pointer gives a proportionate deflection. Whatever be the direction of current in the coil, the two irons are always similarly magnetised.

***Deflecting Torque*** Produced by the current or the voltage to be measured it is proportional to the square of the current or voltage. Hence, the instrument can be used for dc and ac.

Control torque: Spring or Gravity
Damping: Pneumatic (i.e air damping)

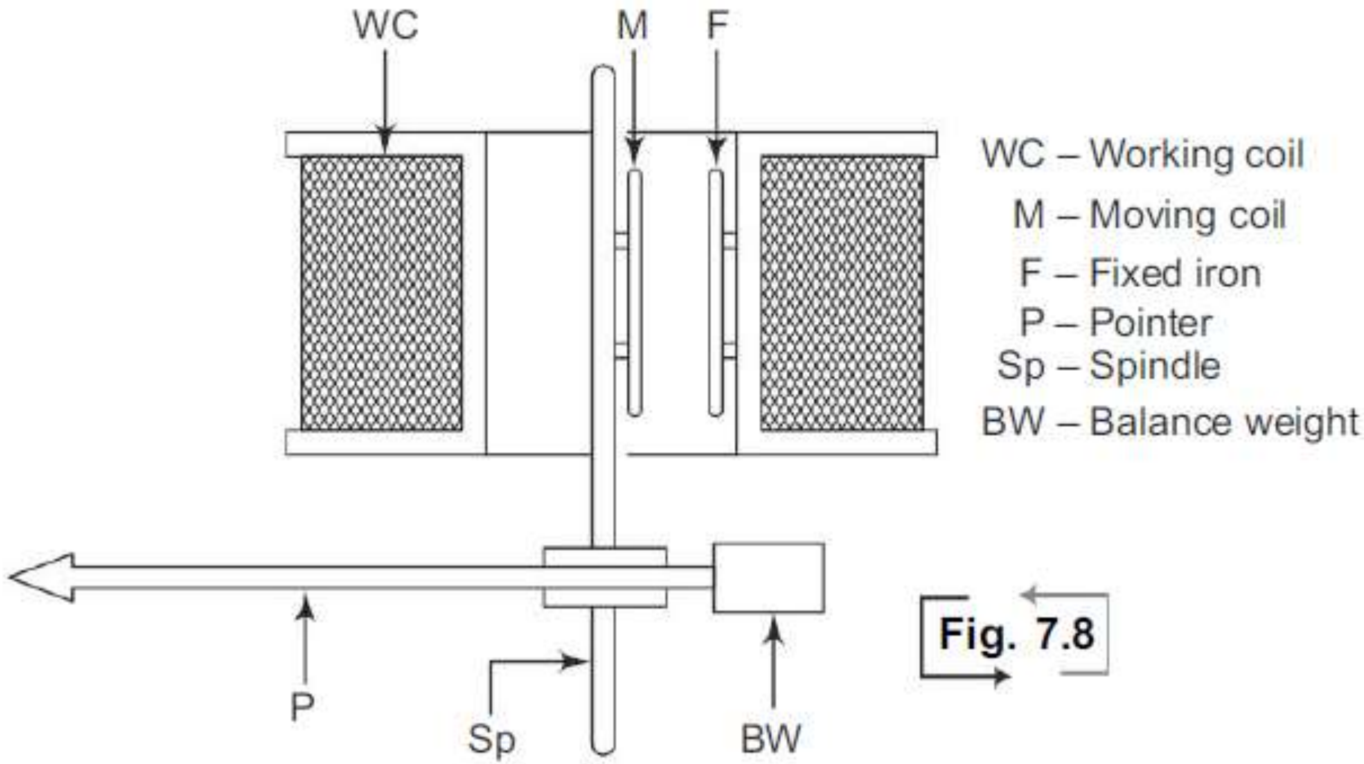
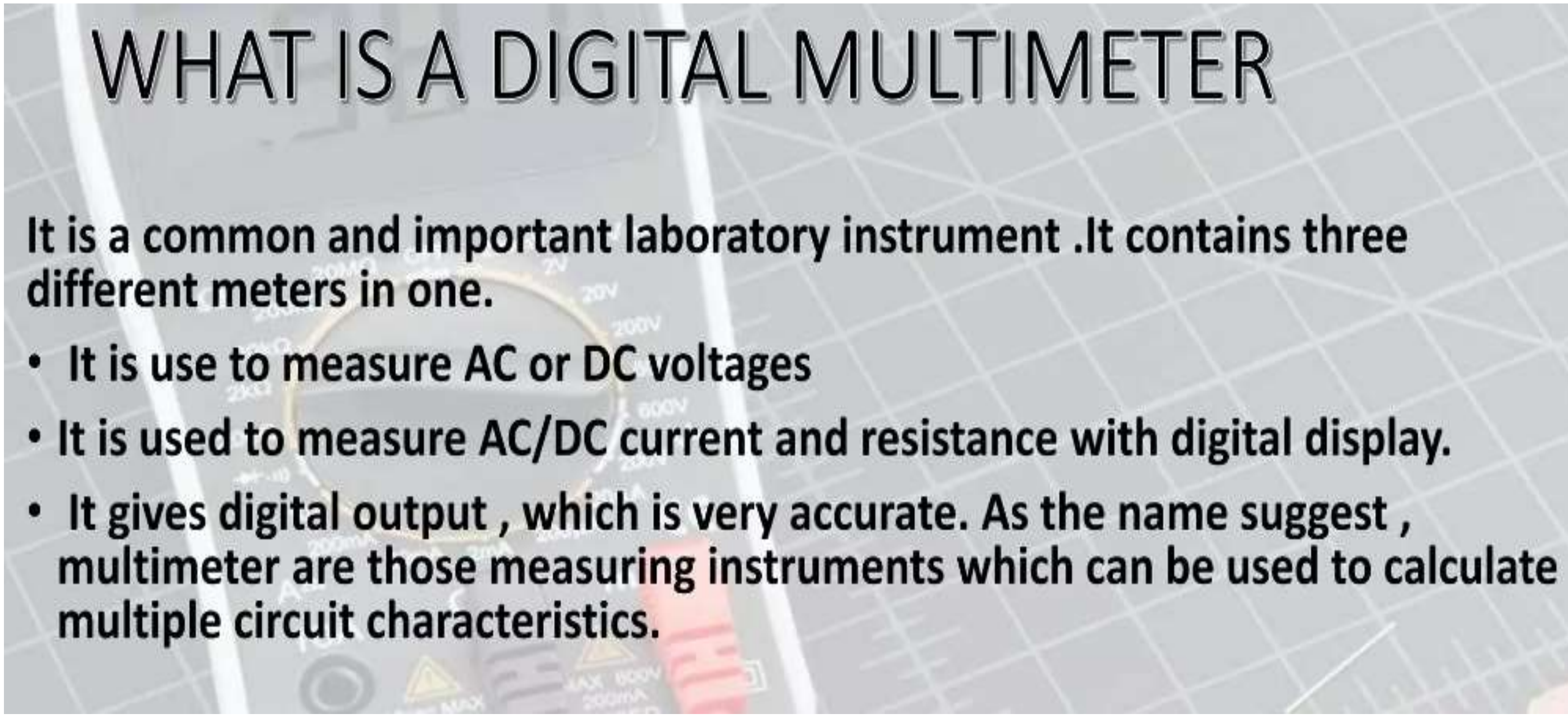


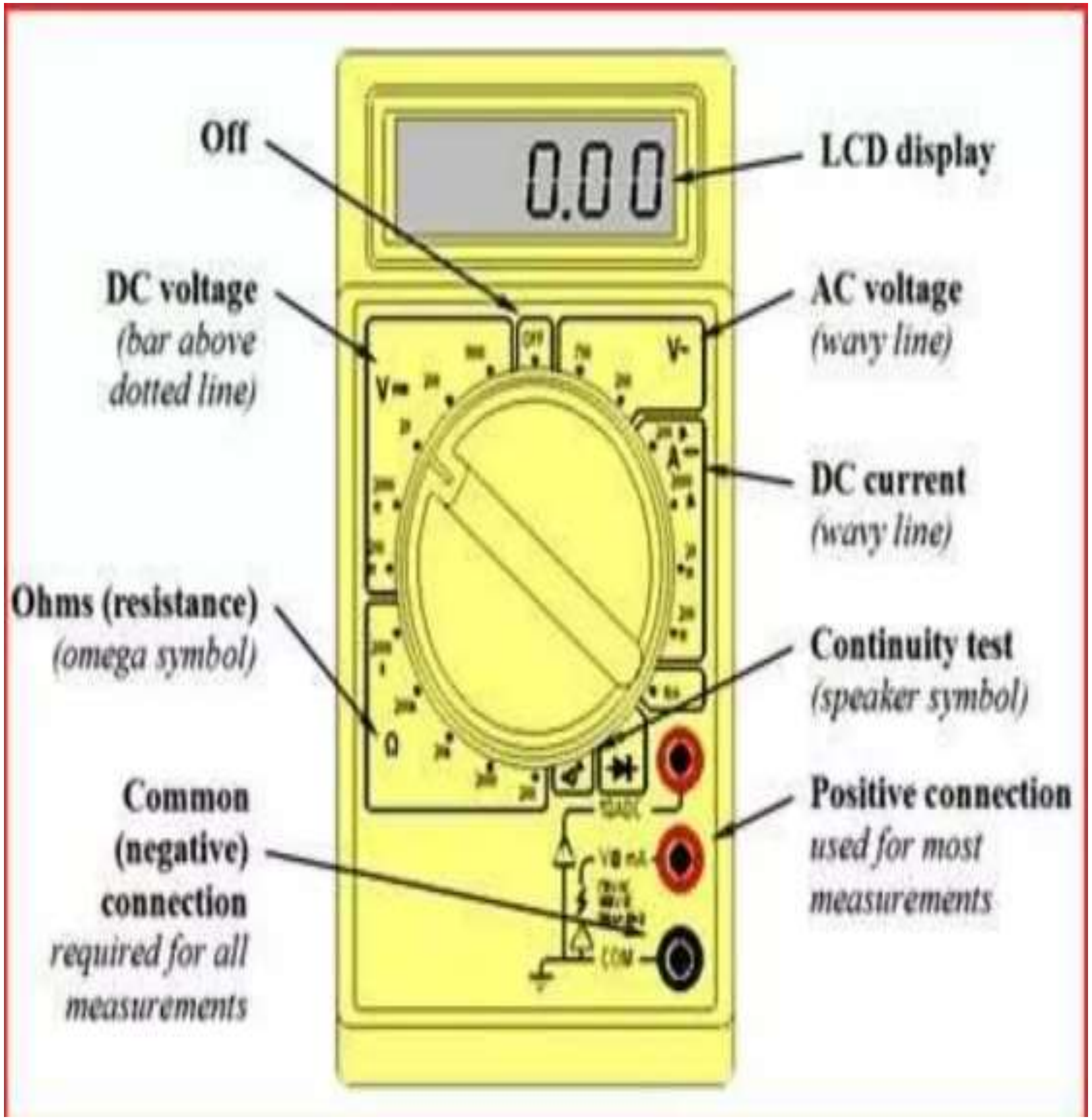

Fig. 7.8

**NOTE:**

1. MC instruments are used for the measurement of DC Quantities only.
2. MI instruments are used for the measurement of both DC & AC Quantities.

# Digital Multimeter (DMM)





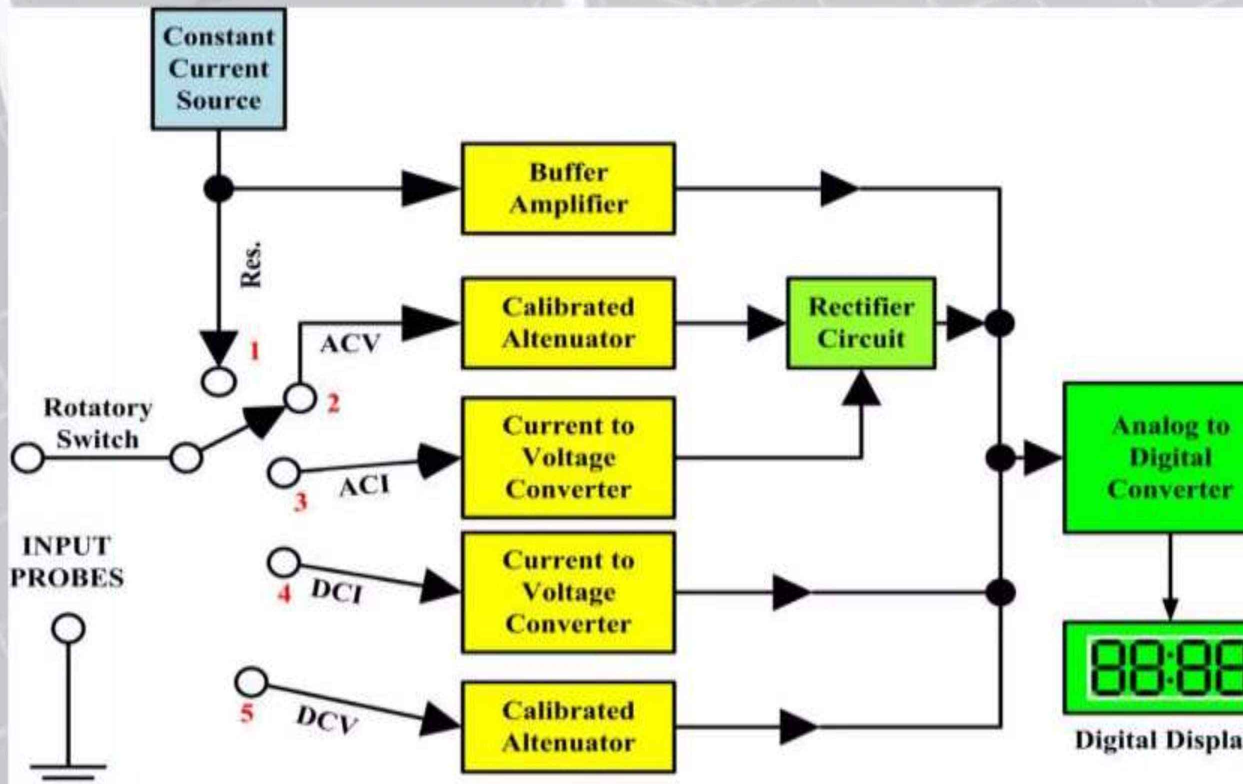
Off
0.00
LCD display
DC voltage
(bar above
dotted line)
AC voltage
(wavy line)
DC current
(wavy line)
Ohms (resistance)
(omega symbol)
Continuity test
(speaker symbol)
Common
(negative)
connection
required for all
measurements
Positive connection
used for most
measurements

# PARTS OF A DIGITAL MULTIMETER

**A multimeter has three parts:-**

- **DISPLAY**
- **SELECTION KNOB**
- **PORTS**

# BLOCK DIAGRAM



- **Display** – The DMM has an illuminated display screen for better visualisation. Most DMM have four digit display, the first of which can only be either a 0 or 1 and a + / - indication as well. There may also be some more indicators like AC / DC etc.
- **Connection Ports** – There are three or four ports available on the front of the DMM. However, only two are needed at a time. Typical ports of the DMM are –
  - **Common** – It is used with all measurements. The negative (black) probe is connected to this.
  - **VΩmA Port** – This port is used for the most measurements and positive (red)probe is connected to it.
  - **10A Port** – It is used to measure the large currents in the circuits.

# Measurements using Digital Multimeter

- **In AC Voltage Mode** – The applied input voltage is fed through a calibrated,compensated attenuator, to a full-wave rectifier followed by a ripple reduction filter.The resulting DC is fed to analog to digital converter (ADC) and finally to the display system.
- **For Current Measurement** –
  - **In DC Current Mode** – The drop across an internal calibrated shunt is measured directly by the ADC.
  - **In AC Current Mode** – After AC to DC conversion, the drop across the internal calibrated shunt is measured by the ADC
- **In Resistance Mode** – In the resistance range, the digital multimeter operates by measuring the voltage across the externally connected resistor, resulting from a current flowing through it from a calibrated internal current source.
- **Special Function –** In addition to AC,DC voltage, AC,DC current and Resistance measurement, most of DMM have following special functions.

# Special Functions



Continuity Tester

Used to test the continuity between two points. Will produce an audio tone.

Diode Tester

Used to test the resistance in a diode for forward bias and reverse bias.

Battery Tester

Used to test 9 volt and 1.5 volt (AAA,AA, C, D) batteries.

# ADVANTAGES OF DIGITAL MULTIMETER

- Very high accuracy
- Has very high input impedance which ensures less loading effect on the input
- The numeric display of digital meters provides zero parallax error.

