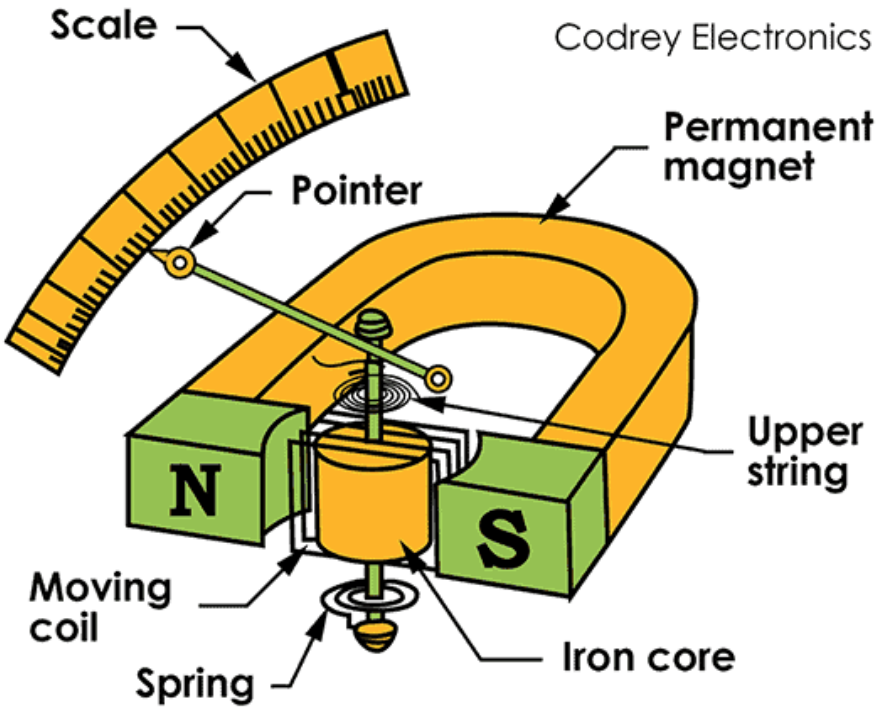
Moving Coil Instrument

Moving coil instrument is widely used measuring instrument because of its accuracy and sensitivity. These instruments are directional and they can be used for DC measurements. This device can be used as an ammeter, voltmeter, galvanometer, and ohmmeter.

Construction

The moving coil instrument works on the principle of the DC motor (electrodynamic effect). It operates by the interaction of the magnetic field produced by a movable coil due to the flow of current with the field of a permanent magnet. It uses a coil for measuring voltage and current.



The moving coil meter construction consists of a U-shaped permanent electromagnet. A movable coil of copper wire wounded on a soft iron core and is mounted in the field of a permanent magnet. The copper coil has many turns and it is pivoted on a jeweled bearing. It can freely rotate in the magnetic field produced by the magnet. Hence these are often known as Permanent magnet type instruments.

The controlling torque is provided by the two control springs (one in lower and other in upper) made of phosphor bronze which is mounted on the jewel bearing and coiled in opposite direction. A pointer is attached to the spindle which moves over a graduated scale. It has a section over the scale to form a fine blade which helps to reduce error while reading the scale.

Moving Coil Instrument Working Principle

The working principle of permanent magnet moving coil type instruments is, when a current being measured is applied to the coil through control springs, it creates a magnetic field. Interaction between this induced field and the field produced by the magnet produces a torque in the coil. This causes the coil to rotate and the pointer deflects on the scale. The spring is controlled by the spring control method. The damping torque is produced by the eddy current damping.

Advantages:

- The moving coil meter is directional and has a uniform scale
- High accuracy
- The torque-weight ratio is high
- Power consumption is less
- The same instrument can be used for measurement of voltage and current

Disadvantages:

- The cost is high
- Moving coil meter can be used for only DC measurements

Applications:

- To construct an AC galvanometer and detect small DC currents.
- Fluxmeters use this instrument to measure the electricity flowing through the coil by eliminating the control springs.
- Ballistic galvanometer adjusting the control springs with a large moment of inertia.

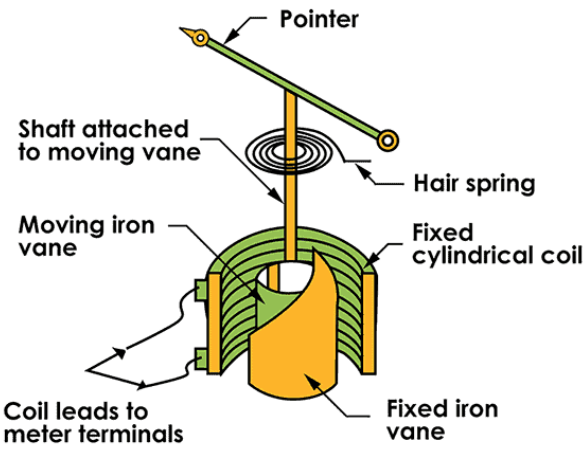
Moving Iron Instrument

Moving iron Instrument is used to measure the current and voltage of AC and DC. They are non-directional. The working principle depends upon the movement of iron attracted by the magnetic field towards it and repulsion between them. The magnetic field is produced by the current in the coil.

This instrument can be used as an ammeter, voltmeter, and wattmeter. The coil has less number of turns if the instrument is ammeter and more turns if the instrument is a voltmeter. The moving iron type supports both AC and DC. To use this instrument as ammeter, connect the circuit in series and the coil must have fewer turns of thick wire which shows less resistance. To use it as a voltmeter, connect the circuit in parallel and the coil has a high impedance and a large number of turns.

Construction:

The repulsion type moving iron instrument consists of soft iron in the form of the vane as the moving element of the meter. It also has a fixed iron vane. A shaft is attached to the moving iron. A cylindrical stationary coil is used to produce the magnetic field when there is a flow of current through it. A pointer is fixed on the shaft which gets deflected shows the reading on a non-uniform scale. The strength of the magnetic field increases or decreases with the magnitude of the current flows through it.



Moving Iron Instrument Working

The moving iron and fixed iron magnetize with the same polarity due to which the two irons repel each other. Because of their repulsive force, the coil starts moving away from the fixed iron.

The controlling torque is exerted by the spiral spring made of phosphor bronze which is connected to the shaft. An air chamber is provided for air friction damping because the magnets can affect the deflection of the pointer and affect the reading. The deflection torque makes the pointer to move away from the zero position.

Torque – Weight Ratio

Torque is a force that makes an object move and weight is a force applied on the object by gravity. If a pointer in the meter has less weight, it will have a high torque-weight ratio. Even for a small deflection in the meter, the pointer will start moving and it shows measured value.

Advantages:

- This type of instrument is simple and cheap in construction.
- It is non-directional hence can be used in both AC and DC circuits.
- Because of the current-carrying part is stationary and has lighter moving parts, the torque weight ratio is high.
- Due to the high torque weight ratio, the frictional error is very less.

Disadvantages:

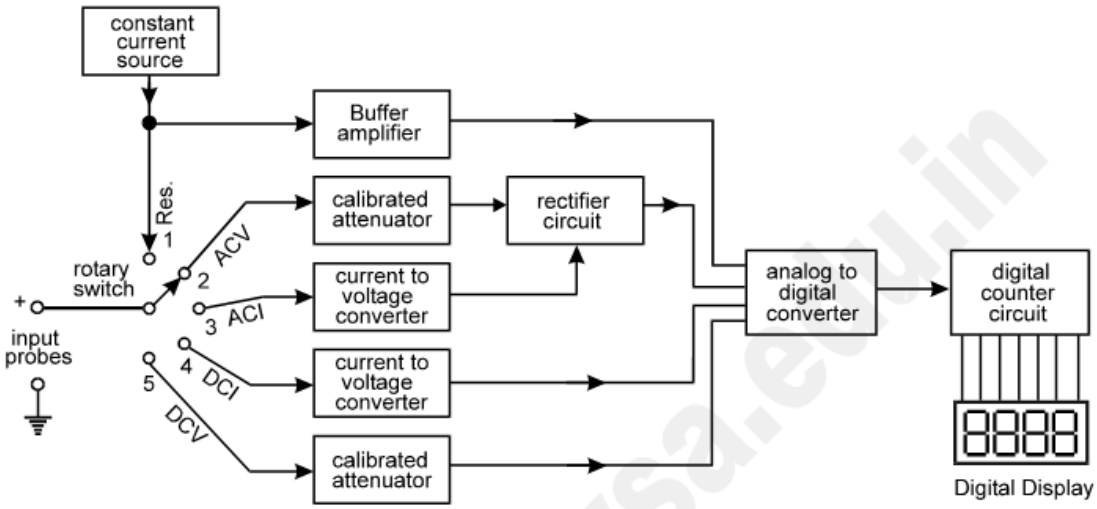
- Accuracy is less because of the instrument is non-directional.
- It cannot be calibrated with a high degree of precision for DC on account of the effect of hysteresis in the iron vanes.
- High power consumption.

Digital Multimeter(DMM)

- The Multimeter important features are given below –
- It can measure AC/DC voltage, AC/DC current and resistance very accurately.
- Accuracy is maximum due to minimum loading effects.
- Audio and visual indication for continuity testing in electrical wiring.
- Automatic sign indication i.e. (+) or (–) indication.
- Automatic null setting.

Working

To understand how digital multimeter works, let us see the block diagram of DMM is given below. The working of each block to measure different types of electrical quantities is as follows.



How to measure resistance?

To measure unknown resistance using digital multimeter, connect an unknown resistor across its input probes. Keep rotary switch in position-1. The proportional current flows through the resistor, from constant current source. According to Ohm's law voltage is produced across it. This voltage is directly proportional to its resistance. This voltage is buffered and fed to A-D converter, to get digital display in Ohms.

How to measure AC voltage?

Connect an unknown AC voltage across input probes. Keep rotary switch in position-2. The voltage is attenuated, if it is above the selected range and then rectified to convert it into proportional DC voltage. It is then fed to A-D converter to get the digital display in Volts.

How to measure AC current?

Current is indirectly measured by converting it into proportional voltage. Connect an unknown AC current across input probes. Keep the switch in position-3. The current is converted into voltage proportionally with the help of I-V converter and then rectified. Now the voltage in terms of AC current is fed to A-D converter to get digital display in Amperes.

How to measure DC current?

The DC current is also measured indirectly. Connect an unknown DC current across input probes. Keep the switch in position-4. The current is converted into voltage proportionally with the help of I-V converter. Now the voltage in terms of DC current is fed to A-D converter to get the digital display in Amperes.

How to measure DC voltage?