# DISADVANTAGES OF DIGITAL MULTIMETER

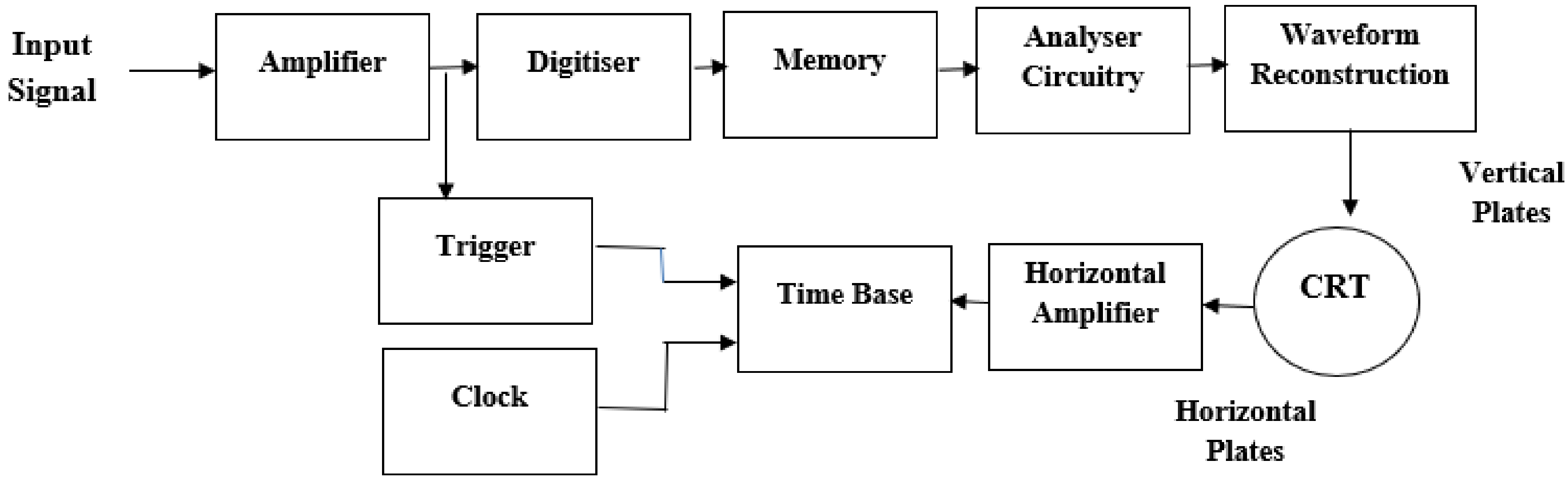
- **It does not do well with measurement fluctuations**
- **It is more expensive than the analog type**
- **It can be difficult to find one for your specific needs**

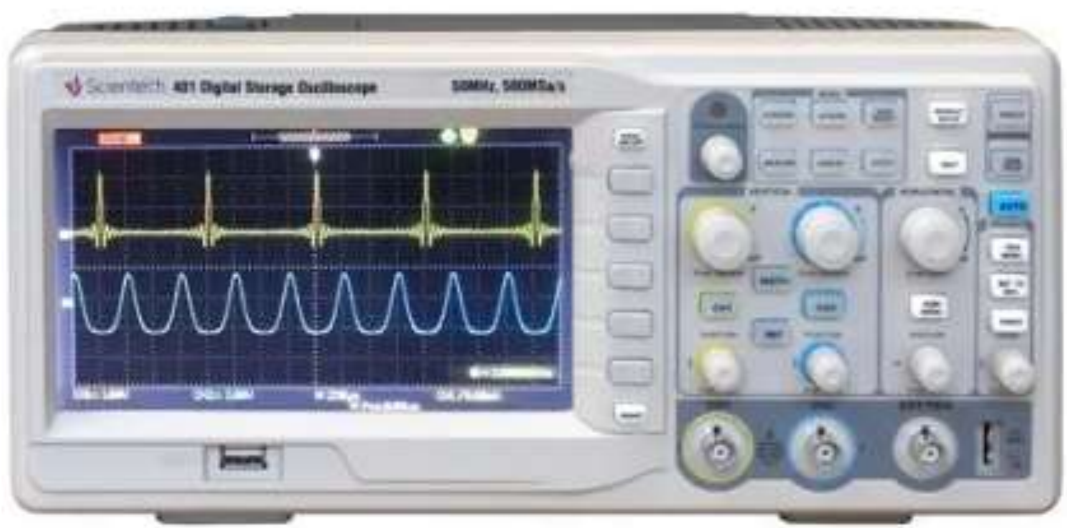
# Digital storage Oscilloscope (DSO)

**Definition:** The digital storage oscilloscope is an instrument which gives the storage of a digital waveform or the digital copy of the waveform. It allows us to store the signal or the waveform in the digital format, and in the digital memory also it allows us to do the digital signal processing techniques over that signal. The maximum frequency measured on the digital signal oscilloscope depends upon two things they are: sampling rate of the scope and the nature of the converter. The traces in DSO are bright, highly defined, and displayed within seconds.

**Block Diagram of Digital Storage Oscilloscope**

The block diagram of the digital storage oscilloscope consists of an amplifier, digitizer, memory, analyzer circuitry. Waveform reconstruction, vertical plates, horizontal plates, cathode ray tube (CRT), horizontal amplifier, time base circuitry, trigger, and clock. The block diagram of the digital storage oscilloscope is shown in the below figure.


Input Signal
Amplifier
Digitiser
Memory
Analyser Circuitry
Waveform Reconstruction
Vertical Plates
Trigger
Clock
Time Base
Horizontal Amplifier
CRT
Horizontal Plates


Scientech
Digital Storage Oscilloscope

As seen in the above figure, at first digital storage oscilloscope digitizes the analog input signal, then the analog input signal is amplified by amplifier if it has any weak signal. After amplification, the signal is digitized by the digitizer and that digitized signal stores in memory. The analyzer circuit process the digital signal after that the waveform is reconstructed (again the digital signal is converted into an analog form) and then that signal is applied to vertical plates of the cathode ray tube (CRT).

The cathode ray tube has two inputs they are vertical input and horizontal input. The vertical input signal is the 'Y' axis and the horizontal input signal is the 'X' axis. The time base circuit is triggered by the trigger and clock input signal, so it is going to generate the time base signal which is a ramp signal. Then the ramp signal is amplified by the horizontal amplifier, and this horizontal amplifier will provide input to the horizontal plate. On the CRT screen, we will get the waveform of the input signal versus time.

The digitizing occurs by taking a sample of the input waveform at periodic intervals. At the periodic time interval means, when half of the time cycle is completed then we are taking the samples of the signal. The process of digitizing or sampling should follow the sampling theorem. The sampling theorem says that the rate at which the samples are taken should be greater than twice the highest frequency present in the input signal. When the analog signal is not properly converted into digital then there occurs an aliasing effect.

## DSO Operation Modes

The digital storage oscilloscope works in three modes of operations they are roll mode, store mode, and hold or save mode.

**Roll Mode:** In roll mode, very fast varying signals are displayed on the display screen.

**Store Mode:** In the store mode the signals stores in memory.

**Hold or Save Mode:** In hold or save mode, some part of the signal will hold for some time and then they will be stored in memory.

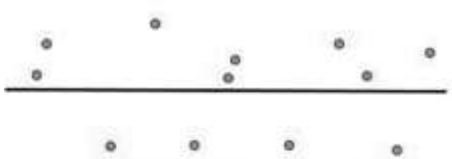
These are the three modes of digital storage oscilloscope operation

## Waveform Reconstruction

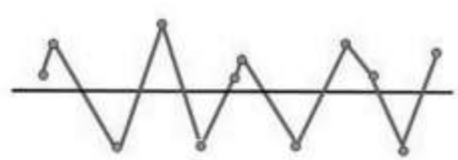
There are two types of waveform reconstructions they are linear interpolation and sinusoidal interpolation.

**Linear Interpolation:** In linear interpolation, the dots are joined by a straight line.

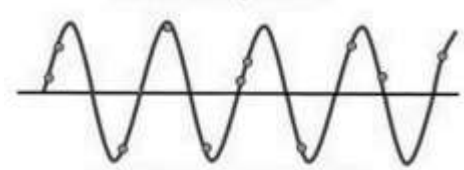
**Sinusoidal Interpolation:** In sinusoidal interpolation, the dots are joined by a sine wave.



Without Interpolation



Linear Interpolation



Sinusoidal Interpolation

The maximum frequency of the signal which is measured by the digital oscilloscope depends on the two factors.

Theses factors are the

1. Sampling rate 2. Nature of converter.

**Sampling Rate** – For safe analysis of input signal the sampling theory is used. The sampling theory states that the sampling rate of the signal must be twice as fast as the highest frequency of the input signal. The sampling rate means analogue to digital converter has a high fast conversion rate.

**Converter** – The converter uses the expensive flash whose resolution decreases with the increases of a sampling rate. Because of the sampling rate, the bandwidth and resolution of the oscilloscope are limited. The need of the analogue to digital signal converters can also be overcome by using the shift register. The input signal is sampled and stored in the shift register. From the shift register, the signal is slowly read out and stored in the digital form. This method reduces the cost of the converter and operates up to 100 megasample per second.

**Applications**

The applications of the DSO are

- It checks faulty components in circuits
- Used in the medical field

- Used to measure capacitor, inductance, time interval between signals, frequency and time period
- Used to observe transistors and diodes V-I characteristics
- Used to analyze TV waveforms
- Used in video and audio recording equipment’s
- Used in designing
- Used in the research field
- For comparison purpose, it displays 3D figure or multiple waveforms
- It is widely used an oscilloscope

**Advantages**

The advantages of the DSO are

- Portable
- Have the highest bandwidth
- The user interface is simple
- Speed is high

**Disadvantages**

The disadvantages of the DSO are

- Complex
- High cost

https://www.elprocus.com/what-is-digital-storage-oscilloscope-working-its-applications/

## Transducer

Transducer is a device which converts the energy from one form to another form. This energy may be electrical, mechanical, chemical, optical or thermal. The transducer that have electrical energy in input or output is known as electrical transducer, [Mostly output ].

The transducers are classified as (i) Active and (ii) Passive transducers.

Active transducers, also known as self generating type, develop their own voltage or current as the output signal. The energy required for production of this output signal is obtained from the physical phenomenon being measured.

Passive transducers, also known as externally powered transducers, derive the power required for energy conversion from an external power source.

# Comparison between active and passive transducer

| Active Transducer | Passive Transducer |
|---|---|
| The active transducer is also called as self generating type transducer. | The passive transducer is also called as externally powered transducer. |
| The active transducer does not require any auxiliary (external) power supply. | The passive transducer requires auxiliary (external) power supply for transduction. |
| The signal conversion is simpler. | The signal conversion is more complicated. |
| The energy required to produce output is obtained from the physical quantity. | They also derived part of the power required for conversion from physical quantity under measurement. |

A few examples of active and passive transducers are given in Table

| *Active transducers* | *Passive transducers* |
|---|---|
| Thermocouple | Resistance |
| Piezoelectric transducer | Potentiometric device |
| Photovoltaic (Photojunction) cell | Resistance strain gauge |
| Moving coil generator | Resistance thermometer |
| Photoelectric (Photoemission) cell | Thermistor |
| | Photoconductive cell |
| | Inductance |
| | Linear Variable Differential Transformer (LVDT) |
| | Capacitance |
| | Voltage and current Devices using Hall effect |
| | Photoemissive cell |
| | Photomultiplier tube |

**Basic requirements of a transducer are:**

(i) Linearity: The input-output characteristics of the transducer should be linear.

(ii) Ruggedness: The transducer should withstand overloads, with measures for overload protection.

(iii) Repeatability: The transducer should produce identical output signals when the same input signal is applied at different times under the same environmental conditions.

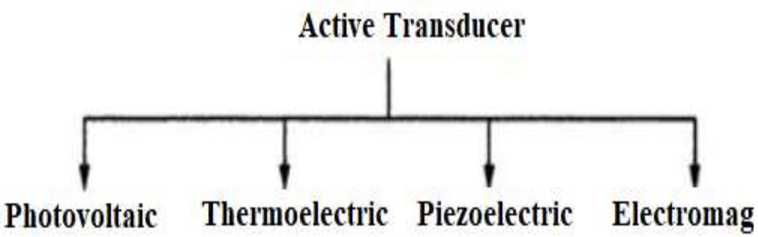
(iv) High stability and reliability: The output from the transducer should not be affected by temperature, vibration and other environmental variations and there should be minimum error in measurements.

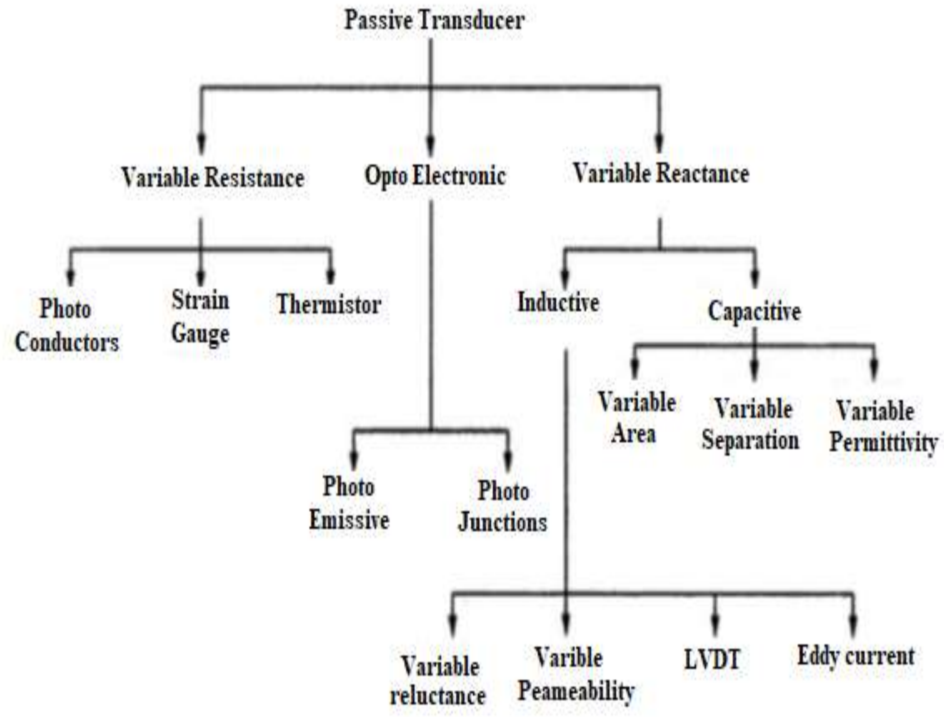
(v) Good dynamic response: In industrial, aerospace and biological applications, the input to the transducer will not be static but dynamic in nature, i.e. the input will vary with time. The transducer should respond to the changes in input as quickly as possible.

(vi) Convenient instrumentation: The transducer should produce a sufficiently high analog output signal with high signal-to-noise ratio, so that the output can be measured either directly or after suitable amplification.

(vii) Good mechanical characteristics: The transducer, under working conditions, will be subjected to various mechanical strains. Such external forces should not introduce any deformity and affect the performance of the transducer.

# Types of active and passive transducers



# Displacement Transducer

Define : A Displacement Transducer is an electromechanical device used to convert mechanical motion or vibrations into a variable electric signals.

Types:

a. Capacitive Transducer

b. Inductive

b (i).Variable Inductance

b (ii). Linear Variable Differential Transformer [LVDT]

# CAPACITIVE TRANSDUCER

The capacitance of a parallel-plate capacitor is given by

$$C = \varepsilon_0 \, \varepsilon_r \frac{A}{d}$$

where $A$ = area of each plate in $m^2$

$d$ = distance between parallel plates in m

$\varepsilon_0$ = dielectric constant (permittivity) of free space in F/m

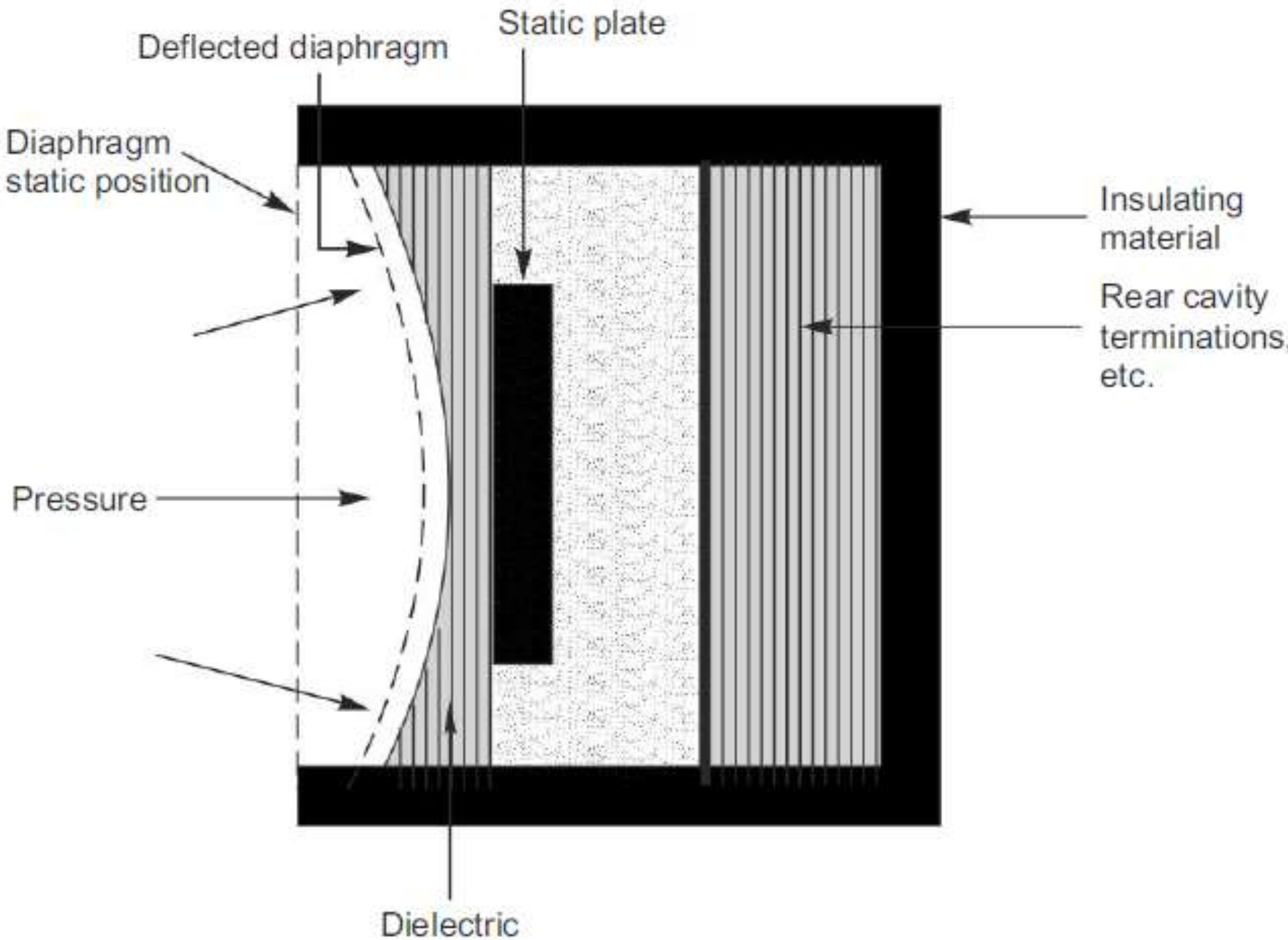
$\varepsilon_r$ = relative dielectric constant (permittivity)

The capacitance is directly proportional to the area of the plate ($A$) and inversely proportional to the distance between the parallel plates ($d$). Obviously, any variation in $A$ or $d$ causes a corresponding variation in the capacitance. This principle of variation in $d$ is used in the capacitive transducer, shown in Fig. .

When a force is applied to a diaphragm which acts as one plate of a capacitor, the distance between the diaphragm and the static plate is changed. The resulting change in capacitance can be measured with an a.c. bridge or an oscillator circuit in which the change in frequency can be measured by an electronic counter and it is a measure of the magnitude of the applied force. In capacitor microphone, the same principle is used in which sound pressure varies the capacitance between the fixed plate and a movable diaphragm.

The capacitive transducer can measure static and dynamic changes. The drawback of this transducer is its sensitivity to temperature variations.

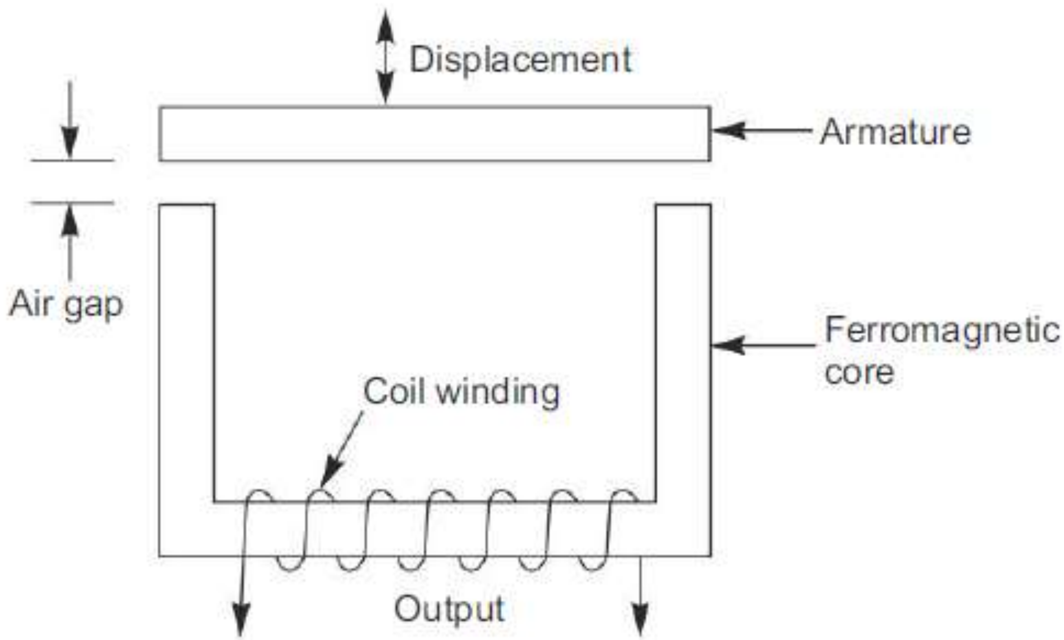
## Capacitive Transducer



# INDUCTIVE TRANSDUCER

When a force is applied to the ferromagnetic armature, the air gap, as shown in Fig. , is changed thereby varying the reluctance of the magnetic circuit. Thus the applied force is measured by the change of inductance in a single coil.

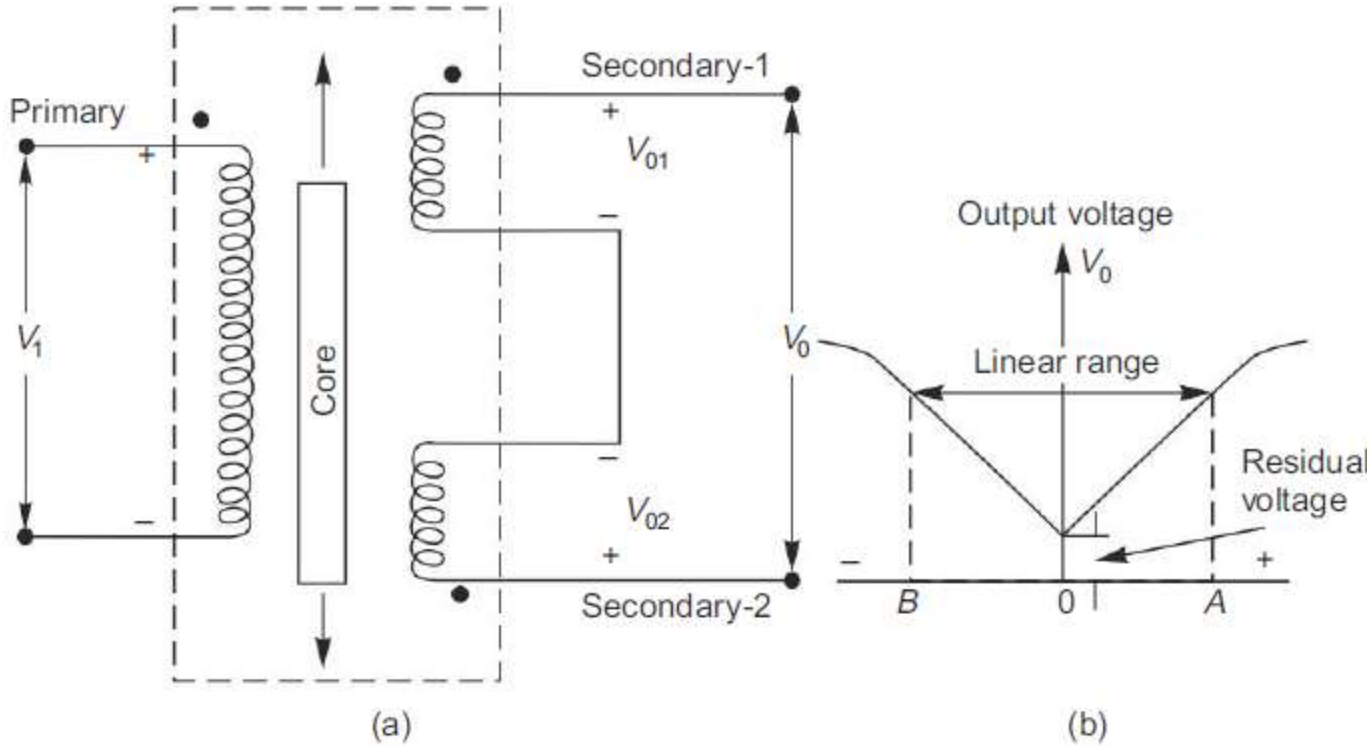
The inductive transducer enables static and dynamic measurements. Its drawback is that it has limited frequency response.



# LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

The most widely used inductance transducer is the Linear Variable Differential Transformer (LVDT) and is shown in Fig. (a). It consists of a primary coil and two exactly similar secondary coils with a rod shaped magnetic core positioned centrally inside the coil. An alternating current is fed into the primary and voltages $V_{o1}$ and $V_{o2}$ are induced in the secondary coils. As these coils are connected in series opposition, the output voltage $V_o = V_{o1} - V_{o2}$. If the core is placed ideally in the central position (null position or reference position), $V_{o1} = V_{o2}$ and hence the output voltage $V_o = 0$. In practice due to incomplete balance, a residual voltage usually remains with the core in this position. As shown in Fig. 11.3, when the core is displaced from the null position, the induced voltage in the secondary towards which the core has moved increases while that in the other secondary decreases. This results in a differential voltage output from the transformer.

The output voltage produced by the displacement of the core is linear over a considerable range [Fig. (b)] but flattens out at both ends, and the voltage phase changes by 180° as the core moves through the center position.




Linear Variable Differential Transformer [LVDT]

LVDT provides continuous resolution and shows low hysteresis and hence, repeatability is excellent under all conditions. As there are no sliding contacts, there is less friction and less noise.

It is sensitive to vibrations and temperature. The receiving instrument must be selected to operate on ac signals or a demodulator network must be used if a dc output is required.

## Advantages, disadvantages and Applications of LVDT

Advt: 1. High Range -1.25mm to 250mm.
2. Low hysteresis
3. Simple, light in weight and easy to maintain.
4. Low Power Consumption

Disadvt: 1. They are sensitive to stray magnetic fields but shielding is possible.
2. Temperature affects the performance of transducer.

Uses: 1. The LVDT can be used in all applications where displacements ranging from fraction of a mm to a few cm have to be measured.
2. Acting as a secondary transducer it can be used as a device to measure force, weight and pressure.

# Thermoelectric Transducers

Define – Converts Temperature to electrical signal or electrical signal to temperature.

Types -

1. Thermistor - Exhibits a large change in resistance proportional to a small change in temperature.

2. Thermocouple - To convert thermal potential difference in to electric potential difference.

# Thermistor

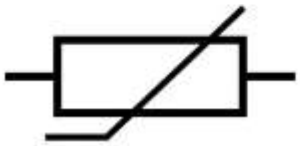
A thermistor (or thermal resistor) is defined as a type of resistor whose electrical resistance varies with changes in temperature. Although all resistors' resistance will fluctuate slightly with temperature, a thermistor is particularly sensitive to temperature changes.

Thermistors act as a passive component in a circuit. They are an accurate, cheap, and robust way to measure temperature.

While thermistors do not work well in extremely hot or cold temperatures, they are the sensor of choice for many different applications.

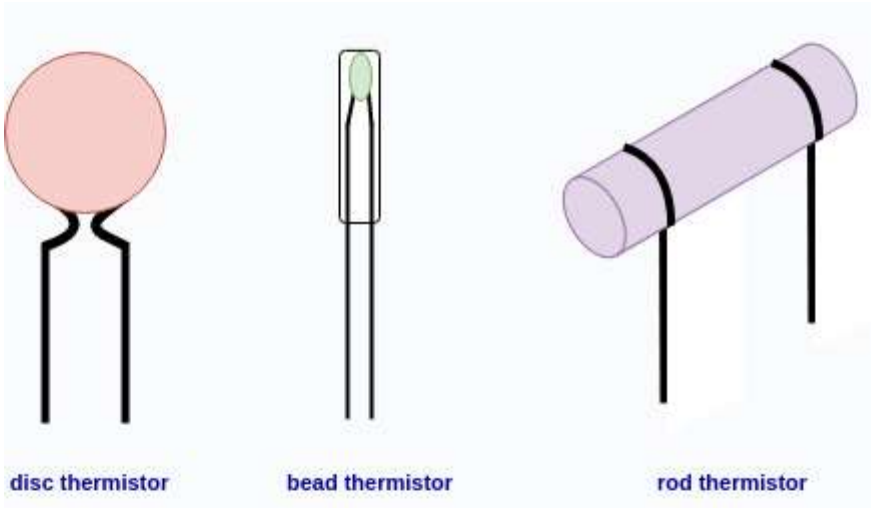
Thermistors are ideal when a precise temperature reading is required.

The circuit symbol for a thermistor is shown below:



## Construction of Thermistor

A thermistor is made of oxides of metals such as Nickel, Manganese, Cobalt, Copper, Uranium etc. It is available in a variety of shapes and sizes. Commonly used for configurations are Disk type, Bead type and Rod type.




The disc type thermistor and rod type thermistor is used when greater power dissipation is required. The rod type thermistor has high power handling capacity.

The smallest thermistor in these configurations is the bead type thermistor. its diameter is low as 0.15 mm. The measurement element is typically encapsulated in a glass probe. It is commonly used for measuring the temperature of liquids.

## Working Principle of Thermistors

The thermistor works on the simple principle of change in resistance due to a change in temperature. When the ambient temperature changes the thermistor starts self-heating its elements. its resistance value is changed with respect to this change in temperature. This change depends on the type of thermistor used. The resistance temperature characteristics of different types of thermistors are given in the following section.

## Types of Thermistors

The two basic types of thermistors available are the NTC and PTC types.

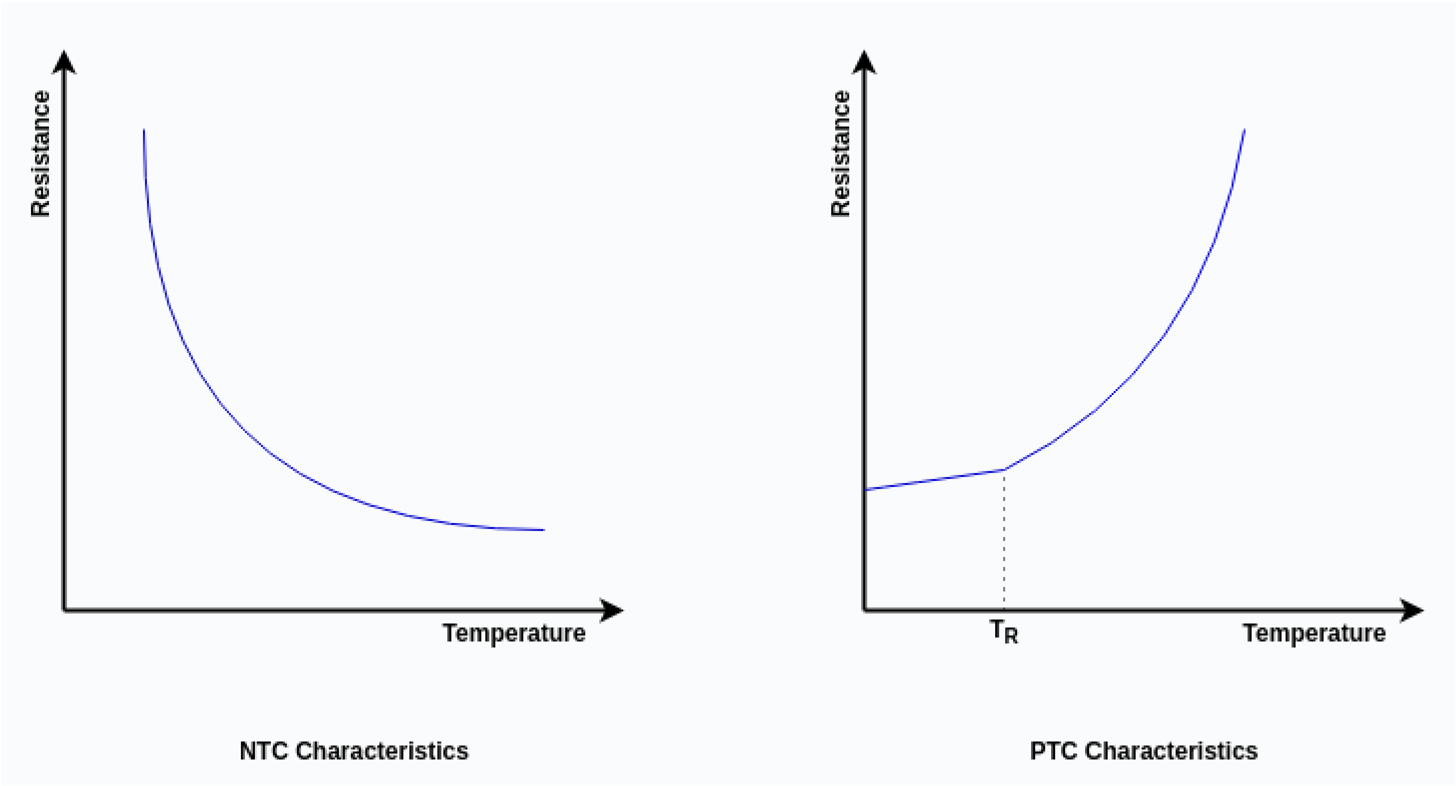
### NTC Thermistor

NTC stands for Negative Temperature coefficient. They are ceramic semiconductors that have a high Negative Temperature Coefficient of resistance. The resistance of an NTC will decrease with increasing temperature in a non-linear manner.