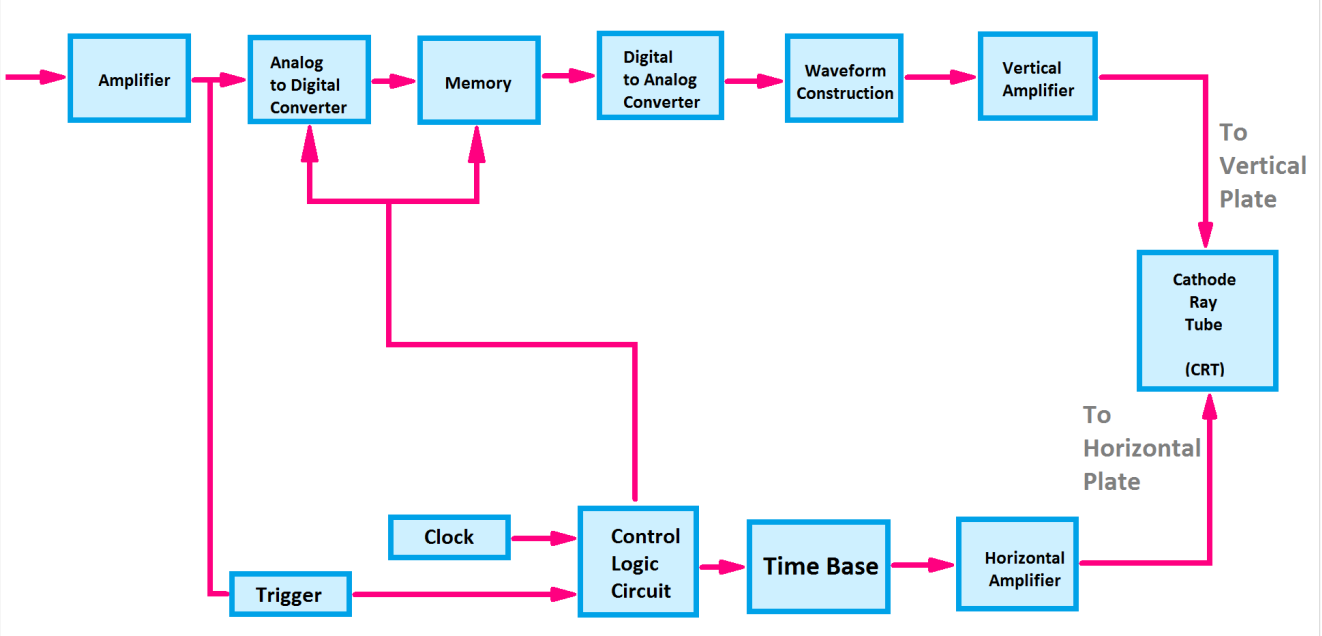
Connect an unknown DC voltage across input probes. Keep the switch in position-5. The voltage is attenuated, if it is above the selected range and then directly fed to A-D converter to get the digital display in Volts.

Digital Storage Oscilloscope (DSO)

The main feature of the DSO is it provides the function to analyze the signals or waveforms later as stored in its memory using the signal Processing technique.

The DSO takes the input signal in the analog format and stores it in its memory. After that, it takes the data from its memory to display. Generally, it stores the signal or data in a binary format such as 0 and 1. The DSO involves in waveform displaying, digital storage, signal processing, etc.

DSO Block Diagram



The main parts of the DSO are,

- A/D and D/A converter
- Memory
- Logic Control Circuit
- Amplifier
- Time Base Circuit
- Cathode Ray Tube

DSO Working Principle

As we know the DSO accepts the signal in the form of an analog signal. So, first of all, it takes the analog signal and amplifies it. After amplifying and noise removing or filtering it starts the analog to the digital conversion process. The maximum acceptance frequency for the input signal depends upon the sampling rate and nature of the converter. So, for the signal conversion, it starts sampling.

After converting the analog signal into a digital signal, it stores the signal in its memory in the form of a digital signal or binary form such as 0 and 1. During the waveform display, it takes the data from the memory.

Control Logic Circuit: It is a very important part of the whole circuit. Actually, it controls so many things. It takes the clock pulses and triggers pulses. It provides the output to the time base circuit.

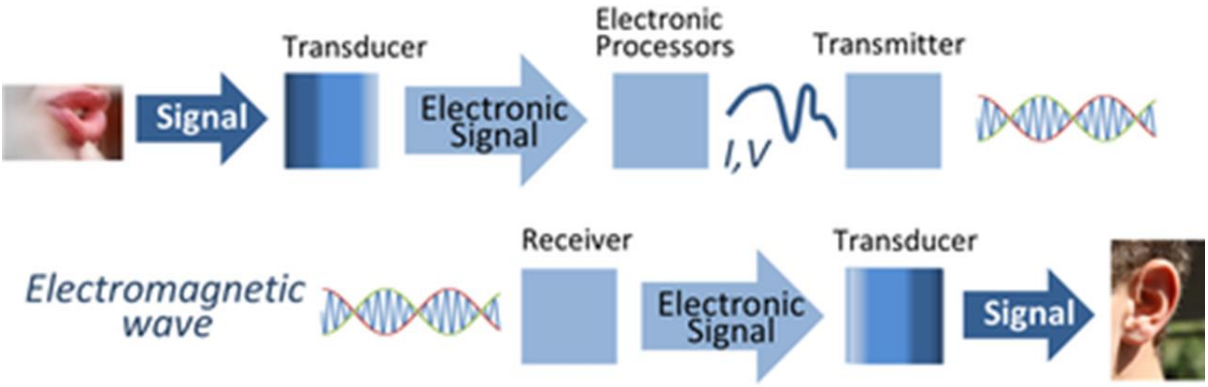
Digital to Analog Converter(D/A): It comes into the use when the DSO displays waveforms or analyzes the signal. The digital data or signal is stored in the memory is being converted into an analog signal.

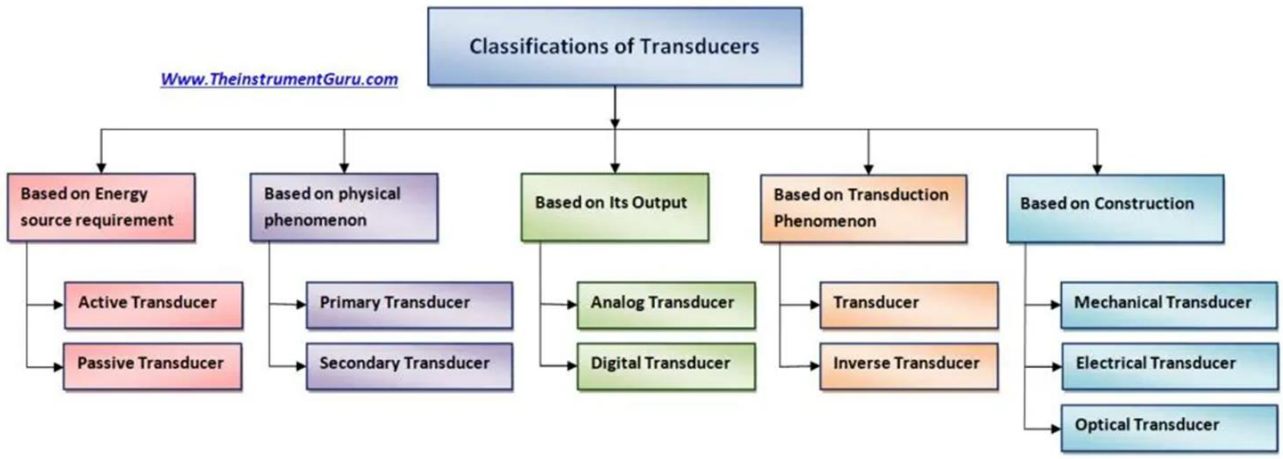
Waveform Construction: The analog signal converted from the digital signal stored in the memory is constructed in the form of waveform through this waveform construction circuit. It gives the actual shape of the waveform which is to be displayed in the CRT display. Basically, it uses the interpolation technique for the visualization of final waves. There are two types of interpolation techniques namely Linear Interpolation and Sinusoidal Interpolation

CRT(Cathode Ray Tube): Cathode ray tube display visualizes the waveforms on the screen. It has two plates Horizontal plate and a vertical plate. The horizontal plate is connected through the horizontal amplifier whereas the vertical plate is connected through the vertical amplifier.

Transducer:

A transducer is an electronic device that converts energy from one form to another. Common examples include microphones, loudspeakers, thermometers, position and pressure sensors.





Capacitive Transducer

The capacitive transducer is used for measuring the displacement, pressure and other physical quantities. It is a passive transducer that means it requires external power for operation. The capacitive transducer works on the principle of variable capacitances. The capacitance of the capacitive transducer changes because of many reasons like overlapping of plates, change in distance between the plates and dielectric constant.

The capacitive transducer contains two parallel metal plates. These plates are separated by the dielectric medium which is either air, material, gas or liquid. In the normal capacitor the distance between the plates are fixed, but in capacitive transducer the distance between them are varied.

The capacitive transducer uses the electrical quantity of capacitance for converting the mechanical movement into an electrical signal. The input quantity causes the change of the capacitance which is directly measured by the capacitive transducer.

The capacitors measure both the static and dynamic changes. The displacement is also measured directly by connecting the measurable devices to the movable plate of the capacitor. It works on with both the contacting and non-contacting modes.

Principle of Operation

The equations below express the capacitance between the plates of a capacitor capactive-equation-1

$$C = \varepsilon A/d$$

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

Where A – overlapping area of plates in m2

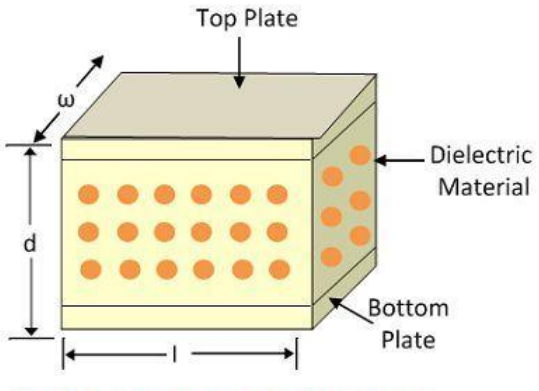
d – The distance between two plates in meter

ε – Permittivity of the medium in F/m

ε_r – Relative permittivity

ε_0 – The permittivity of free space

The schematic diagram of a parallel plate capacitive transducer is shown in the figure below.



The change in capacitance occurs because of the physicals variables like displacement, force, pressure, etc. The capacitance of the transducer also changes by the variation in their dielectric constant which is usually because of the measurement of liquid or gas level. The capacitive transducer uses the following three effects.

1.Variation in capacitance of transducer is because of the overlapping of capacitor plates.

2.The change in capacitance is because of the change in distances between the plates.

3. The capacitance changes because of dielectric constant.

Inductive Transducer

Inductive transducer is also called as Variable Inductance transducer. When a physical quantity to be measured, such as motion, displacement, vibration, acceleration, force, speed etc. make changes in inductance properties of the sensor coil, or magnetic properties of core material or electric properties of magnetic circuits, these sensors or transducers are termed as inductive/ magnetic sensors and fall under category of inductive transducers.