### PTC Thermistor

PTC thermistors are Positive Temperature Coefficient resistors and are made of polycrystalline ceramic materials. The resistance of a PTC will increase with increasing temperature in a non-linear manner. The PTC thermistor shows only a small change of resistance with temperature until the switching point($T_R$) is reached.

The temperature resistance characteristics of an NTC and a PTC is shown in the following figure.



Resistance
Temperature
NTC Characteristics
Resistance
T_R
Temperature
PTC Characteristics

**Advantages of thermistors**

Less expensive.

More sensitive than other sensors.

Fast response.

Small in size.

**Disadvantages of thermistors**

Limited Temperature range.

Resistance to temperature ratio correlation is non-linear.

An inaccurate measurement may be obtained due to the self-heating effect.

Fragile.

**Applications of thermistors**

**NTC Thermistor Application:**

Digital Thermostats.

Thermometers.

Battery pack temperature monitors.

In-rush-current limiting devices

**PTC Thermistor Application:**

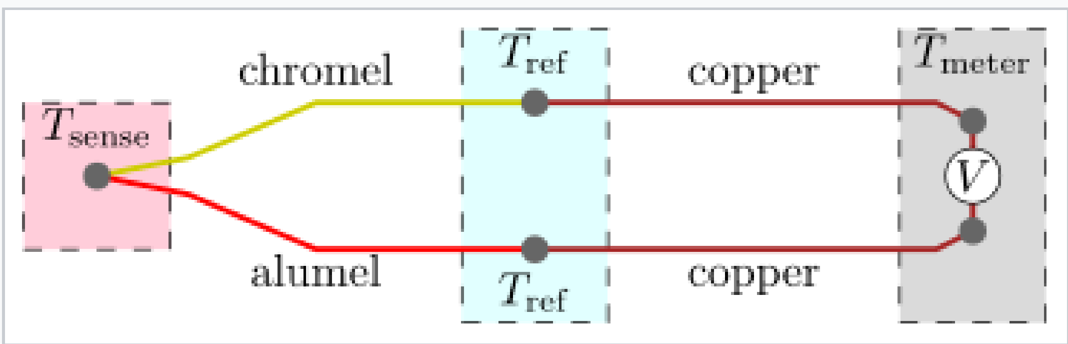
Over-current protection

In-rush-current protection

https://www.electrical4u.com/thermistor/

# Thermocouple

**Thermocouple**, also called as **thermoelectric thermometer**, a temperature-measuring device consisting of two wires of different metals joined at each end. One junction is placed where the temperature is to be measured, and the other is kept at a constant lower temperature. A measuring instrument is connected in the circuit. The temperature difference causes the development of an electromotive force (known as the Seebeck effect) that is approximately proportional to the difference between the temperatures of the two junctions. Temperature can be read from standard tables, or the measuring instrument can be calibrated to read temperature directly.




K-type thermocouple (chromel–alumel) in the standard thermocouple measurement configuration. The measured voltage $V$ can be used to calculate temperature $T_{sense}$, provided that temperature $T_{ref}$ is known.

Any two different metals or metal alloys exhibit the thermoelectric effect, but only a few are used as thermocouples—e.g., antimony and bismuth, copper and iron, or copper and constantan (a copper-nickel alloy). Usually platinum, either with rhodium or a platinum-rhodium alloy, is used in high-temperature thermocouples.

Thermocouple types are named

(e.g., type E [nickel, chromium, and constantan],

J [iron and constantan],

N [two nickel-silicon alloys, one of which contains chromium and magnesium],

B [a platinum-rhodium alloy]) according to the metals used to make the wires.

The most common type is K (nickel-aluminum and nickel-chromium wires) because of its wide temperature range (from about −200 to 1,260 °C [−300 to 2,300 °F]) and low cost.

**The applications of thermocouples** are listed below:

It is used to monitor the temperature in the steel and iron industries. For, this type of application, type B, S, R, and K thermocouples are used in the electric arc furnace.

The principle of a thermocouple is used to measure the intensity of incident radiation (especially visible and infrared light). This instrument is known as a thermopile radiation sensor.

It is used in the temperature sensors in thermostats to measure the temperature of the office, showrooms, and homes.

The thermocouple is used to detect the pilot flame in the appliances that are used to generate heat from gas like a water heater.

To test the current capacity, it is installed to monitor the temperature while testing the thermal stability of switchgear equipment.

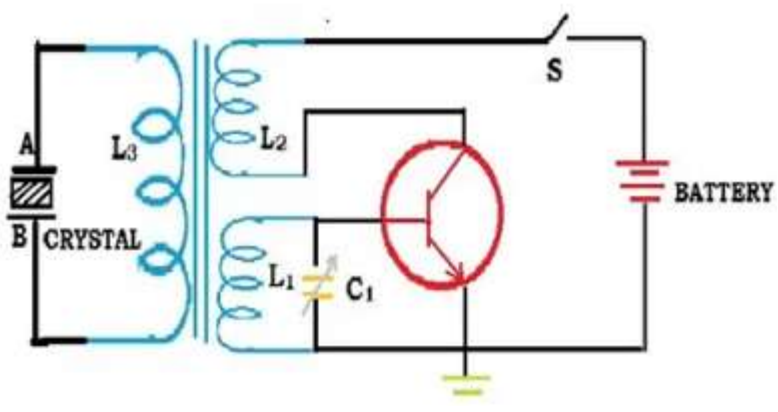
The number of thermocouples is installed in the chemical production plant and petroleum refineries to measure and monitor temperature at different stages of the plant.

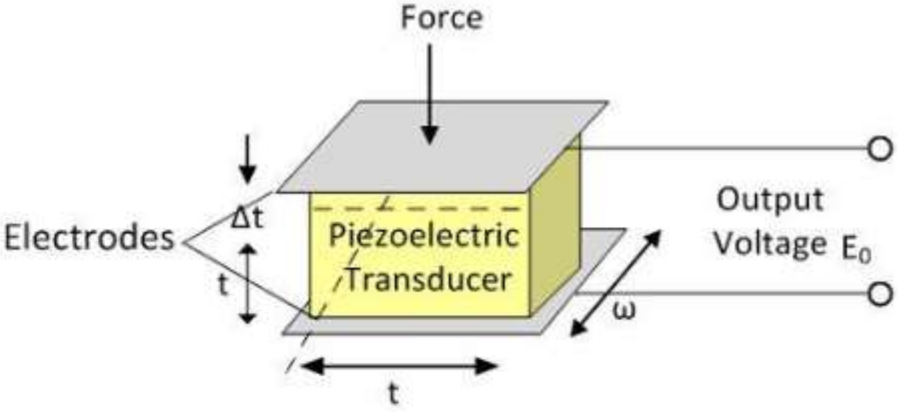
https://www.electrical4u.com/thermocouple/

# Piezoelectric Transducer [ Piezoelectric sensor ]

A **piezoelectric transducer** (also known as a piezoelectric sensor) is a device that uses the piezoelectric effect to measure changes in acceleration, pressure, strain, temperature or force by converting this energy into an electrical charge.

A transducer can be anything that converts one form of energy to another. The piezoelectric material is one kind of transducers. When we squeeze this piezoelectric material or apply any force or pressure, the transducer converts this energy into voltage. This voltage is a function of the force or pressure applied to it.

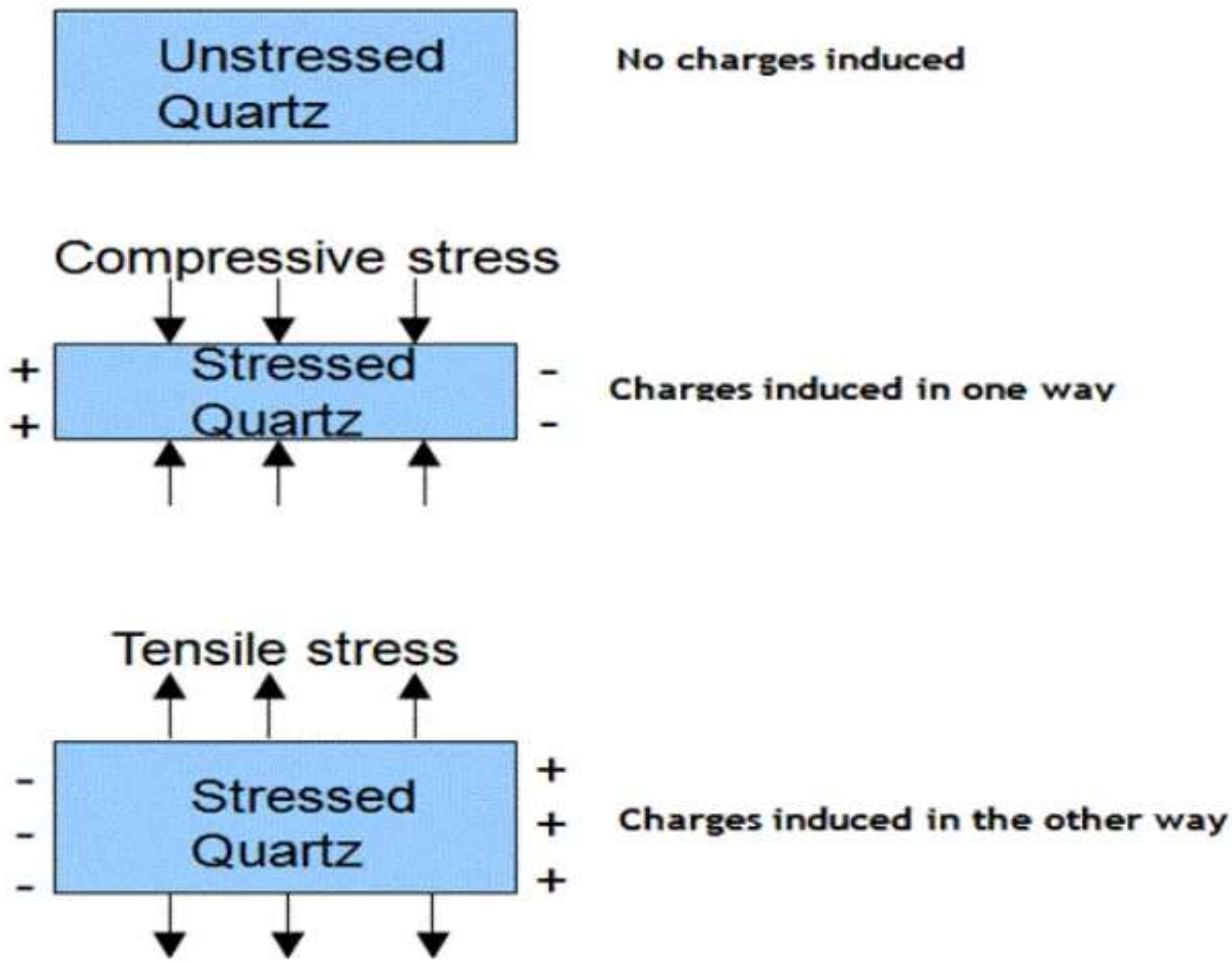


A piezoelectric transducer consists of quartz crystal which is made from silicon and oxygen arranged in crystalline structure ($SiO_2$). Generally, unit cell (basic repeating unit) of all crystal is symmetrical but in piezoelectric quartz crystal, it is not. Piezoelectric crystals are electrically neutral.

The atoms inside them may not be symmetrically arranged but their electrical charges are balanced means positive charges cancel out negative charge. The quartz crystal has the unique property of generating electrical polarity when mechanical stress applied to it along a certain plane. Basically, There are two types of stress. One is compressive stress and the other is tensile stress.

When there is unstressed quartz no charges induce on it. In the case of compressive stress, positive charges are induced on one side and negative charges are induced in the opposite side. The crystal size gets thinner and longer due to compressive stress. In the case of tensile stress, charges are induced in reverse as compare to compressive stress and quartz crystal gets shorter and fatter.


Unstressed Quartz
No charges induced
Compressive stress
Stressed Quartz
Charges induced in one way
Tensile stress
Stressed Quartz
Charges induced in the other way

## Applications

Air Piezoelectric transducers are regularly utilized in automobile, proximity, and level sensors. They are used in medical diagnostics, infertility treatments, and in ultrasonic imaging for medical applications.

They are usually employed in residential products like motion and object identifiers, home security alarms, and pest deterrents. Producers apply them to popular electronic instruments such as games, toys, and remote-control units. You can also find them in electric toothbrushes, inkjet printers, and buzzers.

As piezoelectric materials cannot measure static variations, these are basically employed for measuring plate roughness, in accelerometers, and as a vibration detector. For instance, they are utilized in seismographs to evaluate the vibrations in rockets, or in strain gauges to estimate the vibrations of applied force and stress. They are also utilized for researches on blast waves and high-speed shock waves.

Piezoelectric transducers are also used by automotive producers to evaluate detonations in engines. They are also employed in automobile seat belts to lock in the reaction to a rapid reduction.

The sound pressure is transformed into an electric signal in microphones and this signal is eventually increased to generate a louder sound. In electric lighter in kitchens, when the pressure is applied to the piezoelectric transducer, it produces an electric signal which eventually causes the flash to fire up.

They are also employed in restaurants or airports. In this condition, when a person steps near the door, the door opens automatically using a Piezoelectric transducer. The concept utilized is that when a person is near the door, an electric effect is generated and the door opens automatically.

**https://www.linquip.com/blog/piezoelectric-transducer/**

# Hall Effect Transducer

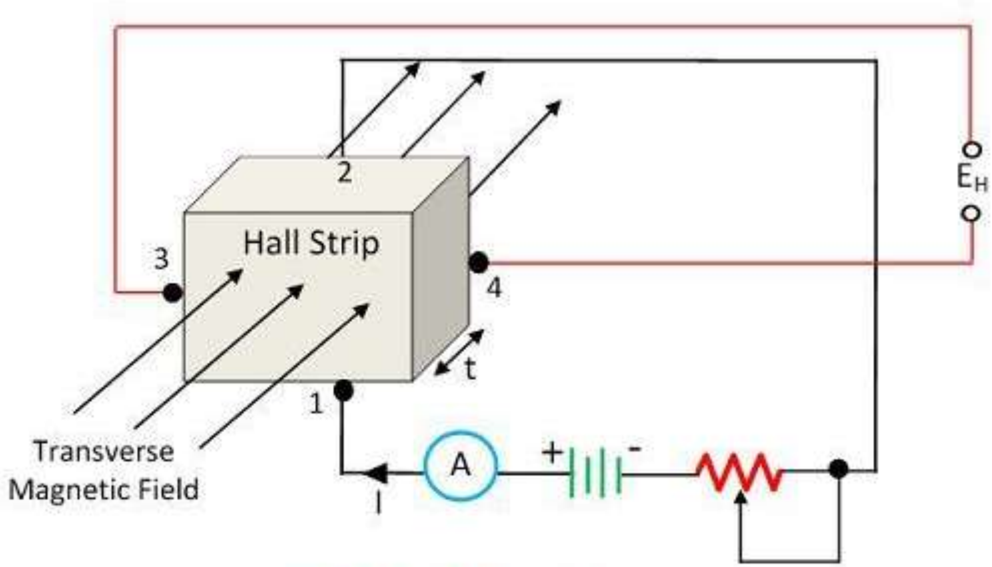
The hall effect element is a type of transducer used for measuring the magnetic field by converting it into an emf. The direct measurement of the magnetic field is not possible. Thus the Hall Effect Transducer is used. The transducer converts the magnetic field into an electric quantity which is easily measured by the analogue and digital meters.

**Principle of Hall Effect Transducer**

The principle of hall effect transducer is that if the current carrying strip of the conductor is placed in a transverse magnetic field, then the EMF develops on the edge of the conductor. The magnitude of the develop voltage depends on the density of flux, and this property of a conductor is called the Hall effect. The Hall effect element is mainly used for magnetic measurement and for sensing the current.

The metal and the semiconductor has the property of hall effect which depends on the densities and the mobility of the electrons.

Consider the hall effect element shown in the figure below. The current supply through the lead 1 and 2 and the output is obtained from the strip 3 and 4. The lead 3 and 4 are at same potential when no field is applied across the strip.




Hall Effect Element

When the magnetic field is applied to the strip, the output voltage develops across the output leads 3 and 4. The develops voltage is directly proportional to the strength of the material.

The output voltage is,

$$E_H = K_H IB/t$$

where,

$$K_H - Hall\ effect\ coefficient\ ;\ \frac{V-m}{A-Wbm^{-2}}$$

$$t - thickness\ of\ Strip\ ;m$$

The I is the current in ampere and the B is the flux densities in $Wb/m^2$

The current and magnetic field strength both can be measured with the help of the output voltages. The hall effect EMF is very small in conductors because of which it is difficult to measure. But semiconductors like germanium produces large EMF which is easily measured by the moving coil instrument.

**Applications of Hall Effect Transducer**

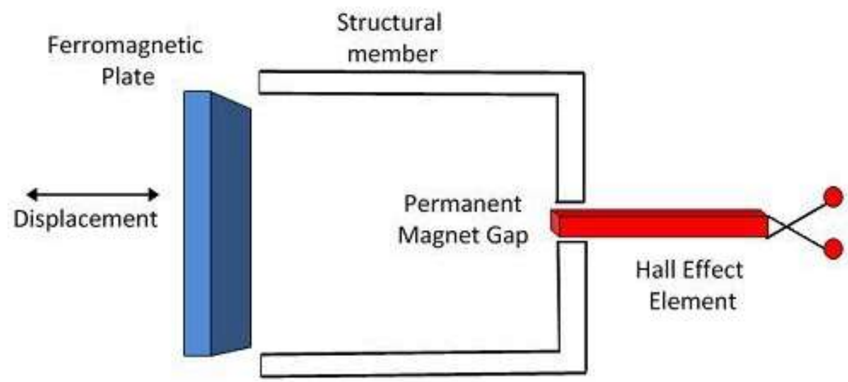
The following are the application of the Hall effect Transducers.

**1. Magnetic to Electric Transducer** – The Hall effect element is used for converting the magnetic flux into an electric transducer. The magnetic fields are measured by placing the semiconductor material in the measurand magnetic field. The voltage develops at the end of the semiconductor strips, and this voltage is directly proportional to the magnetic field density.

The Hall Effect transducer requires small space and also gives the continuous signal concerning the magnetic field strength. The only disadvantage of the transducer is that it is highly sensitive to temperature and thus calibration requires in each case.

**2. Measurement of Displacement** – The Hall effect element measures the displacement of the structural element. For example – Consider the ferromagnetic structure which has a permanent magnet.

The hall effect transducer placed between the poles of the permanent magnet. The magnetic field strength across the hall effect element changes by changing the position of the ferromagnetic field.




Measurement of Displacement Using Hall Efect Transducer

**3. Measurement of Current** – The hall effect transducer is also used for measuring the current without any physical connection between the conductor circuit and meter.

The AC or DC is applied across the conductor for developing the magnetic field. The strength of the magnetic field is directly proportional to the applied current. The magnetic field develops the emf across the strips. And this EMF depends on the strength of the conductor.

**4. Measurement of Power** – The hall effect transducer is used for measuring the power of the conductor. The current is applied across the conductor, which develops the magnetic field. The intensity of the field depends on the current. The magnetic field induces the voltage across the strip. The output voltage of the multiplier is proportional to the power of the transducer.

https://circuitglobe.com/hall-effect-transducer.html

## Photoelectric Transducer

The photoelectric transducer can be defined as, a transducer which changes the energy from the light to electrical. It can be designed with the semiconductor material. This transducer utilizes an element like photosensitive which can be used for ejecting the electrons as the light beam soak ups through it. The electron discharges can change the photosensitive element's property. Therefore the flowing current stimulates within the devices. The flow of the current's magnitude can be equivalent to the whole light absorbed with the photosensitive element.

This transducer soak ups the light radiation which drops over the semiconductor material. The light absorption can boost the electrons in the material, & therefore the electrons begin to move. The electron mobility can generate three effects like

The material resistance will be changed.

The semiconductor's o/p current will be changed.

The semiconductor's o/p voltage will be changed.

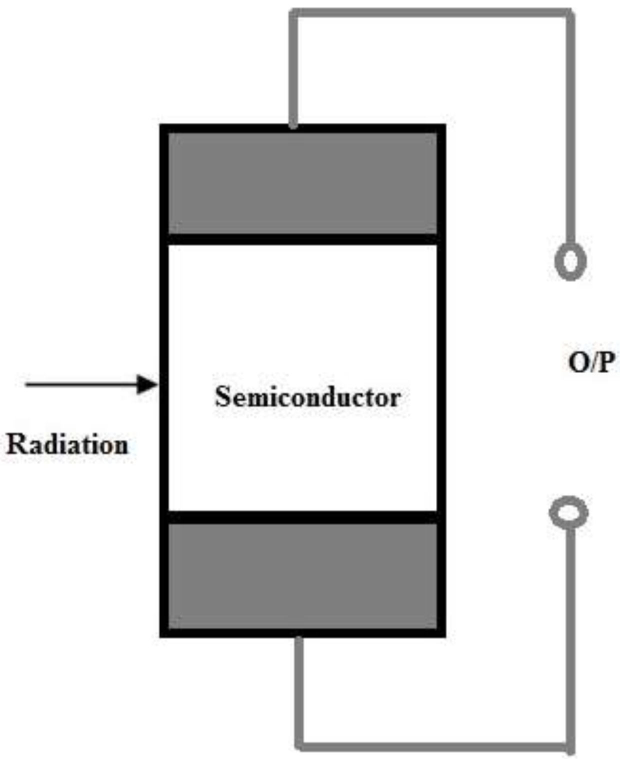
**Photoelectric Transducer Classification**

These transducers are classified into five **types** which include the following

- Photo emissive Cell
- Photodiode
- Phototransistor
- Photo-voltaic cell
- Photoconductive Cell

**Working Principle**

The working principle of Photoelectric Transducer can be classified like photoemissive, photovoltaic otherwise photoconductive. In photoemissive type devices, once the radiation drops over a cathode can cause emission of electrons from the cathode plane. The output of the PV cells can generate a voltage which is relative to the intensity of radiation. The occurrence of radiation can be IR (infrared), UV (ultraviolet), X-rays, gamma rays, and visible light. In photo-conductive devices, the material's resistance can be changed once it is light up.




**Applications of Photoelectric Transducer**

The applications of this transducer mainly include the following.

- These transducers are used in biomedical applications
- Pickups of pulse
- Pneumograph respiration
- Measure blood pulsatile volume changes
- Records Body movements.

https://www.elprocus.com/photoelectric-transducer-working-applications/#:~:text=The%20photoelectric%20transducer%20can%20be,beam%20soak%20ups%20through%20it.

# Introduction to Opto-electronics Devices

Definition : Converts light energy to electrical energy and vice versa.

Types:

- Laser diode, light-emitting diode - convert electrical power into forms of light.
- Photodiode, photo resistor, phototransistor, photomultiplier tube, solar cells - converts changing light levels into electrical form.
- The major developments of optoelectronic devices are:

  1. They have a longer wavelength.
  2. They are easily fabricated materials.
  3. They are of low cost.
  4. They have high optoelectronic conversion efficiency.
  5. These are Nano-scale devices.
  6. They have high power light sources.

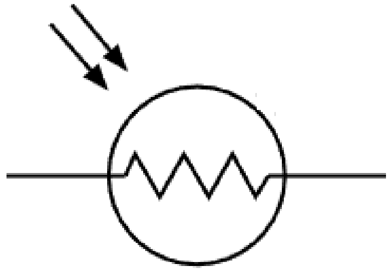
## Light-dependent resistor (LDR) or Photo-resistor or photocell or photo-conductive cell

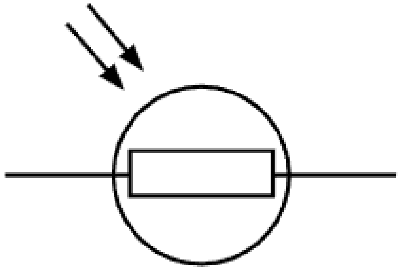
A light dependent resistor is an electronic component that is sensitive to light. When light falls upon it, then the resistance decreases. Values of the resistance of the LDR may decrease over many orders of magnitude the value of the resistance falling as the level of light increases.

It is common for the values of resistance of an LDR to be several megaohms in darkness and then to fall to a few hundred ohms in bright light.

LDRs are made from semiconductor materials to enable them to have their light sensitive properties. Many materials can be used, but one popular material for these photoresistors is cadmium sulphide. Also lead sulphide, PbS and indium antimonide are also used to manufacture LDRs.

**Symbols**





## Working Principle of light dependent resistor (LDR)

An LDR or photoresistor is made any semiconductor material with a high resistance. It has a high resistance because there are very few electrons that are free and able to move - the vast majority of the electrons are locked into the crystal lattice and unable to move. Therefore in this state there is a high LDR resistance.

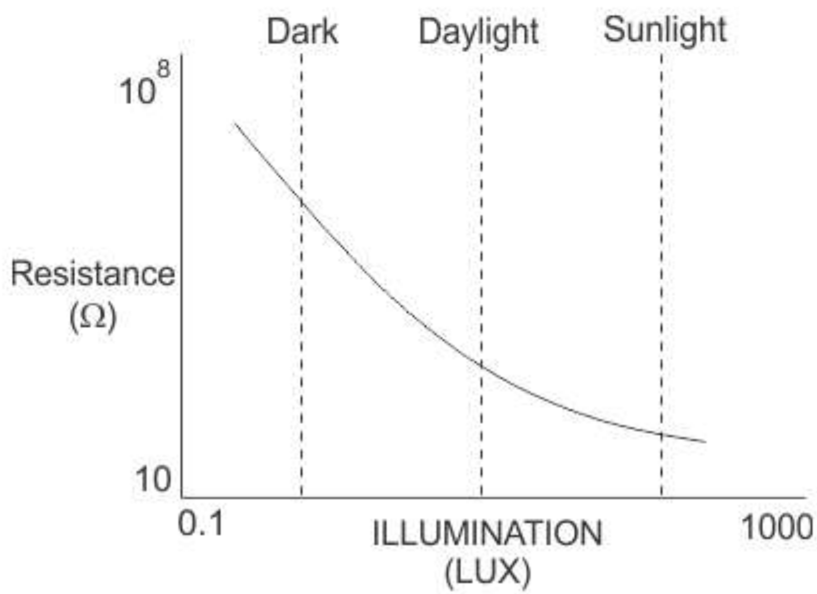
As light falls on the semiconductor, the light photons are absorbed by the semiconductor lattice and some of their energy is transferred to the electrons.

The amount of energy transferred to the electrons gives some of them sufficient energy to break free from the crystal lattice so that they can then conduct electricity. This results in a lowering of the resistance of the semiconductor and hence the overall LDR resistance.

The process is progressive, and as more light shines on the LDR semiconductor, so more electrons are released to conduct electricity and the resistance falls further.

**Characteristics of light dependent resistor (LDR)**

Photoresistor/ LDR's are light-dependent devices whose resistance is decreased when light falls on them and that is increased in the dark. When a light dependent resistor is kept in dark, its resistance is very high. This resistance is called as dark resistance. It can be as high as 1012 Ω and if the device is allowed to absorb light its resistance will be decreased drastically. If a constant voltage is applied to it and the intensity of light is increased the current starts increasing. The figure below shows the resistance vs. illumination curve for a particular **LDR**.

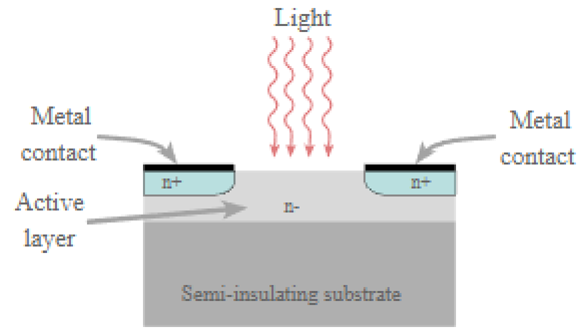


## Photoresistor / LDR structure

Structurally the photoresistor is a light sensitive resistor that has a horizontal body that is exposed to light.

The basic format for a photoresistor is that shown below:

Photoresistor structure




The active semiconductor region is normally deposited onto a semi-insulating substrate and the active region is normally lightly doped.

In many discrete photoresistor devices, an interdigital pattern is used to increase the area of the photoresistor that is exposed to light. The pattern is cut in the metallisation on the surface of the active area and this lets the light through. The two metallise areas act as the two contacts for the resistor. This area has to be made relatively large because the resistance of the contact to the active area needs to be minimised.

**Types of light dependent resistor**

Light dependent resistors, LDRs or photoresistors fall into one of two types or categories:

***Intrinsic light dependent resistor :*** Intrinsic photoresistors use un-doped semiconductor materials including silicon or germanium. Photons fall on the LDR excite electrons moving them from the valence band to the conduction band.

As a result, these electrons are free to conduct electricity. The more light that falls on the device, the more electrons are liberated and the greater the level of conductivity, and this results in a lower level of resistance.

***Extrinsic light dependent resistor :*** Extrinsic photoresistors are manufactured from semiconductor of materials doped with impurities. These impurities or dopants create a new energy band above the existing valence band.

As a result, electrons need less energy to transfer to the conduction band because of the smaller energy gap.

Regardless of the type of light dependent resistor or photoresistor, both types exhibit an increase in conductivity or fall in resistance with increasing levels of incident light.

**Applications of light dependent resistor (LDRs)**

Photoresistors (LDRs) have low cost and simple structure and are often used as light sensors. Other applications of photoresistors include:

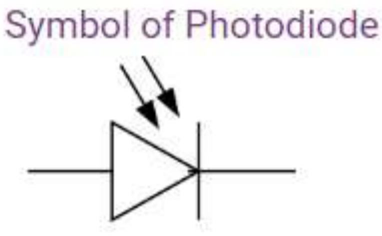
- Detect absences or presences of light like in a camera light meter.
- Used in street lighting design (can be combined with a good Arduino starter kit to act as a street light controller)
- Alarm clocks
- Burglar alarm circuits
- Light intensity meters
- Used as part of a SCADA system to perform functions such as counting the number of packages on a moving conveyor belt

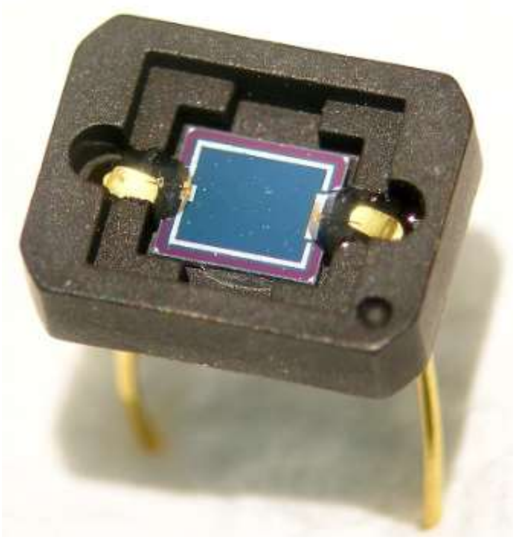
https://www.electrical4u.com/light-dependent-resistor-ldr-working-principle-of-ldr/

# Photodiodes

Photodiodes are a class of diodes that converts light energy to electricity. Their working is exactly the opposite of LEDs which are also diodes but they convert electricity to light energy. Photodiodes can also be used in detecting the brightness of the light.

A photodiode is a PN-junction diode that consumes light energy to produce an electric current. They are also called a photo-detector, a light detector, and a photo-sensor. Photodiodes are designed to work in reverse bias condition. Typical photodiode materials are Silicon, Germanium and Indium gallium arsenide.



**Photodiode Working**

A photodiode is subjected to photons in the form of light which affects the generation of electron-hole pairs. If the energy of the falling photons (hv) is greater than the energy gap ($E_g$) of the semiconductor material, electron-hole pairs are created near the depletion region of the diode. The electron-hole pairs created are separated from each other before recombining due to the electric field of the junction. The direction of the electric field in the diode forces the electrons to move towards the n-side and consequently the holes move towards the p-side. As a result of the increase in the number of electrons on the n-side and holes on the p-side, a rise in the electromotive force is observed. Now when an external load is connected to the system, a current flow is observed through it.

The more the electromotive force created, the greater the current flow. The magnitude of the electromotive force created depends directly upon the intensity of the incident light. This effect of the proportional change in photocurrent with the change in light intensity can be easily observed by applying a reverse bias.

Since photodiodes generate current flow directly depending upon the light intensity received, they can be used as photodetectors to detect optical signals. Built-in lenses and optical filters may be used to enhance the power and productivity of a photodiode.

**Applications of Photodiode**

- Photodiodes are used in simple day-to-day applications. The reason for their prominent use is their linear response of photodiode to light illumination.
- Photodiodes with the help of optocouplers provide electric isolation. When two isolated circuits are illuminated by light, optocouplers are used to couple the circuit optically. Optocouplers are faster compared to conventional devices.
- Photodiodes are used in safety electronics such as fire and smoke detectors.
- Photodiodes are used in numerous medical applications. They are used in instruments that analyze samples, detectors for computed tomography and also used in blood gas monitors.
- Photodiodes are used in solar cell panels.
- Photodiodes are used in logic circuits.
- Photodiodes are used in the detection circuits.
- Photodiodes are used in character recognition circuits.
- Photodiodes are used for the exact measurement of the intensity of light in science and industry.
- Photodiodes are faster and more complex than normal PN junction diodes and hence are frequently used for lighting regulation and optical communication.

https://byjus.com/physics/photodiodes-applications/

# Phototransistors

A **Phototransistor** is an electronic switching and current amplification component which relies on exposure to light to operate. When light falls on the junction, reverse current flows which are proportional to the luminance. Phototransistors are used extensively to detect light pulses and convert them into digital electrical signals. These are operated by light rather than electric current. Providing a large amount of gain, low cost and these phototransistors might be used in numerous applications. It is capable of converting light energy into electric energy. Phototransistors work in a similar way to photoresistors commonly known as LDR (light dependent resistor) but are able to produce both current and voltage while photoresistors are only capable of producing current due to change in resistance.