Mostly, the change in inductive properties as an effect of physical quantity to be measured results as change in electrical properties such as change in AC voltage (or EMF) and or AC current which can be measured directly and hence can be calibrated in terms of unit of measurement for a range. Another output form can be pulse signals in which number of pulses counted, or pulse frequency change is detected. Thus it can be used object counting application and for speed measurement. There are both types self generating and passive type of inductive transducers exist.

Electromagnetic Transducer

Electromagnetic transducers are self-generating inductive transducers in which voltage signal or EMF is induced due to relative motion between a permanent magnet and an iron core/ other Ferro-magnetic material core. It consists of a fixed permanent magnet on which a coil is wounded and an iron core is placed near to magnet so that magnetic flux of permanent magnet can be linked to moving iron core. When there is core movement, the magnetic flux also changes and thus it produces EMF in coil which can be measured. This arrangement is also called as magnetic pick up. The most useful application of electro-magnetic transducer is speed measurement of a rotor shaft where a magnetic pick up is placed near the teeth or rotating gear of shaft and hence speed measurement is performed by calibrating pick up for speed detection with great accuracy. A diagram for electromagnetic transducer/ magnetic pick up is shown below.

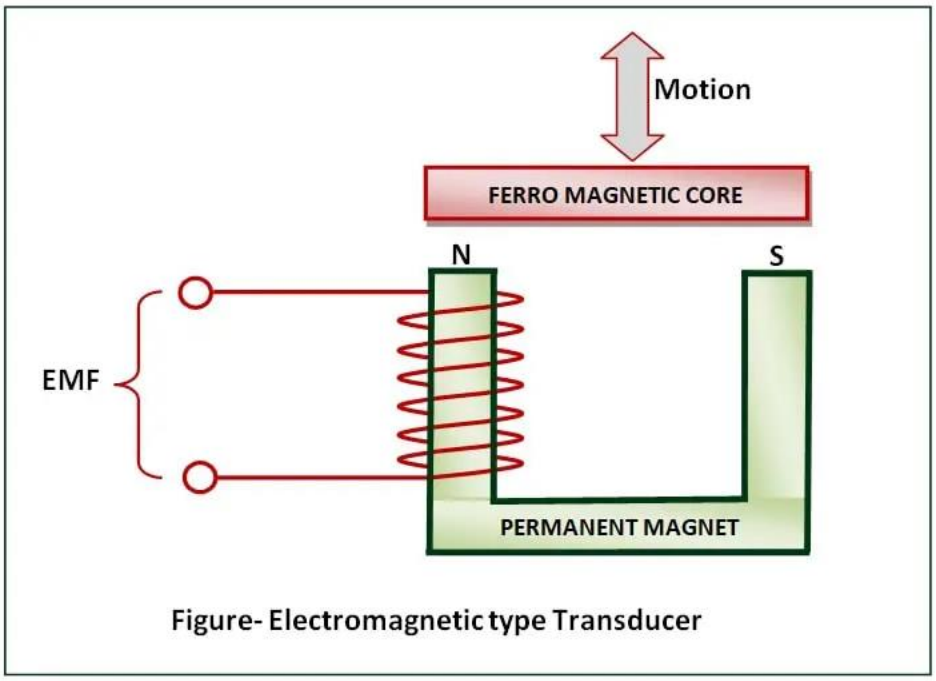


Figure- Electromagnetic type Transducer

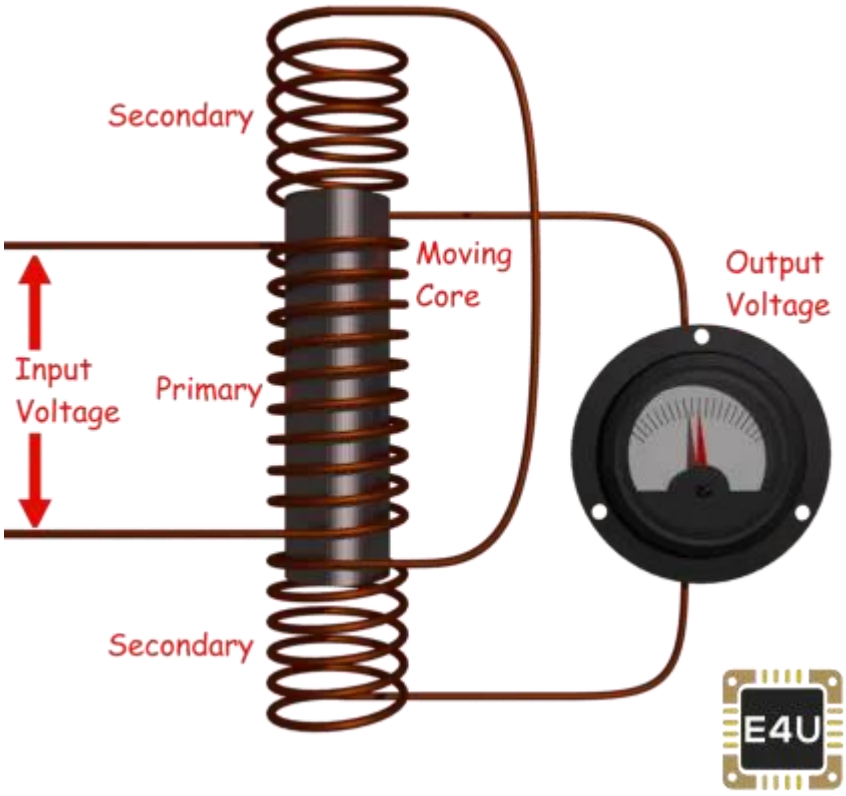
Linear variable differential transformer (LVDT)

The LVDT most widely used inductive transducer that converts the linear motion into the electrical signal. The output across secondary of this transformer is the differential thus it is called so. It is very accurate inductive transducer as compared to other inductive transducers.

Construction of LVDT

- The transformer consists of a primary winding P and two secondary windings S1 and S2 wound on a cylindrical former (which is hollow in nature and contains the core).
- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.
- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.

- The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.



Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S_1 is e_1 and in the secondary S_2 is e_2.

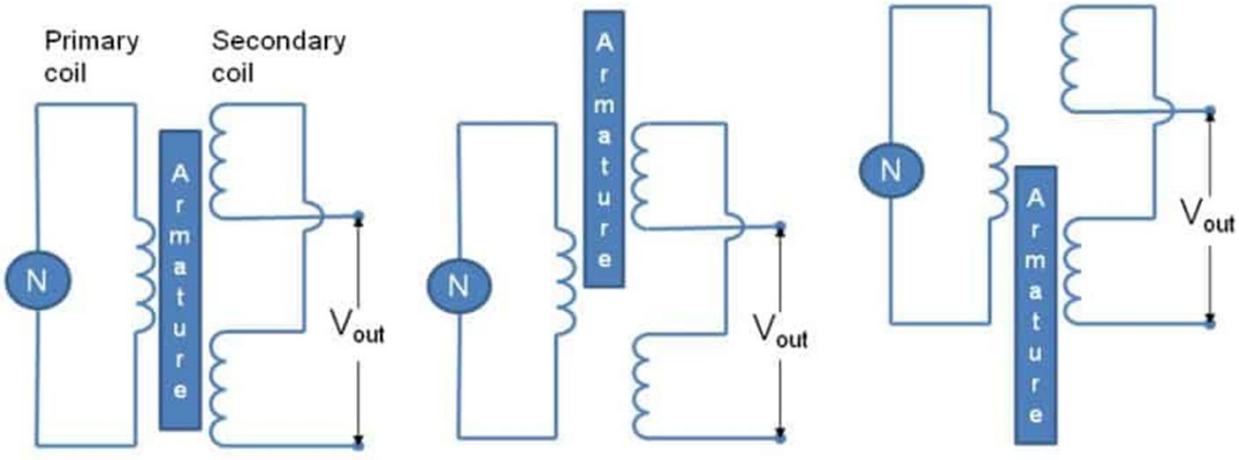
Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

CASE I When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no

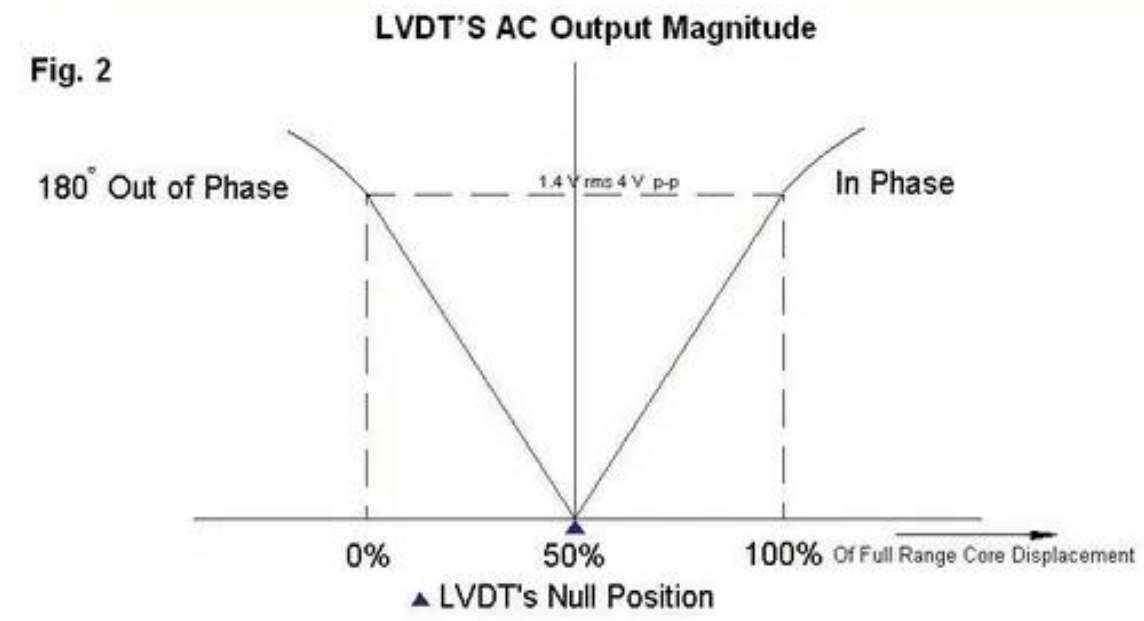
displacement the value of output V_{out} is zero as e_1 and e_2 both are equal. So it shows that no displacement took place.

CASE II When the core is moved to upward of null position (For displacement to the upward of reference point) In the this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Due to this e_1 will be more as that of e_2. Due to this output voltage V_{out} is positive.

CASE III When the core is moved to downward of Null position (for displacement to the downward of the reference point). In this case magnitude of e_2 will be more as that of e_1. Due to this output V_{out} will be negative and shows the output to downward of the reference point.



Output Vs Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.



Some important points about magnitude and sign of voltage induced in LVDT

- The amount of change in voltage either negative or positive is proportional to the amount of movement of core and indicates amount of linear motion.
- By noting the output voltage increasing or decreasing the direction of motion can be determined
- The output voltage of an LVDT is linear function of core displacement.