Phototransistors are transistors with the base terminal exposed. Instead of sending current into the base, the photons from striking light activate the transistor. This is because a phototransistor is made of a bipolar semiconductor and focuses on the energy that is passed through it. These are activated by light particles and are used in virtually all electronic devices that depend on light in some way. All silicon photosensors (phototransistors) respond to the entire visible radiation range as well as to infrared.

## Construction

A **phototransistor** is nothing but an ordinary bi-polar transistor in which the base region is exposed to illumination. It is available in both the P-N-P and N-P-N types having different configurations like common emitter, common collector, and common base but generally, common emitter **configuration** is used. It can also work while the base is made open. Compared to the conventional transistor it has more base and collector areas.

Ancient phototransistors used single semiconductor materials like silicon and germanium but now a day's modern components use materials like gallium and arsenide for high-efficiency levels. The base is the lead responsible for activating the transistor. It is the gate controller device for the larger electrical supply. The collector is the positive lead and the larger electrical supply. The emitter is the negative lead and the outlet for the larger electrical supply.

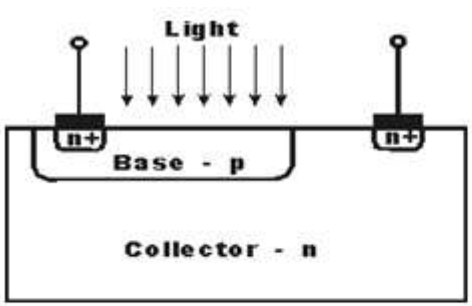
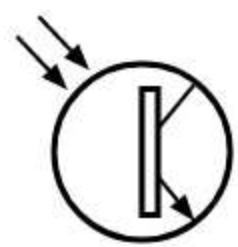



Photo Transistor Construction



Phototransistor Symbol

With no light falling on the device there will be a small current flow due to thermally generated hole-electron pairs and the output voltage from the circuit will be slightly less than the supply value due to the voltage drop across the load resistor R. With light falling on the collector-base junction the current flow increases. With the base connection open circuit, the collector-base current must flow in the base-emitter circuit, and hence the current flowing is amplified by normal transistor action.

The collector-base junction is very sensitive to light. Its working condition depends upon the intensity of light. The base current from the incident photons is amplified by the gain of the transistor, resulting in current gains that range from hundreds to several thousand. A phototransistor is 50 to 100 times more sensitive than a photodiode with a lower level of noise.

A phototransistor activates once the light strikes the base terminal & the light triggers the phototransistor by allowing the configuration of hole-electron pairs as well as the current flow across the emitter or collector. When the current increases, then it is concentrated as well as changed into voltage.

Generally, a phototransistor doesn’t include a base connection. The base terminal is disconnected as the light is used to allow the flow of current to supply throughout the phototransistor.

**Applications of Phototransistors**

The Areas of application for the Phototransistor include:

Punch-card readers.

Security systems

Encoders – measure speed and direction

IR detectors photo

electric controls

Computer logic circuitry.

Relays

Lighting control (highways etc)

Level indication

Counting systems

The **difference between photodiode and phototransistor** includes the following.

The **difference between photodiode and phototransistor** includes the following.

| Photodiode | Phototransistor |
|---|---|
| The photodiode is a PN-junction diode, used to generate electric current once a photon of light strikes on their surface. | The phototransistor is used to change the energy of the light into an electrical energy |
| It is less sensitive | It is more sensitive |
| The output response of photodiode is fast | The output response of the phototransistor is low |
| It produces current | It produces voltage and current |
| It is used in solar power generation, detecting UV otherwise IR rays & also for light measuring, etc. | It is used in compact disc players, smoke detectors, lasers, invisible light receivers, etc. |
| It is more reactive to incident lights | It is less reactive |
| The photodiode has a less dark current<br>In this, both the biasing is used like forward and reverse | Phototransistor has high dark current<br>In this, forward biasing is used |
| The linear response range of photodiode is much wider | The linear response range of phototransistor is much lower |
| Photodiode allows low current as compared to a phototransistor | Phototransistor allows high current as compared to the photodiode |
| The photodiode is used for battery-powered devices that use less power. | The phototransistor is used as a solid-state switch, not like a photodiode. |

# Photovoltaic cells (solar cells)

A **photovoltaic** (**PV**) **cell** is an energy harvesting technology, that converts solar energy into useful electricity through a process called the photovoltaic effect. There are several different types of PV cells which all use semiconductors to interact with incoming photons from the Sun in order to generate an electric current.

**Layers of a PV Cell**

A photovoltaic cell is comprised of many layers of materials, each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer. It is comprised of two distinct layers (p-type and n-type—see Figure 2), and is what actually converts the Sun's energy into useful electricity through a process called the photovoltaic effect (see below). On either side of the semiconductor is a layer of conducting material which "collects" the electricity produced. Note that the backside or shaded side of the cell can afford to be completely covered in the conductor, whereas the front or illuminated side must use the conductors sparingly to avoid blocking too much of the Sun's radiation from reaching the semiconductor.

The final layer which is applied only to the illuminated side of the cell is the anti-reflection coating. Since all semiconductors are naturally reflective, reflection loss can be significant. The solution is to use one or several layers of an anti-reflection coating (similar to those used for eyeglasses and cameras) to reduce the amount of solar radiation that is reflected off the surface of the cell.

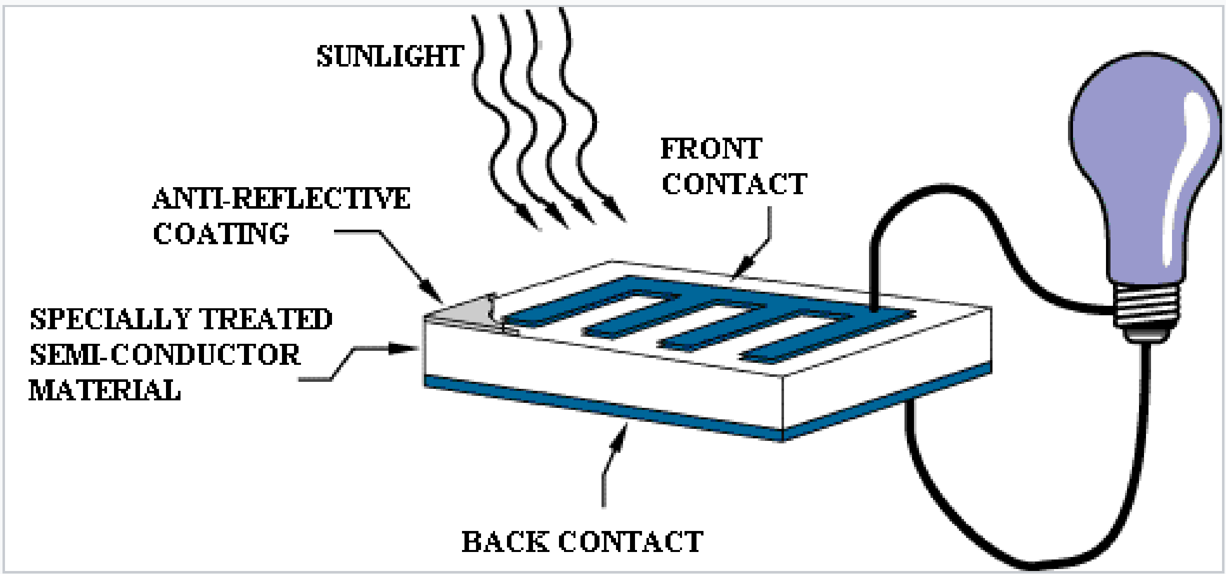



Figure 1 The basic operation of a PV cell.

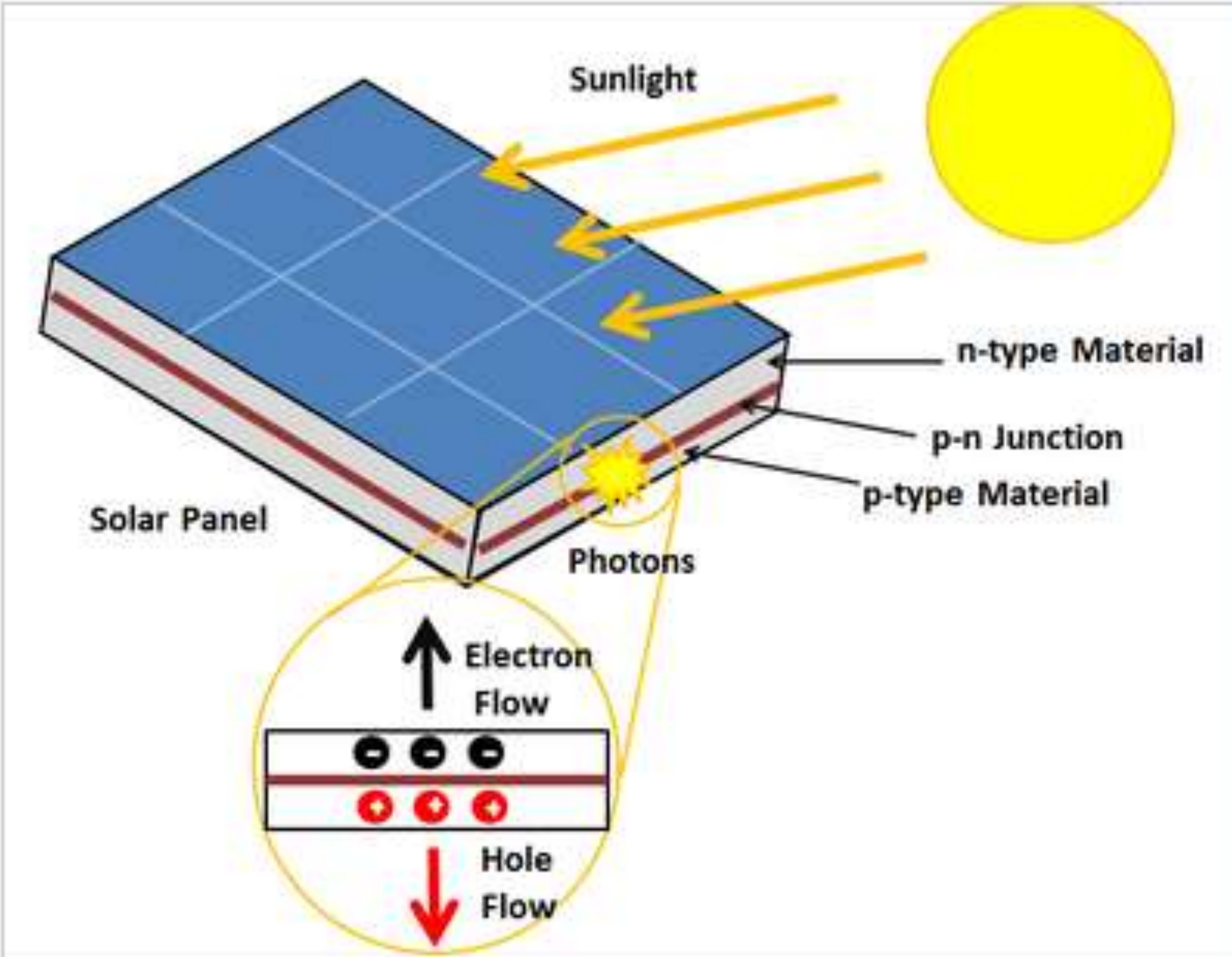



Figure 2. A diagram showing the photovoltaic effect.[4]

## Photovoltaic Effect

The **photovoltaic effect** is a process that generates voltage or electric current in a photovoltaic cell when it is exposed to sunlight. These solar cells are composed of two different types of semiconductors—a p-type and an n-type—that are joined together to create a p-n junction. By joining these two types of semiconductors, an electric field is formed in the region of the junction as electrons move to the positive p-side and holes move to the negative n-side. This field causes negatively charged particles to move in one direction and positively charged particles in the other direction.[5] Light is composed of photons, which are simply small bundles of electromagnetic radiation or energy. When light of a suitable wavelength is incident on these cells, energy from the photon is transferred to an electron of the semiconducting material, causing it to jump to a higher energy state known as the conduction band. In their excited state in the conduction band, these electrons are free to move through the material, and it is this motion of the electron that creates an electric current in the cell.

## Solar Cell Efficiency

Efficiency is a design concern for photovoltaic cells, as there are many factors that limit their efficiency. The main factor is that 1/4 of the solar energy to the Earth cannot be converted into electricity by a silicon semiconductor. The physics of semiconductors requires a minimum photon energy to remove an electron from a crystal structure, known as the band-gap energy. If a photon has less energy than the band-gap, the photon gets absorbed as thermal energy. For silicon, the band-gap energy is 1.12 electron volts.Since the energy in the photons from the sun cover a wide range of energies, some of the incoming energy from the Sun does not have enough energy to knock off an electron in a silicon PV cell. Even from the light that can be absorbed, there is still a problem. Any energy above the band-gap energy will be transformed into heat. This also cuts the efficiency because that heat energy is not being used for any useful task.Of the electrons that are made available, not all of them will actually make it to the metal contact and generate electricity. Some electrons will not be accelerated sufficiently by the voltage inside the semiconductor to leave the system. These effects combine to create a theoretical efficiency of silicon PV cells is about **33%**.

There are ways to improve the efficiency of PV cells, all of which come with an increased cost. Some of these methods include increasing the purity of the semiconductor, using a more efficient semiconducting material such as Gallium Arsenide, by adding additional layers or p-n junctions to the cell, or by concentrating the Sun's energy using concentrated photovoltaics. On the other hand, PV cells will also degrade, outputting less energy over time, due to a variety of factors including UV exposure and weather cycles. A comprehensive report from the National Renewable Energy Laboratory (NREL) states that the median degradation rate is 0.5% per year.

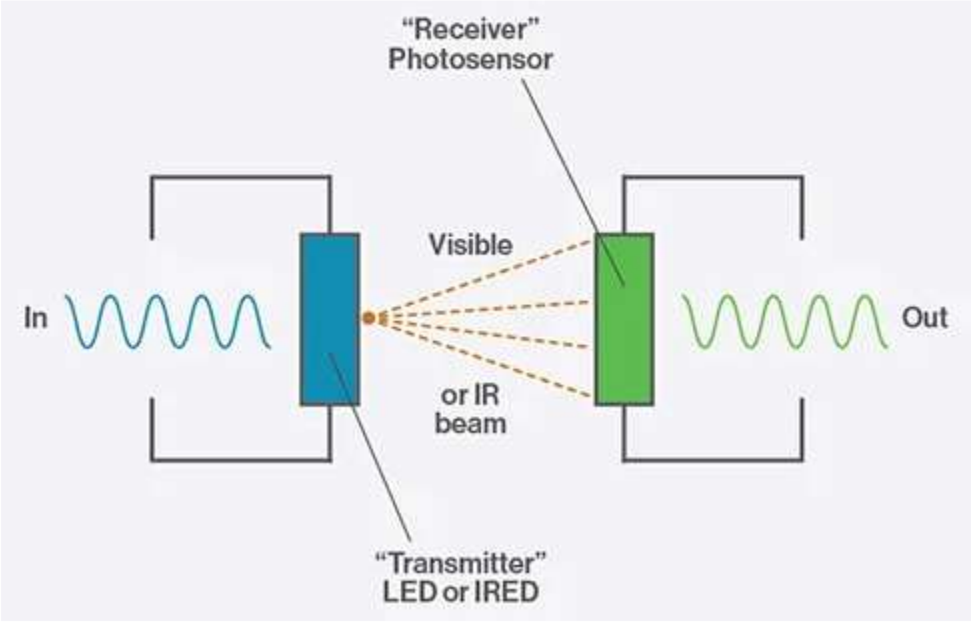
**Types of PV Cells:** Photovoltaic cell can be manufactured in a variety of ways and from many different materials. The most common material for commercial solar cell construction is Silicon (Si), but others include Gallium Arsenide (GaAs), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide (CIGS). Solar cells can be constructed from brittle crystalline structures (Si, GaAs) or as flexible thin-film cells (Si, CdTe, CIGS). Crystalline solar cells can be further classified into two categories—*monocrystalline* and *polycrystalline*. As the names suggest, monocrystalline PV cells are comprised of a uniform or single crystal lattice, whereas polycrystalline cells contain different or varied crystal structures.

https://energyeducation.ca/encyclopedia/Photovoltaic_cell

# Optocoupler

An **optocoupler** (also called an **opto-isolator**, **photocoupler**, or **optical isolator**) is an semiconductor device that transfers electrical signals between two isolated circuits by using light. Optocoupler prevent high voltages from affecting the system receiving the signal.

Two parts are used in an optocoupler: an LED that emits infrared light and a photosensitive device that detects light from the LED. Both parts are contained within a black box with pins for connectivity. The input circuit takes the incoming signal, whether the signal is AC or DC, and uses the signal to turn on the LED.



The photosensor is the output circuit that detects the light and depending on the type of output circuit, the output will be AC or DC. Current is first applied to the optocoupler, making the LED emit an infrared light proportional to the current going through the device. When the light hits the photosensor a current is conducted, and it is switched on. When the current flowing through the LED is interrupted, the IR beam is cut-off, causing the photosensor to stop conducting.

## Types of Optocoupler

There are four configurations of optocouplers, the difference being the photosensitive device used. Photo-transistor and Photo-Darlington are typically used in DC circuits, and Photo-SCR and Photo-TRIAC are used to control AC circuits. In the photo-transistor optocoupler, the transistor could either be PNP or NPN. The Darlington transistor is a two transistor pair, where one transistor controls the other transistor's base. The Darlington transistor provides high gain ability.

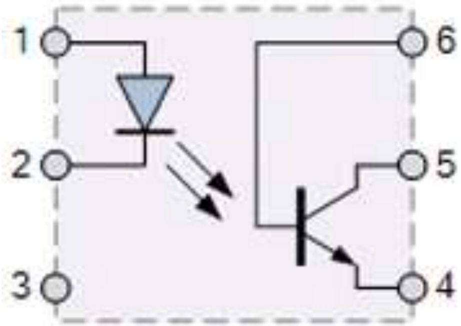



Photo-transistor

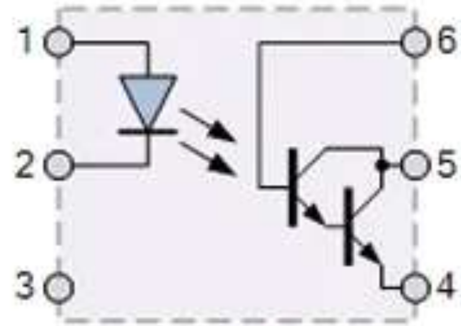



Photo-darlington

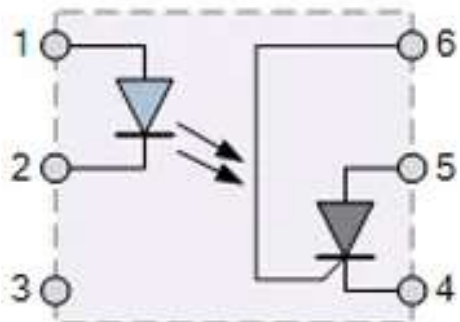



Photo-SCR

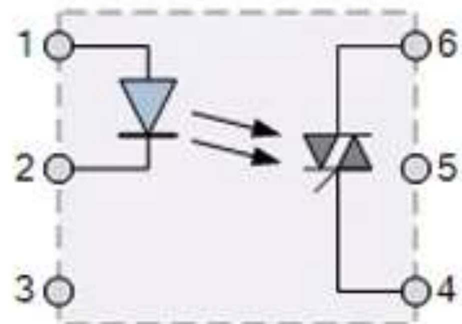



Photo-TRIAC

**An Optocoupler Can Effectively:**

•Remove electrical noise from signals

•Isolate low-voltage devices from high-voltage circuits. The device is able to avoid disruptions from voltage surges (ex: from radio frequency transmissions, lightning strikes, and spikes in a power supply)

•Allow the usage of small digital signals to control larger AC voltages.

**Advantages**

•Optocouplers allow easy interfacing with logic circuits.

•Electrical isolation provides circuit protection.

•It allows wideband signal transmission.

•It is small in size and lightweight device.

**Disadvantages**

•The operational speed of Optocouplers is low.

•In case of a very high power signal, the possibility of signal coupling may arise.

**Applications**

•It is used in high power inverters.

•It is used in high power choppers.

•In AC to DC converters optocouplers are widely used.

https://www.jameco.com/Jameco/workshop/Howitworks/what-is-an-optocoupler-and-how-it-works.html

## Liquid crystal display (LCD)

A **liquid-crystal display** (LCD) is a flat-panel display or other electronically modulated optical device that uses the light-modulating properties of liquid crystals combined with polarizers. Liquid crystals do not emit light directly, instead using a backlight or reflector to produce images in color or monochrome.

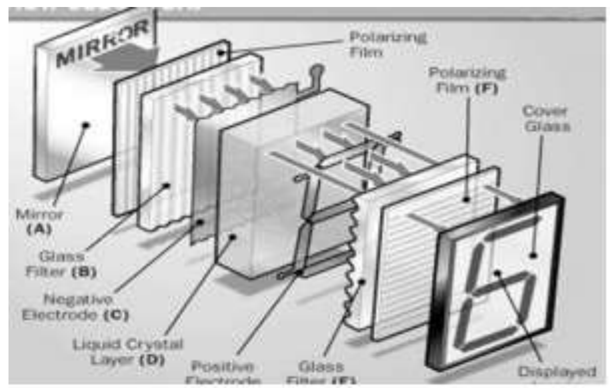
LCDs are available to display arbitrary images (as in a general-purpose computer display) or fixed images with low information content, which can be displayed or hidden. For instance: preset words, digits, and seven-segment displays, as in a digital clock, are all good examples of devices with these displays.

They use the same basic technology, except that arbitrary images are made from a matrix of small pixels, while other displays have larger elements. LCDs can either be normally on (positive) or off (negative), depending on the polarizer arrangement. For example, a character positive LCD with a backlight will have black lettering on a background that is the color of the backlight, and a character negative LCD will have a black background with the letters being of the same color as the backlight. Optical filters are added to white on blue LCDs to give them their characteristic appearance.

## Construction of LCD

Simple facts that should be considered while making an LCD:

1. The basic structure of the LCD should be controlled by changing the applied current.
2. We must use polarized light.
3. The liquid crystal should able be to control both of the operations to transmit or can also able to change the polarized light.




LCD Construction

As mentioned above that we need to take two polarized glass pieces filter in the making of the liquid crystal. The glass which does not have a polarized film on the surface of it must be rubbed with a special polymer that will create microscopic grooves on the surface of the polarized glass filter. The grooves must be in the same direction as the polarized film.

Now we have to add a coating of pneumatic liquid phase crystal on one of the polarizing filters of the polarized glass. The microscopic channel causes the first layer molecule to align with filter orientation. When the right angle appears at the first layer piece, we should add a second piece of glass with the polarized film. The first filter will be naturally polarized as the light strikes it at the starting stage.

Thus the light travels through each layer and guided to the next with the help of a molecule. The molecule tends to change its plane of vibration of the light to match its angle. When the light reaches the far end of the liquid crystal substance, it vibrates at the same angle as that of the final layer of the molecule vibrates. The light is allowed to enter into the device only if the second layer of the polarized glass matches with the final layer of the molecule.

**Working of LCD**

The principle behind the LCDs is that when an electrical current is applied to the liquid crystal molecule, the molecule tends to untwist. This causes the angle of light which is passing through the molecule of the polarized glass and also causes a change in the angle of the top polarizing filter. As a result, a little light is allowed to pass the polarized glass through a particular area of the LCD.

Thus that particular area will become dark compared to others. The LCD works on the principle of blocking light. While constructing the

LCDs, a reflected mirror is arranged at the back. An electrode plane is made of indium-tin-oxide which is kept on top and a polarized glass with a polarizing film is also added on the bottom of the device. The complete region of the LCD has to be enclosed by a common electrode and above it should be the liquid crystal matter.

Next comes the second piece of glass with an electrode in the form of the rectangle on the bottom and, on top, another polarizing film. It must be considered that both the pieces are kept at the right angles. When there is no current, the light passes through the front of the LCD it will be reflected by the mirror and bounced back. As the electrode is connected to a battery the current from it will cause the liquid crystals between the common-plane electrode and the electrode shaped like a rectangle to untwist. Thus the light is blocked from passing through. That particular rectangular area appears blank.

**Advantages**

•LCD's consumes less amount of power compared to CRT and LED

•LCD's are consist of some microwatts for display in comparison to some mill watts for LED's

•LCDs are of low cost

•Provides excellent contrast

•LCD's are thinner and lighter when compared to cathode-ray tube and LED

**Disadvantages**

- Require additional light sources
- Range of temperature is limited for operation
- Low reliability
- Speed is very low
- LCD’s need an AC drive

**Applications**

LCDs are used in a wide range of applications, including LCD televisions, computer monitors, instrument panels, aircraft cockpit displays, and indoor and outdoor signage. Small LCD screens are common in LCD projectors and portable consumer devices such as digital cameras, watches, digital clocks, calculators, and mobile telephones, including smartphones. LCD screens are also used on consumer electronics products such as DVD players, video game devices and clocks. LCD screens have replaced heavy, bulky cathode-ray tube (CRT) displays in nearly all applications. LCD screens are available in a wider range of screen sizes than CRT and plasma displays, with LCD screens available in sizes ranging from tiny digital watches to very large television receivers. LCDs are slowly being replaced by OLEDs.

https://www.elprocus.com/ever-wondered-lcd-works/

# Proximity sensor

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

A proximity sensor often emits an electromagnetic field or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal. The object being sensed is often referred to as the proximity sensor's target.

Different proximity sensor targets demand different sensors. For example, a capacitive proximity sensor or photoelectric sensor might be suitable for a plastic target; an inductive proximity sensor always requires a metal target.

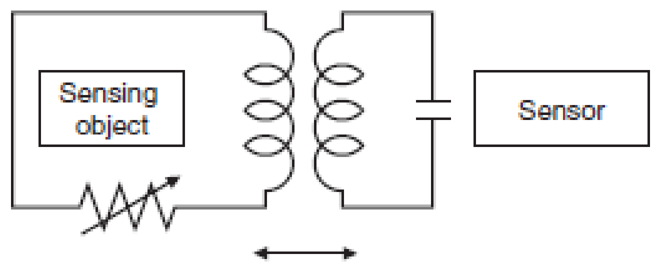
**Operating Principles**

**Detection Principle of Inductive Proximity Sensors**

Inductive Proximity Sensors detect magnetic loss due to eddy currents that are generated on a conductive surface by an external magnetic field. An AC magnetic field is generated on the detection coil, and changes in the impedance due to eddy currents generated on a metallic object are detected.

Other methods include Aluminum-detecting Sensors, which detect the phase component of the frequency, and All-metal Sensors, which use a working coil to detect only the changed component of the impedance. There are also Pulse-response Sensors, which generate an eddy current in pulses and detect the time change in the eddy current with the voltage induced in the coil.

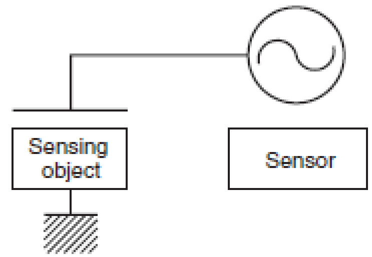
The sensing object and Sensor form what appears to be a transformer-like relationship.




The transformer-like coupling condition is replaced by impedance changes due to eddy-current losses.

The impedance changes can be viewed as changes in the resistance that is inserted in series with the sensing object. (This does not actually occur, but thinking of it this way makes it easier to understand qualitatively.)

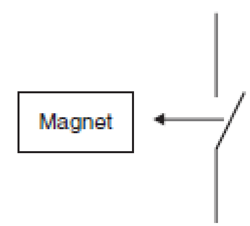
## Detection Principle of Capacitive Proximity Sensors




Capacitive Proximity Sensors detect changes in the capacitance between the sensing object and the Sensor. The amount of capacitance varies depending on the size and distance of the sensing object. An ordinary Capacitive Proximity Sensor is similar to a capacitor with two parallel plates, where the capacity of the two plates is detected. One of the plates is the object being measured (with an imaginary ground), and the other is the Sensor's sensing surface. The changes in the capacity generated between these two poles are detected. The objects that can be detected depend on their dielectric constant, but they include resin and water in addition to metals.

## Detection Principle of Magnetic Proximity Sensors

The reed end of the switch is operated by a magnet.
When the reed switch is turned ON,
the Sensor is turned ON.



**Applications**

•Parking sensors, systems mounted on car bumpers that sense distance to nearby cars for parking
•Inductive sensors
•Ground proximity warning system for aviation safety
•Vibration measurements of rotating shafts in machinery
•Top dead centre (TDC)/camshaft sensor in reciprocating engines.
•Sheet break sensing in paper machine.
•Anti-aircraft warfare
•Roller coasters
•Conveyor systems
•Beverage and food can making lines
•Mobile devices
•Touch screens that come in close proximity to the face
•Attenuating radio power in close proximity to the body, in order to reduce radiation exposure
•Automatic faucets

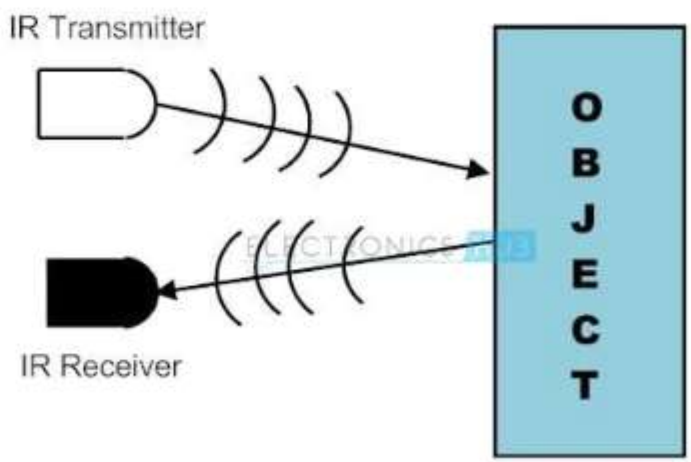
https://www.omron-ap.co.in/service_support/technical_guide/proximity_sensor/principles.

# IR Sensor

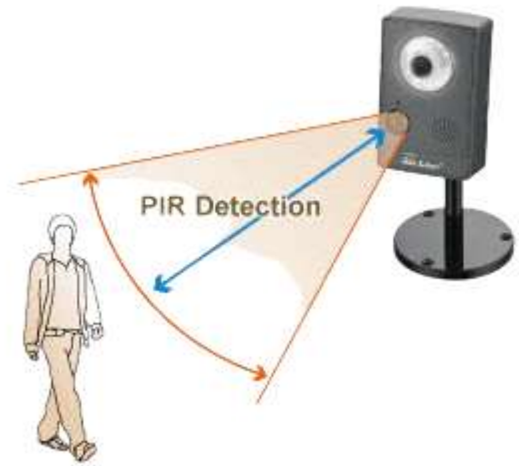
IR sensor is an electronic device, that emits the light in order to sense some object of the surroundings. It measures and detects infrared radiation in its surrounding environment.

There are two types of infrared sensors: active and passive. Active infrared sensors both emit and detect infrared radiation. Active IR sensors have two parts: a light emitting diode (LED) and a receiver. When an object comes close to the sensor, the infrared light from the LED reflects off of the object and is detected by the receiver. Active IR sensors act as proximity sensors, and they are commonly used in obstacle detection systems (such as in robots).

Passive infrared (PIR) sensors only detect infrared radiation and do not emit it from an LED. Passive infrared sensors are comprised of:
Two strips of pyroelectric material (a pyroelectric sensor)
An infrared filter (that blocks out all other wavelengths of light)
A fresnel lens (which collects light from many angles into a single point)
•A housing unit (to protect the sensor from other environmental variables, such as humidity)




ACTIVE IR SENSOR




PASSIVE IR SENSOR

## APPLICATIONS OF IR SENSORS

IR sensors have found their applications in most of today's equipment. Following is the list of sensors that are named after their usage.

**1. Proximity Sensor**
These are used in smartphones to find the distance of objects. They use a principle called Reflective Indirect Incidence. Radiation transmitted by the transmitter is received by the receiver after being reflected from an object. Distance is calculated based on the intensity of radiation received.

**2. Item Counter**
This uses the direct incidence method to count the items. Constant radiation is maintained between transmitter and receiver. As soon as the object cuts the radiation, the item is detected and the count is increased. The same count is shown on a display system.

**3. Burglar Alarm**

This is one of the widely and commonly used sensor applications. It is another example of the direct incidence method.

It works similar to the item counter, where the transmitter and receiver are kept on both sides of a door frame. Constant radiation is maintained between transmitter and receiver, whenever an object crosses the path alarm starts.

**4. Radiation Thermometers**

It is one of the key applications of Infrared sensors. The working of a radiation thermometer depends on temperature and type of object.

These have faster response and easy pattern measurements. They can do measurements without direct contact with an object.

**5. Human Body Detection**

This method is used in intrusion detection, auto light switches, etc. An intrusion alarm system senses the temperature of the human body.

If the temperature is more than the threshold value, it sets the alarms. It uses an electromagnetic system that is suitable for the human body to protect it from unwanted harmful radiation.

**6. Gas Analyzers**

Gas Analyzers are used to measure gas density by using the absorption properties of gas in the IR region. Dispersive and Non Dispersive types of gas analyzers are available.

**7. Other Applications**

IR sensors are also used in IR imaging devices, optical power meters, sorting devices, missile guidance, remote sensing, flame monitors, moisture analyzers, night vision devices, infrared astronomy, rail safety, etc.

https://robocraze.com/blogs/post/ir-sensor-working

# Pressure Sensor

A pressure sensor is a transducer that senses pressure and converts it into an electric signal where the amount depends upon the pressure applied. A pressure transducer consists of a pressure-sensitive element that can measure, detect or monitor the pressure being applied and electronic components to convert the information into an electrical output signal.