Advantages of LVDT

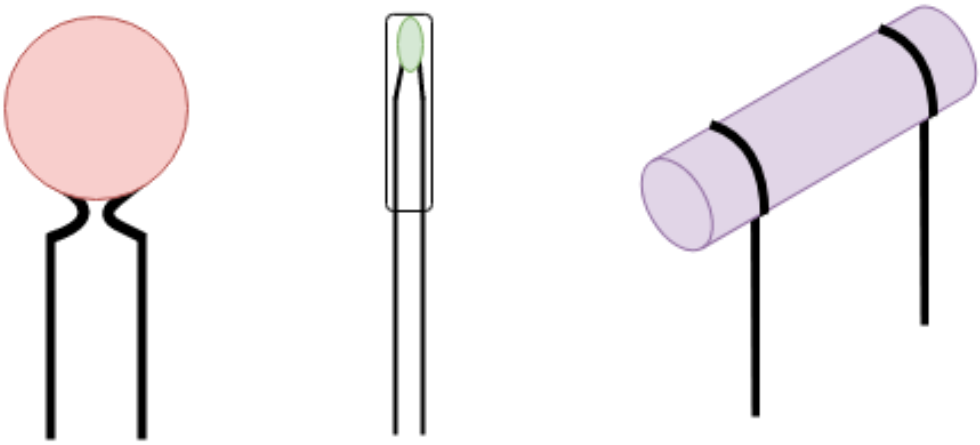
- High Range.
- No Frictional Losses.
- High Input and High Sensitivity.
- Low Hysteresis
- Low Power Consumption.
- Direct Conversion to Electrical Signals – They convert the linear displacement to electrical voltage which are easy to process.

Thermistor:

The Thermistor or simply Thermally Sensitive Resistor is a temperature sensor that works on the principle of varying resistance with temperature. They are made of semiconducting materials. The circuit symbol of the thermistor is shown in the figure.

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.



disc thermistor bead thermistor rod thermistor

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.

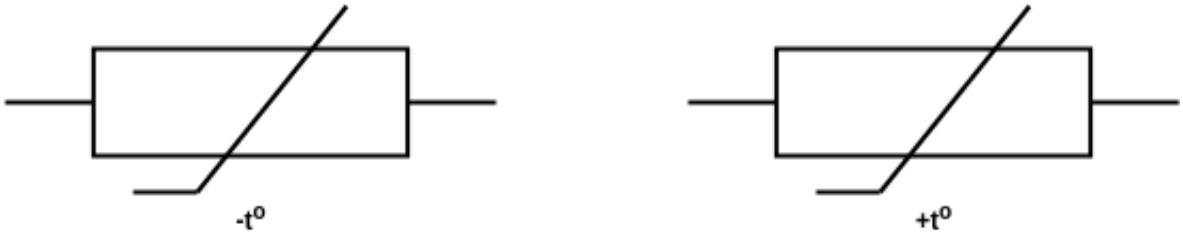
Types of Thermistors

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

NTC Thermistor

The 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.

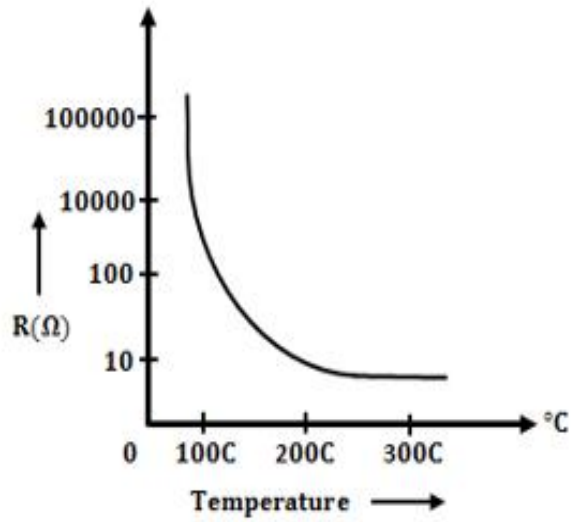
Circuit symbols of NTC and PTC thermistors are shown in the following figure.



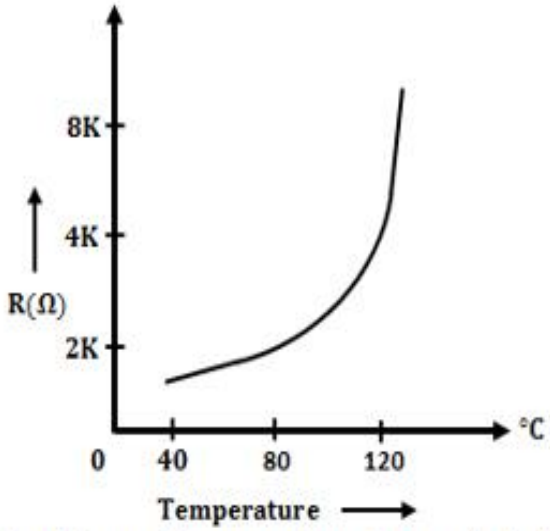
NTC Thermistor PTC Thermistor

PTC Thermistor

The 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 Characteristics of NTC Thermistor



Resistance Temperature Characteristics of PTC Thermistor

Advantages of thermistors

- Less expensive.
- More sensitive than other sensors.
- Fast response.
- Small in size.

Dis-advantages of thermistors

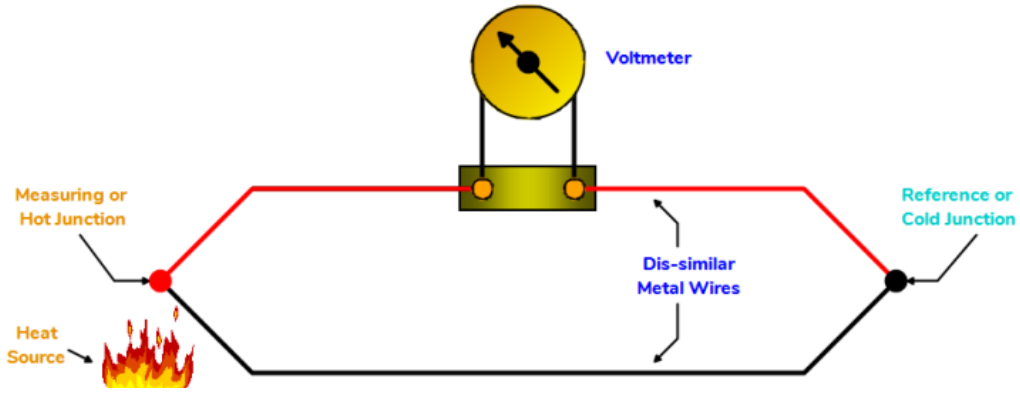
- Limited Temperature range.
- Resistance to temperature ratio correlation is non-linear.
- An inaccurate measurement may be obtained due to the self-heating effect.
- Fragile.

Applications of thermistors

- Digital Thermostats.
- Thermometers.
- Battery pack temperature monitors.
- In-rush-current limiting devices
- Over-current protection
- In-rush-current protection

Thermocouple:

The thermocouple can be defined as a kind of temperature sensor that is used to measure the temperature at one specific point in the form of the EMF or an electric current. This sensor comprises two dissimilar metal wires that are connected together at one junction. The temperature can be measured at this junction, and the change in temperature of the metal wire stimulates the voltages.

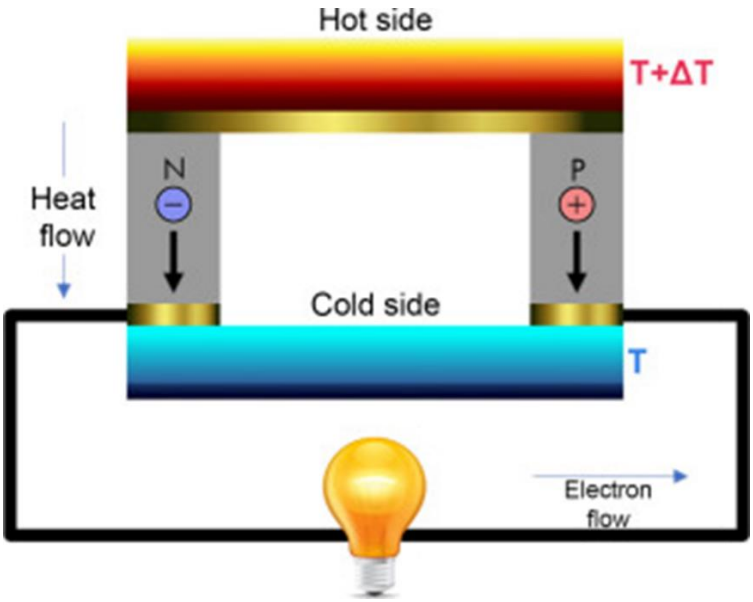


The amount of EMF generated in the device is very minute (millivolts), so very sensitive devices must be utilized for calculating the e.m.f produced in the circuit.

Thermocouple Working Principle

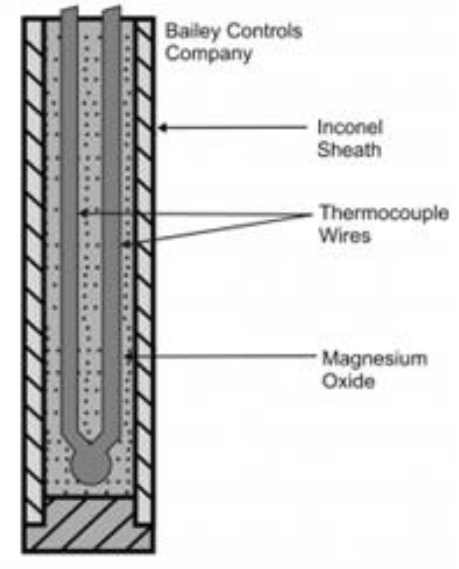
Generally, a thermocouple is designed with two different metal wires namely iron and constantan that makes in detecting element by connecting at one junction that is named as a hot junction. This consist of two junctions, one junction is connected by a voltmeter or transmitter where the cold junction and the second junction is associated in a process that is called a hot junction.

The thermocouple principle mainly depends on the Seebeck effects. This type of effect occurs among two dissimilar metals. When the heat offers to any one of the metal wires, then the flow of electrons supplies from hot metal wire to cold metal wire. Therefore, direct current stimulates the circuit.



Construction of Thermocouple

The construction of the device is shown below. It comprises two different metal wires and that are connected together at the junction end. The junction thinks as the measuring end. The end of the junction is classified into three type's namely ungrounded, grounded, and exposed junction.



Ungrounded-Junction

In this type of junction, the conductors are totally separated from the protecting cover. The applications of this junction mainly include high-

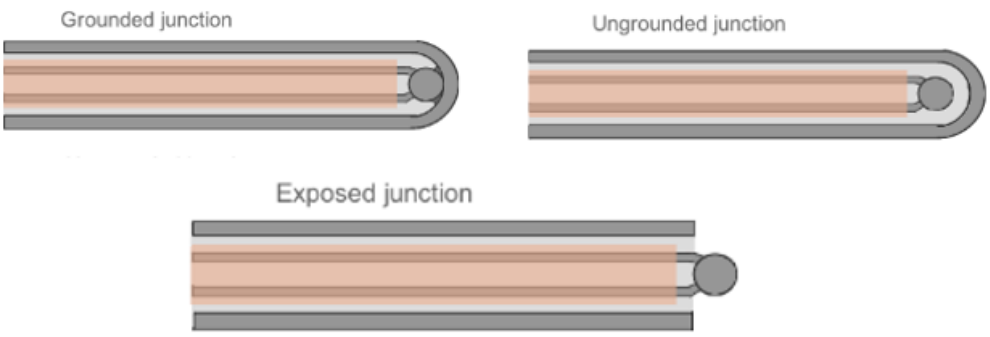
pressure application works. The main benefit of using this function is to decrease the stray magnetic field effect.

Grounded-Junction

In this type of junction, the metal wires, as well as the protection cover, are connected together. This function is used to measure the temperature in the acidic atmosphere, and it supplies resistance to the noise.

Exposed-Junction

The exposed junction is applicable in the areas where a quick response is required. This type of junction is used to measure the gas temperature. The metal used to make the temperature sensor depends on the range of temperature.



Thermocouple Types			
Type	Conductor Combination	Temperature Range	
		°F	°C
B	Platinum 30% Rhodium / Platinum 6% Rhodium	2500 to 3100	1370 to 1700
E	Nickel-chromium / Constantan	32 to 1600	0 to 870
J	Iron / Constantan	32 to 1400	0 to 760
K	Nickel-chromium / Nickel-aluminium	32 to 2300	0 to 1260
N	Nicrosil / Nisil	32 to 2300	0 to 1260
R	Platinum 13% Rhodium / Platinum	1600 to 2640	870 to 1450
S	Platinum 10% Rhodium / Platinum	1800 to 2640	980 to 1450
T	Copper / Constantan	-75 to +700	-59 to +370

Advantages

- Accuracy is high
- It is robust and can be used in harsh environments
- The thermal reaction is fast
- The operating range of the temperature is wide.
- Wide operating temperature range
- Cost is low and extremely consistent

Disadvantages

- Least stability
- Low voltage
- Reference is required
- least sensitivity
- Nonlinearity
- The thermocouple recalibration is hard

Applications

- These are used as the temperature sensors in thermostats in offices, homes, offices & businesses.
- These are used in industries for monitoring temperatures of metals in iron, aluminum, and metal.
- These are used to test temperature in chemical plants, petroleum plants.
- These are used in gas machines for detecting the pilot flame.

Photodiode

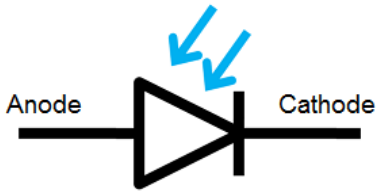
A photodiode is a p-n junction or pin semiconductor device that consumes light energy to generate electric current. It is also sometimes referred as photo-detector, photo-sensor, or light detector. Photodiodes are specially designed to operate in reverse bias condition. Reverse bias means that the p-side of the photodiode is connected to the negative terminal of the battery and n-side is connected to the positive terminal of the battery.

Photodiode is very sensitive to light so when light or photons falls on the photodiode it easily converts light into electric current. Solar cell is also known as large area photodiode because it converts solar energy or light energy into electric energy. However, solar cell works only at bright light.

The construction and working of photodiode is almost similar to the normal p-n junction diode. PIN (p-type, intrinsic and n-type) structure is mostly used for constructing the photodiode instead of p-n (p-type and n-type) junction structure because PIN structure provide fast response time. PIN photodiodes are mostly used in high-speed applications. In a normal p-n junction diode, voltage is used as the energy source to generate electric current whereas in photodiodes, both voltage and light are used as energy source to generate electric current.

Photodiode symbol

The symbol of photodiode is similar to the normal p-n junction diode except that it contains arrows striking the diode. The arrows striking the diode represent light or photons. A photodiode has two terminals: a cathode and an anode.



Photodiode symbol

How photodiode works?

A normal p-n junction diode allows a small amount of electric current under reverse bias condition. To increase the electric current under reverse bias condition, we need to generate more minority carriers. The external reverse voltage applied to the p-n junction diode will supply energy to the minority carriers but not increase the population of minority carriers. However, a small number of minority carriers are generated due to external reverse bias voltage.

The minority carriers generated at n-side or p-side will recombine in the same material before they cross the junction. As a result, no electric current flows due to these charge carriers. For example, the minority carriers generated in the p-type material experience a repulsive force from the external voltage and try to move towards n-side. However, before crossing the junction, the free electrons recombine with the holes within the same material. As a result, no electric current flows.

To overcome this problem, we need to apply external energy directly to the depletion region to generate more charge carriers. A special type of diode called photodiode is designed to generate more number of charge carriers in depletion region. In photodiodes, we use light or photons as the external energy to generate charge carriers in depletion region.

Types of photodiodes

The working operation of all types of photodiodes is same. Different types of photodiodes are developed based on specific application. For example, PIN photodiodes are developed to increase the response speed. PIN photodiodes are used where high response speed is needed.

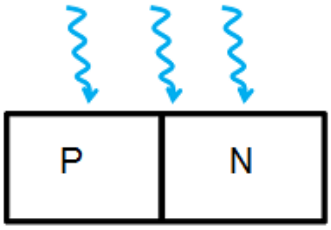
The different types of photodiodes are

- PN junction photodiode
- PIN photodiode

Among all the three photodiodes, PN junction and PIN photodiodes are most widely used.

PN junction photodiode

PN junction photodiodes are the first form of photodiodes. They are the most widely used photodiodes before the development of PIN photodiodes. PN junction photodiode is also simply referred as photodiode. Nowadays, PN junction photodiodes are not widely used.



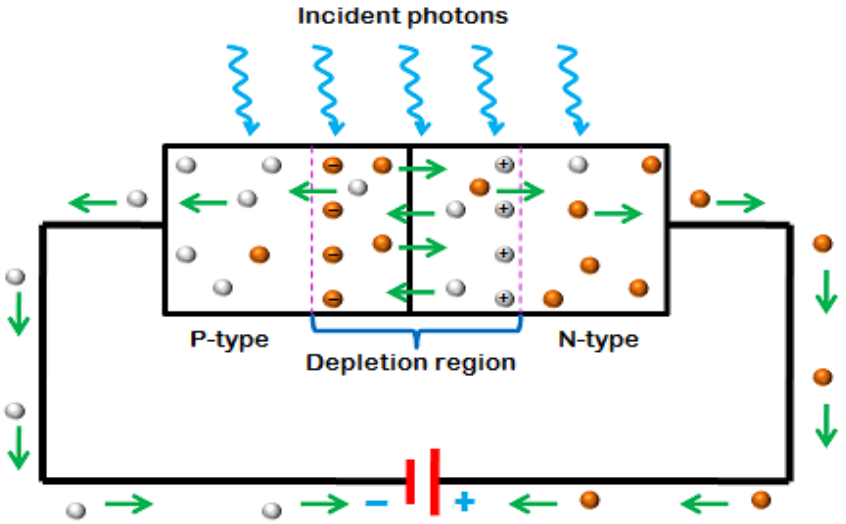
When external light energy is supplied to the p-n junction photodiode, the valence electrons in the depletion region gains energy. If the light energy applied to the photodiode is greater the band-gap of semiconductor material, the valence electrons gain enough energy and break bonding with the parent atom. The valence electron which breaks bonding with the parent atom will become free electron. Free electrons moves freely from one place to another place by carrying the electric current.

When the valence electron leave the valence shell an empty space is created in the valence shell at which valence electron left. This empty space in the valence shell is called a hole. Thus, both free electrons and holes are generated as pairs. The mechanism of generating electron-hole pair by using light energy is known as the inner photoelectric effect.

The minority carriers in the depletion region experience force due to the depletion region electric field and the external electric field. For example, free electrons in the depletion region experience repulsive and attractive force from the negative and positive ions present at the edge of depletion region at p-side and n-side. As a result, free electrons move towards the n region. When the free electrons reaches n region, they are attracted towards the positive terminals of the battery. In the similar way, holes move in opposite direction.

The strong depletion region electric field and the external electric field increase the drift velocity of the free electrons. Because of this high drift velocity, the minority carriers (free electrons and holes) generated in the depletion region will cross the p-n junction before they recombine with atoms. As a result, the minority carrier current increases.

When no light is applied to the reverse bias photodiode, it carries a small reverse current due to external voltage. This small electric current under the absence of light is called dark current. It is denoted by I_{λ}.



In a photodiode, reverse current is independent of reverse bias voltage. Reverse current is mostly depends on the light intensity. In photodiodes, most of the electric current is carried by the charge carriers generated in the depletion region because the charge carriers in depletion region has high drift velocity and low recombination rate whereas the charge carriers in n-side or p-side has low drift velocity and high recombination rate. The electric current generated in the photodiode due to the application of light is called photocurrent. The total current through the photodiode is the sum of the dark current and the photocurrent. The dark current must be reduced to increase the sensitivity of the device. The electric current flowing through a photodiode is directly proportional to the incident number of photons.

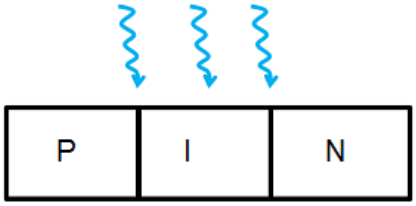
PIN photodiode

PIN photodiodes are developed from the PN junction photodiodes. The operation of PIN photodiode is similar to the PN junction photodiode except that the PIN photodiode is manufactured differently to improve its performance. The PIN photodiode is developed to increase the minority carrier current and response

speed. PIN photodiodes generate more electric current than the PN junction photodiodes with the same amount of light energy.

Layers of PIN photodiode

A PN junction photodiode is made of two layers namely p-type and n-type semiconductor whereas PIN photodiode is made of three layers namely p-type, n-type and intrinsic semiconductor. In PIN photodiode, an addition layer called intrinsic semiconductor is placed between the p-type and n-type semiconductor to increase the minority carrier current.



P-type semiconductor

If trivalent impurities are added to the intrinsic semiconductor, a p-type semiconductor is formed. In p-type semiconductors, the number of free electrons in the conduction band is lesser than the number of holes in the valence band. Therefore, holes are the majority charge carriers and free electrons are the minority charge carriers. In p-type semiconductors, holes carry most of the electric current.

N-type semiconductor

If pentavalent impurities are added to the intrinsic semiconductor, an n-type semiconductor is formed. In n-type semiconductors, the number of free electrons in the conduction band is greater than the number of holes in the valence band. Therefore, free electrons are the majority charge carriers and holes are the minority charge carriers. In n-type semiconductors, free electrons carry most of the electric current.