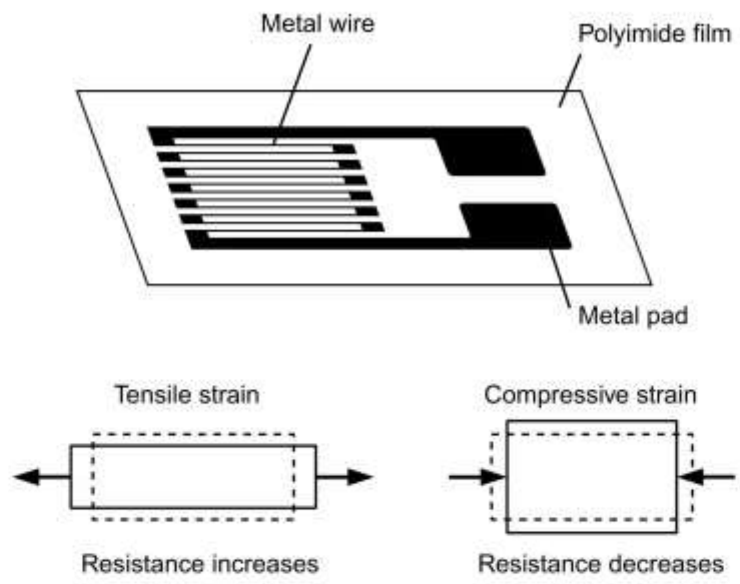
Pressure is defined as the amount of force (exerted by a liquid or gas) applied to a unit of "area" (P=F/A), and the common units of pressure are Pascal (Pa), Bar (bar), N/mm2 or psi (pounds per square inch). Pressure sensors often utilize piezoresistive technology, as the piezoresistive element changes its electrical resistance proportional to the strain (pressure) experienced.

Most of the pressure sensor works on the principle and piezo-resistive effect, which is measured by the strain gauge. A metal foil strain gage is a transducer whose electrical resistance varies with applied force. In other words, it converts force, pressure, tension, compression, torque, and weight into a change in electrical resistance, which can then be measured.

Strain gauges are electrical conductors tightly attached to a film in a zigzag shape. When this film is pulled, it — and the conductors — stretches and elongates. When it is pushed, it is contracted and gets shorter. This change in shape causes the resistance in the electrical conductors to also change. The strain applied in the load cell can be determined based on this principle, as strain gauge resistance increases with applied strain and diminishes with contraction.

Structurally, a pressure sensor is made of a metal body (also called flexure) to which the metal foil strain gauges are bonded. These force measuring sensors body is usually made of aluminum or stainless steel, which gives the sensor two important characteristics: (1) provides the sturdiness to withstand high loads and (2) has the elasticity to minimally deform and return to its original shape when the force is removed.

The strain gauges are arranged in what is called a Wheatstone Bridge Amplifier Circuit (see below animated diagram). This means that four strain gages are interconnected as a loop circuit and the measuring grid of the force being measured is aligned accordingly.




The strain gauge bridge amplifiers provide regulated excitation voltage and convert the mv/V output signal into another form of signal that is more useful to the user. The signal generated by the strain gage bridge is a low strength signal and may not work with other components of the system, such as PLC, data acquisition modules (DAQ) or computers. Thus, pressure sensor signal conditioner functions include excitation voltage, noise filtering or attenuation, signal amplification, and output signal conversion.

Furthermore, the change in the pressure sensor amplifier output is calibrated to be proportional to the force applied to the flexure, which can be calculated via the pressure sensor circuit equation.

## Types of pressure sensors

Pressure sensors can be classified in terms of pressure ranges they measure, temperature ranges of operation, and most importantly the type of pressure they measure. Pressure sensors are variously named according to their purpose, but the same technology may be used under different names.

**Absolute pressure sensor**

This sensor measures the pressure relative to perfect vacuum. Absolute pressure sensors are used in applications where a constant reference is required, like for example, high-performance industrial applications such as monitoring vacuum pumps, liquid pressure measurement, industrial packaging, industrial process control and aviation inspection.

**Gauge pressure sensor**

This sensor measures the pressure relative to atmospheric pressure. A tire pressure gauge is an example of gauge pressure measurement; when it indicates zero, then the pressure it is measuring is the same as the ambient pressure. Most sensors for measuring up to 50 bar are manufactured in this way, since otherwise the atmospheric pressure fluctuation (weather) is reflected as an error in the measurement result.

**Vacuum pressure sensor**

This term can cause confusion. It may be used to describe a sensor that measures pressures below atmospheric pressure, showing the difference between that low pressure and atmospheric pressure, but it may also be used to describe a sensor that measures absolute pressure relative to a vacuum.

**Differential pressure sensor**

This sensor measures the difference between two pressures, one connected to each side of the sensor. Differential pressure sensors are used to measure many properties, such as pressure drops across oil filters or air filters, fluid levels (by comparing the pressure above and below the liquid) or flow rates (by measuring the change in pressure across a restriction). Technically speaking, most pressure sensors are really differential pressure sensors; for example a gauge pressure sensor is merely a differential pressure sensor in which one side is open to the ambient atmosphere.

**Sealed pressure sensor**

This sensor is similar to a gauge pressure sensor except that it measures pressure relative to some fixed pressure rather than the ambient atmospheric pressure (which varies according to the location and the weather).

## Applications of pressure sensors

**Automotive applications**

In automobiles, hydraulic brakes are a crucial component in passenger safety. The ability to control a vehicle using brakes is down to a complex blend of components, including pressure sensors. These can be used to monitor pressure within the chambers of the braking system, alerting drivers and engine management systems alike if pressures are too low to be effective. If pressure inside chambers is not measured, systems can fail without the driver knowing and lead to a sudden loss of braking efficacy and accidents.

**Life-saving medical applications**

Raising the air pressure in a sealed chamber containing a patient is known as hyperbaric therapy. It can be effective for treating a number of medical conditions, from skin grafts, burn injuries, and carbon monoxide poisoning to decompression sickness experienced by divers.

Measuring blood pressure correctly is crucial to patient care, as errors in readings can lead to a misdiagnosis. Thanks to recent innovations, tiny pressure sensors can even be implanted into the body, known as In Vivo Blood Pressure Sensing for more accurate monitoring.

**Automated building applications**

As building and home automation technologies become increasingly popular, pressure sensors continue to play a central role in controlling the environments we live in. Refrigeration systems are one such example. Common coolants in HVACs like ammonia can cause significant danger to people in the event of a leak. Using relative pressure sensors to monitor the pressure of the ammonia as it passes through the system ensures it stays within safe limits.

**Life-enhancing consumer applications**

The things we use, carry and wear on a daily basis are growing in intelligence. Adding a pressure sensor to a consumer device can provide new information for an improved user experience.

Take vacuum cleaners, or example. By measuring suction changes, they can detect what kind of flooring is being cleaned and adjust settings accordingly, or notify their owners when a filter needs replacing.

**Industrial applications**

Submersible pressure sensors can be used to measure liquid pressures (up to 30 PSI) with either a voltage or current (4-20mA) output in liquid tanks. By positioning these sensors at the bottom of a tank, you can get an accurate reading of the contents in order to alert workers or the process control system when levels in the tank fall below safe limits.

https://www.futek.com/store/pressure-sensors

# Introduction to Biosensor

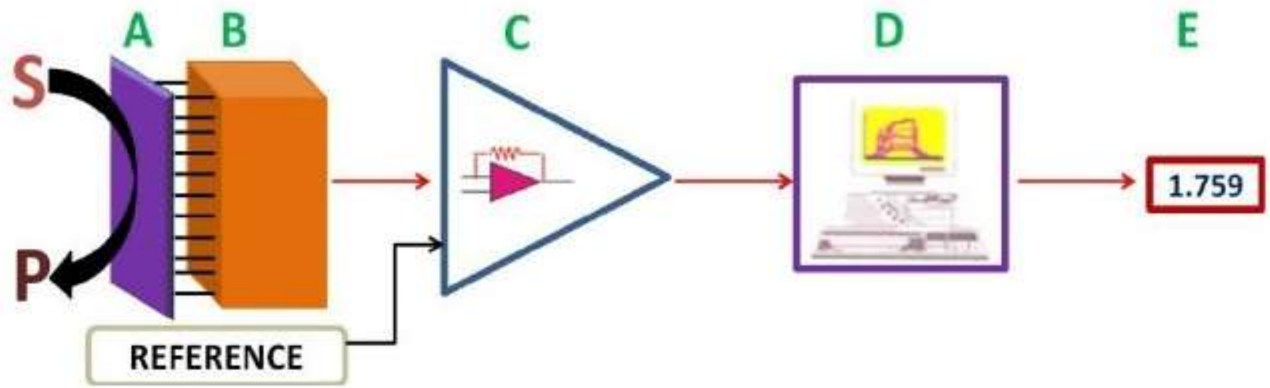
Biosensors can be defined as analytical devices which include a combination of biological detecting elements like a sensor system and a transducer. When we compare with any other presently existing diagnostic device, these sensors are advanced in the conditions of selectivity as well as sensitivity. The **applications of these Biosensors** mainly include checking ecological pollution control, in the agriculture field as well as food industries. The main features of biosensors are stability, cost, sensitivity, and reproducibility.

**Main Components of a Biosensor**

The block diagram of the biosensor includes three segments namely, sensor, transducer, and associated electrons. In the first segment, the sensor is a responsive biological part, the second segment is the detector part that changes the resulting signal from the contact of the analyte, and for the results, it displays in an accessible way. The final section comprises an amplifier which is known as a signal conditioning circuit, a display unit as well as the processor.

**Working Principle of Biosensor**

Usually, a specific enzyme or preferred biological material is deactivated by some of the usual methods, and the deactivated biological material is in near contact with the transducer. The analyte connects to the biological object to shape a clear analyte which in turn gives the electronic reaction that can be calculated. In some examples, the




analyte is changed to a device that may be connected to the discharge of gas, heat, electron ions, or hydrogen ions. In this, the transducer can alter the device linked convert it into electrical signals which can be changed and calculated.

**Working of Biosensors**

The electrical signal of the transducer is frequently low and overlays upon a fairly high baseline. Generally, the signal processing includes deducting a position baseline signal, obtained from a related transducer without any biocatalyst covering.

The comparatively slow character of the biosensor reaction significantly eases the electrical noise filtration issue. In this stage, the direct output will be an analog signal however it is altered into digital form and accepted to a microprocessor phase where the information is progressed, influenced to preferred units, and o/p to a data store.

**Features**

A biosensor includes two main distinct components like Biological component such as cell, enzyme and a physical component like an amplifier and transducer.

The biological component identifies as well as communicates through the analyte for generating a signal that can be sensed through the transducer. The biological material is properly immobilized over the transducer & these can be frequently used numerous times for a long period.

**Types of Biosensors**

Electrochemical Biosensor, Amperometric Biosensor, Potentiometric Biosensor, Impedimetric Biosensor, Voltammetric Biosensor, Physical Biosensor, Piezoelectric Biosensors, Thermometric Biosensor, Optical Biosensor, Wearable Biosensors, Enzyme Biosensor, DNA Biosensor, Immunosensors , Magnetic Biosensors, Resonant Biosensors, Thermal Detection Biosensor

**Biosensors Applications**

Biosensor devices include a biological element as well as a physiochemical detector and the main function of this device is to detect analytes. So, the applications of biosensors are in a wide range. These devices are applicable in the medical, food industry, the marine sector as they offer good sensitivity & stability as compared with the usual techniques. In recent years, these sensors have become very popular, and they are applicable in different fields which are mentioned below

Common healthcare checking, Metabolites Measurement, Screening for sickness, Insulin treatment, Clinical psychotherapy & diagnosis of disease, In Military, Agricultural, and Veterinary applications, Drug improvement, offense detection, Processing & monitoring in Industrial, Ecological pollution control, Diagnostic & Clinical, Industrial & Environmental Applications, Study & Interaction of Biomolecules, Development of Drug, Detection of Crime, Medical Diagnosis, Monitoring of Environmental Field, Quality Control, Process Control in Industries, Pharmaceuticals Manufacturer & Organs Replacement.

https://www.elprocus.com/what-is-a-biosensor-types-of-biosensors-and-applications/

# Sensors for smart building

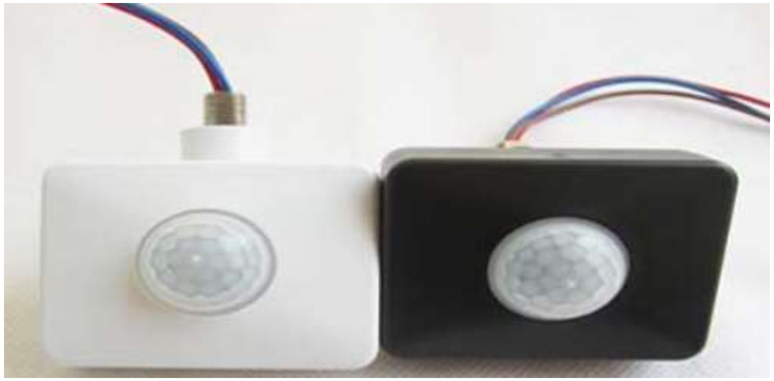
Sensors Used in Smart Buildings are solely dedicated to providing smart facilities to their workers and people while providing their users with an efficient and comfortable humanized building environment within the budget.

**Popular Sensors Used in Smart Buildings**

**1. Passive Infrared (PIR) Sensors**

**What is it:** Similar to its name, PIR technology refers to the fact that PIR devices do not spread energy for detection but work by receiving infrared radiation emitted or reflected from objects. PIR sensors are typically mounted under desks, to detect when and for how long the workspace is being used.

**How they Work:** As discussed above, PIR Sensors operate by leveraging infrared radiation that is either emitted or reflected from objects. However, PIR sensors cannot capture who exactly used the space.



## 2. Temperature & Humidity Sensors

**What is it:** According to its name, temperature sensors can measure the temperature in the environment. This is one of the most commonly used Sensors used in Smart Buildings as they work according to the user's requirements and its position of installation. Similarly, humidity sensors measure the relative humidity in the air and are often used in combination with temperature sensors.

**How they Work:** In simple terms, temperature and humidity sensors measure the temperature and humidity of the surrounding area within fixed intervals and if any fluctuations are seen at anytime that crosses the fixed threshold limit set in the sensor, the sensors instantly send out the signal assigned to it.

### 3. Indoor Air Quality (IAQ) Room Sensors

**What is it:** Air quality sensors are typically used to monitor the concentration of pollutants in the air of the concerned area. It forms an important part of air purifiers and fresh air systems working in the facility, thus coming under the list of popular Sensors Used in Smart Buildings.

**How they Work:** IAQ sensors deploy IoT and computer technology to configure the air quality data to collect indoor air temperature and humidity, particulate matter, TVOC, illuminance, formaldehyde, noise, carbon dioxide and other environmental factors in real-time.

### 4. Water Leak sensors

**What is it:** Despite having regular and timely inspections in any building, water leakage from the drain systems or HVAC system is a common occurrence. The water leak sensor is a liquid leak detection device.

**How they Work:** Considering the complex structures of the drain system, HVAC system and air conditioning system in a building, keeping a track of every gap is nearly impossible, therefore water leak sensors are often employed to give an alarm as soon as it detects a water leak.

https://www.bisinfotech.com/types-of-sensors-used-in-smart-buildings/

**5. Thermal imaging**

Thermal imaging cameras can provide a host of benefits including the identification of heating/cooling leak points, monitoring of high-voltage systems and even checking the temperatures of occupants as the enter a building. Until recently, thermal imaging cameras were very expensive and the thought of strategically placing sensors throughout a building was simply not cost-effective. However, advancements in the technology are lowering prices to the point where thermal cameras can be deployed. This type of data can be collected and combined with other building-centric data to preemptively identify aspects of a facility or its occupants that need addressing.

**6. Ambient lighting**

Smart lighting systems are great, but their true benefits become more apparent when combined with other IoT sensor information such as occupancy levels and ambient light sensor data. The ability to utilize daylight as best as possible can help cut energy costs by intelligently maintaining the amount of electrical light required in occupied parts of a building while bringing in outdoor lighting where needed. Doing so can create a comfortable environment for occupants while reducing lighting costs to the bare minimum.

https://www.smartbuildingstech.com/intelligent-building-systems/article/21183792/7-musthave-iot-sensors-for-smart-buildings

**7. Door/cabinet open/close detection**

The protection of occupants and resources within a building can be a time consuming and difficult challenge without the use of technology geared toward automating these monitoring processes. Sensors can be installed at critical doors, entryways, and cabinets to monitor open/closed activities in real-time. These sensors can either be hardwired into the network or leverage Wi-Fi or LTE/5G for connectivity back to a centralized monitoring/alerting platform. Historical information can then be used to retroactively investigate any instances where people or resources need to be located.

**Benefits of smart building sensors**

Smart building sensors can collect and analyze real-time data, and make optimal solutions to problems. It is of great significance to modern architecture:

- Can save building energy
- Improve the sustainability of building use
- Real-time monitoring reduces maintenance costs
- Optimize space utilization
- Enhance the safety, comfort and safety of tenants