Intrinsic semiconductor

Intrinsic semiconductors are the pure form of semiconductors. In intrinsic semiconductor, the number of free electrons in the conduction band is equal to

the number of holes in the valence band. Therefore, intrinsic semiconductor has no charge carriers to conduct electric current. However, at room temperature a small number of charge carriers are generated. These small number of charge carriers will carry electric current.

PIN photodiode operation

A PIN photodiode is made of p region and n region separated by a highly resistive intrinsic layer. The intrinsic layer is placed between the p region and n region to increase the width of depletion region.The p-type and n-type semiconductors are heavily doped. Therefore, the p region and n region of the PIN photodiode has large number of charge carriers to carry electric current. However, these charge carriers will not carry electric current under reverse bias condition.

On the other hand, intrinsic semiconductor is an undoped semiconductor material. Therefore, the intrinsic region does not have charge carriers to conduct electric current.

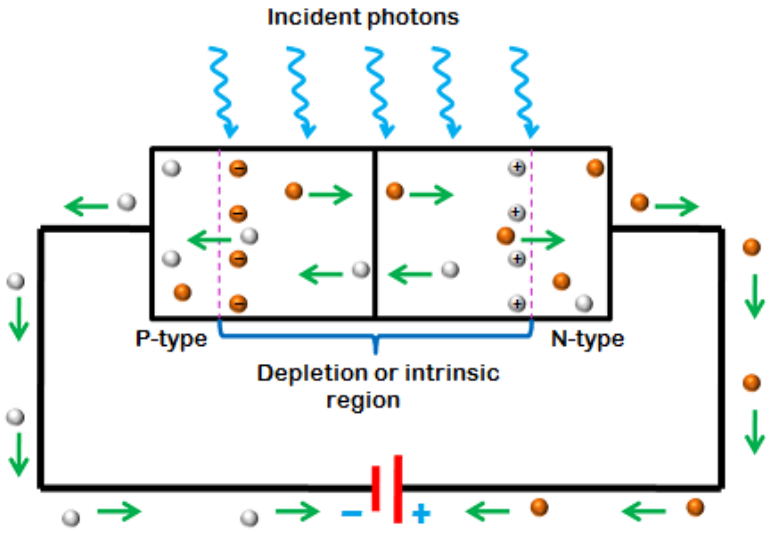
Under reverse bias condition, the majority charge carriers in n region and p region moves away from the junction. As a result, the width of depletion region becomes very wide. Therefore, majority carriers will not carry electric current under reverse bias condition.

However, the minority carriers will carry electric current because they experience repulsive force from the external electric field. In PIN photodiode, the charge carriers generated in the depletion region carry most of the electric current. The charge carriers generated in the p region or n region carry only a small electric current.

When light or photon energy is applied to the PIN diode, most part of the energy is observed by the intrinsic or depletion region because of the wide depletion width. As a result, a large number of electron-hole pairs are generated. Free electrons generated in the intrinsic region move towards n-side whereas holes

generated in the intrinsic region move towards p-side. The free electrons and holes moved from one region to another region carry electric current.

When free electrons and holes reach n region and p region, they are attracted to towards the positive and negative terminals of the battery.



The population of minority carriers in PIN photodiode is very large compared to the PN junction photodiode. Therefore, PIN photodiode carry large minority carrier current than PN junction photodiode. When forward bias voltage is applied to the PIN photodiode, it behaves like a resistor. We know that capacitance is directly proportional to the size of electrodes and inversely proportional to the distance between electrodes. In PIN photodiode, the p region and n region acts as electrodes and intrinsic region acts as dielectric.

The separation distance between p region and n region in PIN photodiode is very large because of the wide depletion width. Therefore, PIN photodiode has low capacitance compared to the PN junction photodiode. In PIN photodiode, most of the electric current is carried by the charge carriers generated in the depletion region. The charge carriers generated in p region or n region carry only a small electric current. Therefore, increasing the width of depletion region increases the minority carrier electric current.

Advantages of PIN photodiode

1. Wide bandwidth

2. High quantum efficiency
3. High response speed

Performance parameters of a photodiode

Responsivity

Responsivity is the ratio of generated photocurrent to the incident light power.

Quantum efficiency

Quantum efficiency is defined as the ratio of the number of electron-hole pairs (photoelectrons) generated to the incident photons.

Response time or transit time

The response time of a photodiode is defined as the time it takes for light generated charge carriers to cross p-n junction.

Photodiode applications

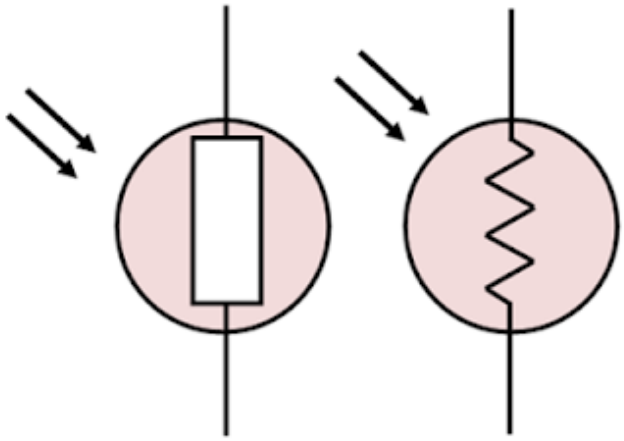
The various applications of photodiodes are

1. Compact disc players
2. Smoke detectors
3. Space applications
4. Photodiodes are used in medical applications such as computed tomography, instruments to analyze samples, and pulse oximeters.
5. Photodiodes are used for optical communications.
6. Photodiodes are used to measure extremely low light intensities.

Light Dependent Resistor (LDR)

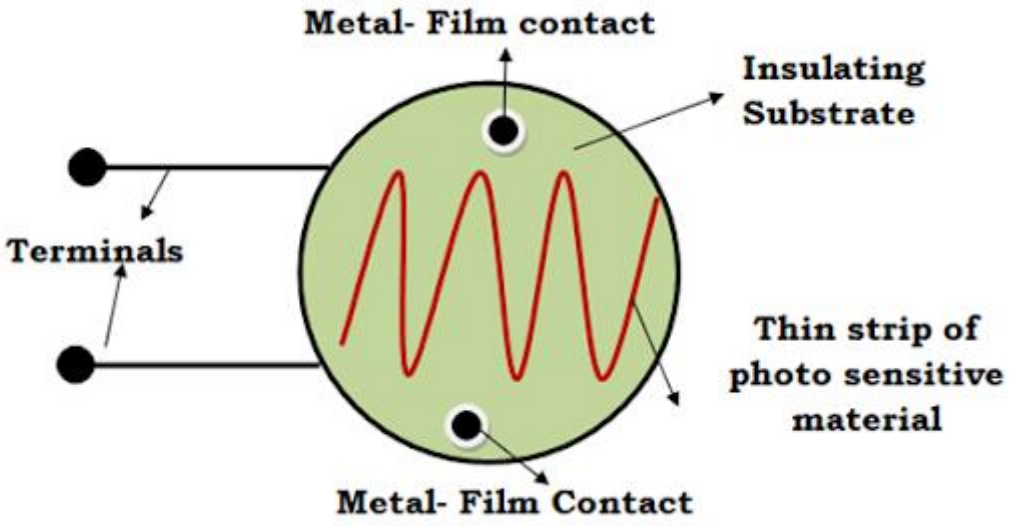
Light Dependent Resistor is called by many names such as photoresistor, photocell, photoconductor, photoconductive cells. The resistivity of LDR depends on the light incident on it and the sensitivity of LDR depends on the wavelength of the incident light. Thus it is a light sensitive device. Mostly it is used in circuits to detect the presence of the level of the light.

Symbol of LDR:



There are many symbols. The most commonly used symbol of LDR is shown in the figure. The arrow in the symbol indicates the light falling on it.

Construction of LDR:

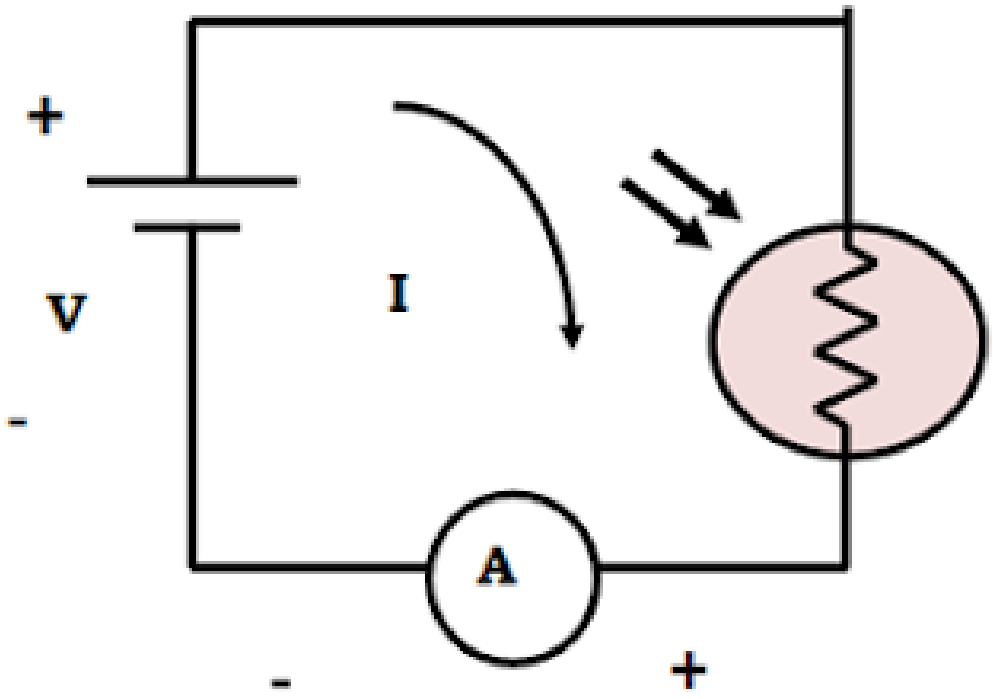


The LDR is constructed by placing a thin zigzag shaped strip of photosensitive device upon the insulating material. The light sensitive materials used in LDR are Cadmium Sulphide (Cds), Cadmium Selenide (CdSe) or lead Sulphide (Pbs). The insulating material used in LDR is ceramic. The metal films are connected

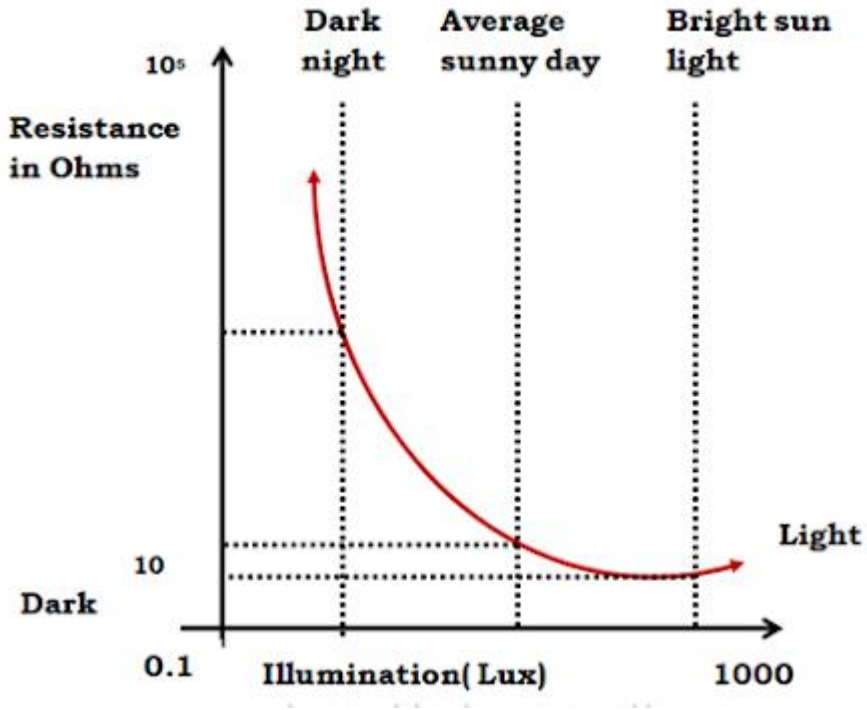
with the terminal leads. The whole structure is placed inside a plastic or resin case to have direct exposure to the sunlight. When there is no light the resistance is very high in Mega Ohms. When the light is incident the resistance value decreases and the conductivity increases.

Working of LDR:

The photoconductive material does not consists of any free electrons or it consists of few free electrons when it is not exposed to light. When the light is incident on the LDR the covalent bond breaks and many free electrons and holes are formed. The free electrons and holes gains energy and they jump from valence band to the conduction band. Thus current is generated. The resistivity of LDR decreases with increase in the incident light. More the light, more the charge carriers.



Illumination characteristics of LDR:



When there is no light resistivity is very high of Mega Ohms. When the light is incident the resistance decreases to kilo Ohms.

Advantages:

- Low cost
- Available in many shapes and sizes
- Low power operation
- High sensitivity

Disadvantages:

- Large response time-

Application:

- Used in automatic street lighting
- Used in cameras
- Used in alarm clocks
- Used in burglar circuit

Phototransistor

A Phototransistor is a device that has the ability to detect the level of the incident radiation and accordingly change the flow of electric current between emitter and collector terminal. It is a 3-layer semiconductor device that consists of a light sensitive base region. It is basically a transistor whose action depends on the application of light. Hence named phototransistor.

The phototransistor is basically an enhancement of Photodiode. Both photodiode and phototransistor are light sensing device but the sensitivity of phototransistor is somewhat more as compared to the photodiode. As phototransistor has the ability to give larger gain than that of the photodiode. It is similar to a normal BJT but the only variation is that in phototransistor, virtually the base region exists but it is kept unconnected with the external supply.

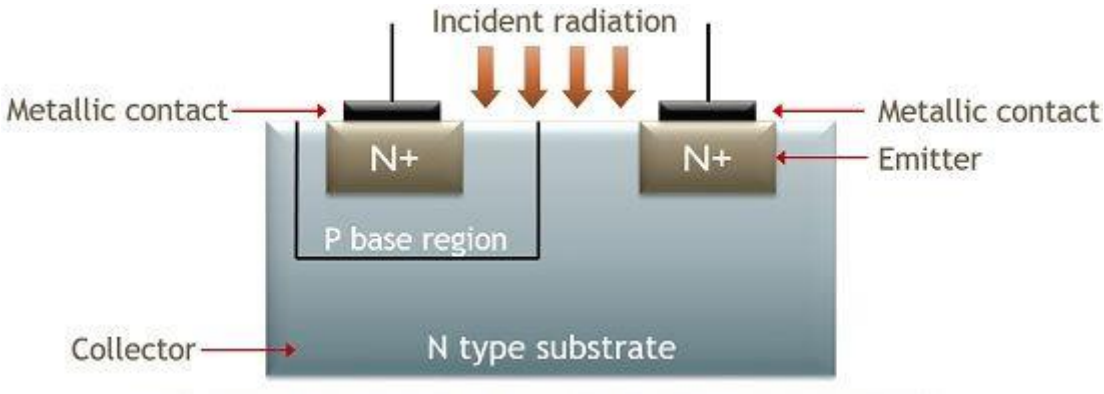
This means that as in normal BJT, base current is used to drive the circuit, however, in phototransistor light energy falling on the base region acts as the overall input of the device.

A phototransistor is said to exhibit the combined operation of the photodiode as well as a normal transistor. It operates on the principle of Photoelectric effect. As it changes light signal incident on its surface into its electrical equivalent form. And the transistor action permits it to perform amplification of the current flowing through it.

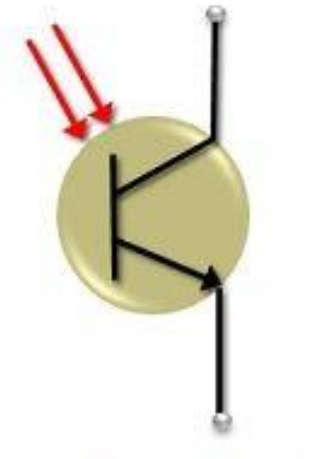
Construction of Phototransistor

Initially, phototransistors were fabricated from silicon or germanium as their basic material that resultantly provides homojunction structure. However, in recent times, these are constructed using materials likes gallium or arsenide. Thereby, providing a heterojunction structure. This is so because these structures exhibit large conversion efficiency. This implies they are more capable of changing light energy into electrical energy as compared to homojunction transistors.

Phototransistors are mainly enclosed in a metallic case that consists of the lens at the top in order to gather the incident radiation.



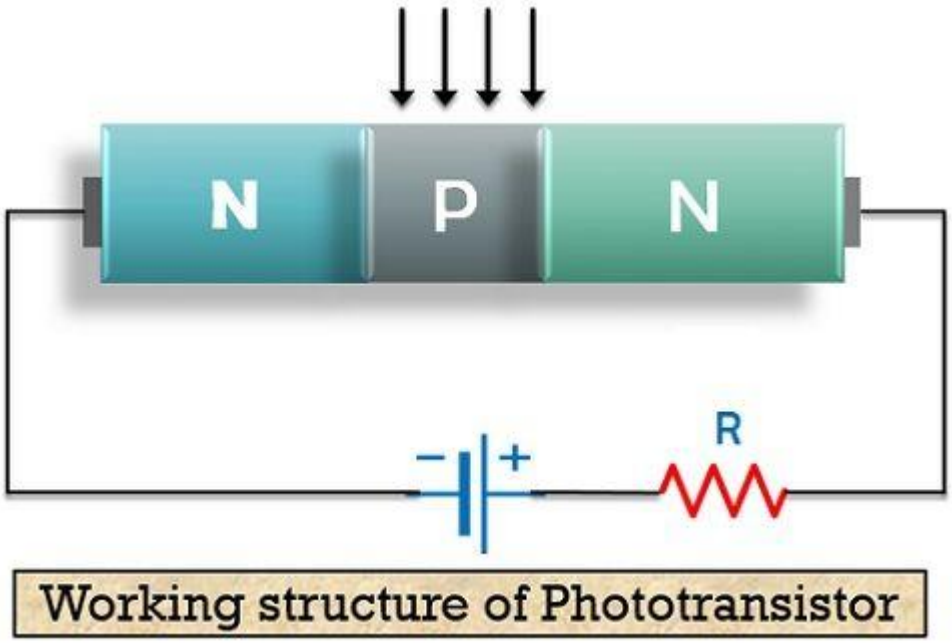
Symbol of Phototransistor



The symbolic representation is almost similar to a normal BJT but the only variation is the presence of two inward arrows at the base region that shows the incident of light radiation.

Working of Phototransistor

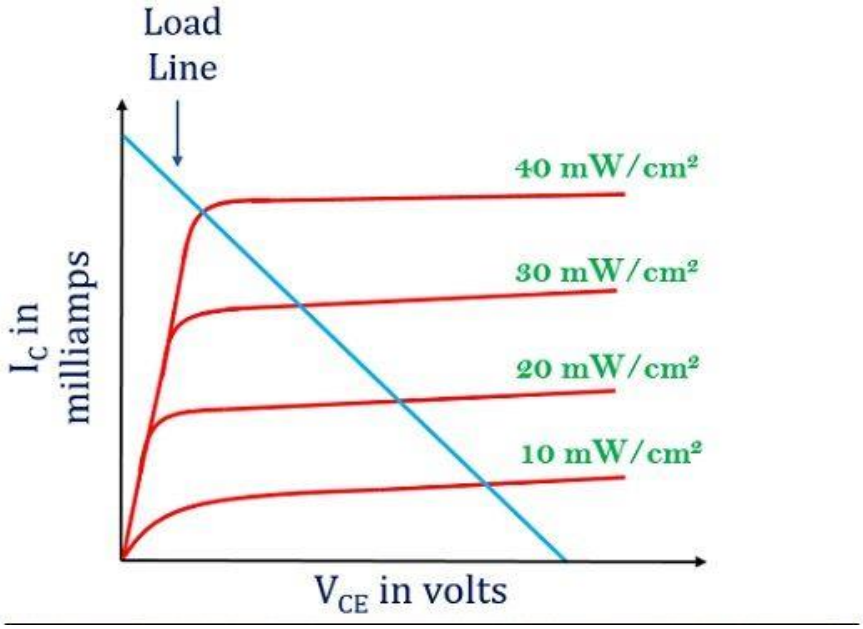
The operation of a phototransistor depends on the intensity of radiation falling at its base region. Its working is almost similar to a normal transistor, however; the variation lies in the input current that drives the circuit. And in the case of a phototransistor, the incident light generates driving current. The figure below represents the biasing arrangement of a phototransistor:



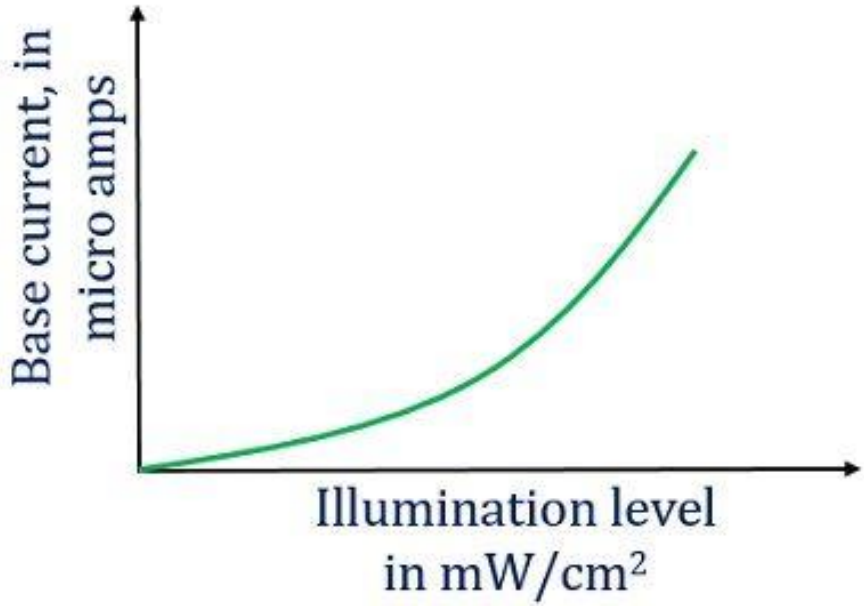
In the circuit arrangement, we can clearly see that the base region is kept unconnected with the external supply voltage and is used as the region for radiation incidence. Only the collector region is connected to the positive side of the supply provided along with emitter which is connected to the negative side. However, the output is taken at the emitter terminal of the transistor.

When no any light is allowed to incident at the base region of the transistor, the due to temperature variation, movement of minority carriers across the junction generates a very small current through the transistor which is reverse saturation current basically termed as dark current. Here, the base current $\mathbf{I_B}$ is majorly **0**. Here, in this case, the output current will be less as compared to supply provided. But, when a certain amount of light energy is allowed to fall at the base of the transistor, then electron and hole pair gets generated. The applied electric field causes the electrons to move into the emitter region, thereby generating large electric current.

Characteristics Curve of Phototransistor:



Here x-axis represents the voltage applied at the collector-emitter terminal of the transistor and the y-axis represents the collector current that flows through the device in mill amperes. As all the curves in the above figure are clearly indicating that current increases with the intensity of the radiation that falls at the base region. Also, the figure below represents the variation in the base current with the variation in the light intensity.



Advantages

1. These are a highly sensitive optoelectronic device.
2. It is less complex and inexpensive.
3. Phototransistors provides a large output current with high gain.

Disadvantages

1. It provides a low-frequency response.
2. In the case when a small amount of illumination is provided, the circuit is not able to detect it effectively.
3. Electric surges are more severe in phototransistors rather than a photodiode.
4. Phototransistors gets affected by the variation in electromagnetic energy.

Applications

- In light controlling and detection: As phototransistors are a very sensitive light detector. Thus these are widely used in light detection and controlling applications.
- In an indication of level and relays: The device finds its uses in indicating the level of some systems because of their light sensing ability.
- In counting systems: Phototransistors can be effectively utilized in counting systems. As it has tremendous ability to combinely operate as photodiode and transistors. Thus, failure of supply will not cause much adverse effects on the system.
- In punch card readers: Phototransistors widely finds its applications in punch card reading.

Optocoupler

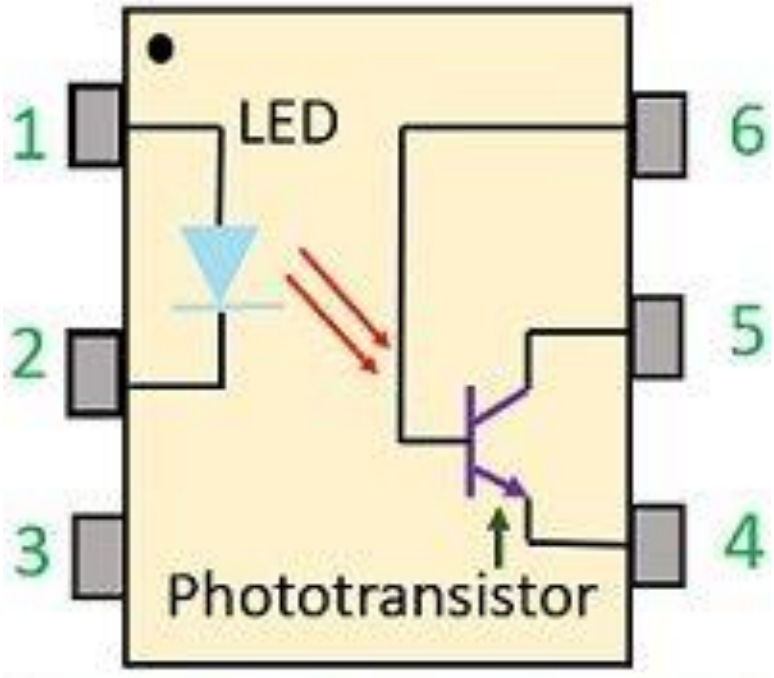
An optocoupler is an electronic component that basically acts as an interface between the two separate circuits with different voltage levels. Optocouplers are common component by which electrical isolation can be supplied between the input and output source. It is a 6 pin device and can have any number of photodetectors.

Here, a beam of light emitted by a light source exists as an only contact between input and output. Due to this, we can have an insulation resistance of megaohms between the two circuits.

Construction of an Optocoupler

An optocoupler mainly consists of an infrared LED and a photosensitive device that detects the emitted infrared beam. The semiconductor photosensitive device can be a photodiode, phototransistor, a Darlington pair, SCR or TRIAC.

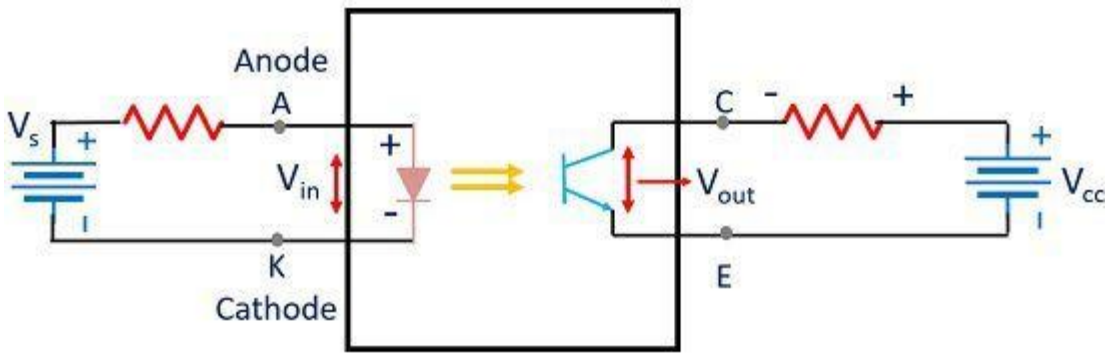
Let’s have a look at the basic diagram of an Optocoupler:



The infrared LED and the device that are light sensitive is packed in a single package. The LED is kept on the input side and the light-sensitive material is placed on the output side. A resistance is connected at the beginning of the circuit which is used to limit the current and the other resistance is connected between the supply voltage and the collector terminal.

Working Of an Optocoupler

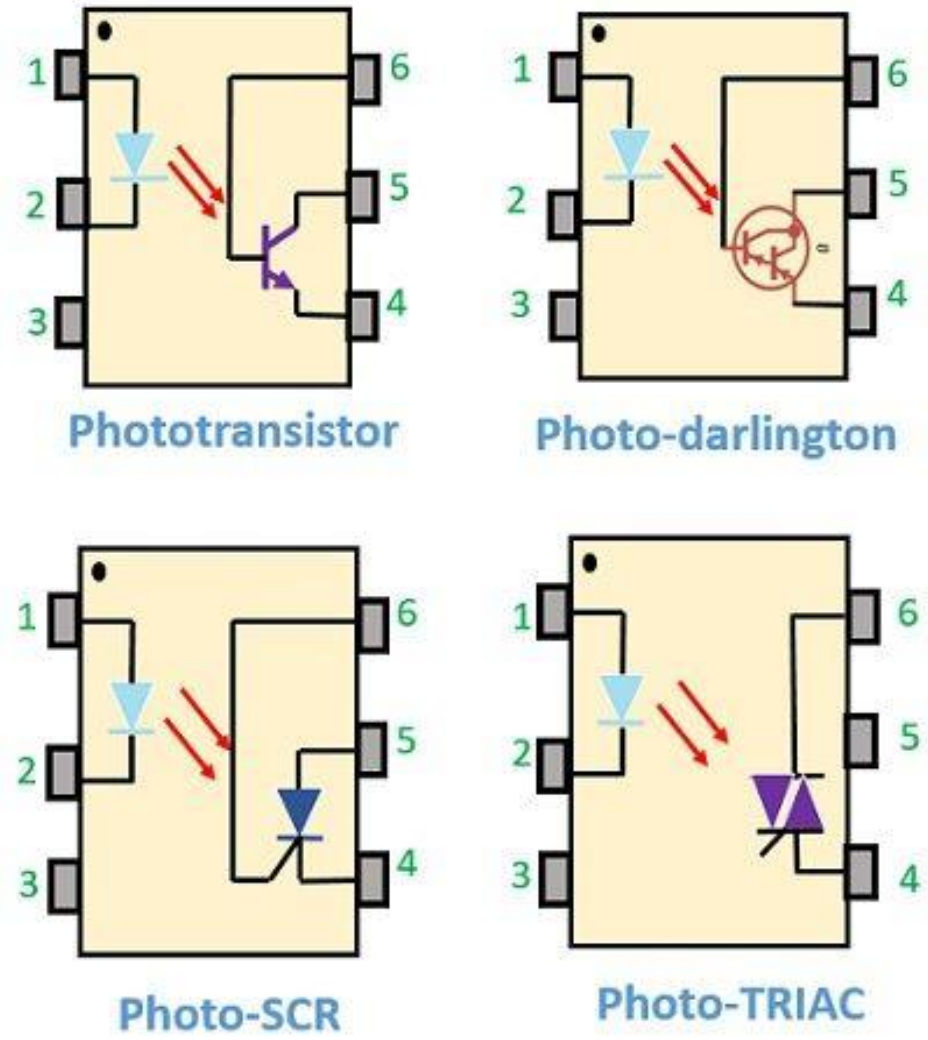
An Optocoupler is a combination of LED and a Photo-diode packed in a single package. As we can see in the below-shown circuit diagram, when a high voltage appears across the input side of the Optocoupler, a current start to flow through the LED.



Due to this current LED will emit light. This emitted light when falls on a phototransistor cause a current to flow through the same. The current flowing through the phototransistor is directly proportional to the supplied input voltage. An input resistance placed at the beginning of the circuit will decrease the amount of current flowing through the LED if its value is increased. As the LED glows due to this current, hence, when current will be low so as the light intensity of LED. The intensity of emitted light by the LED will be equal to the corresponding current flowing through the phototransistor. This means that the low-intensity light emitted by the LED will cause a low-level current to flow through the phototransistor. Thus a changing voltage is generated across the collector-emitter terminal of the transistor.

Types of Optocoupler

The various types of the optocoupler are shown in the diagram given below:



Advantages

1. Optocouplers allow easy interfacing with logic circuits.
2. Electrical isolation provides circuit protection.
3. It allows wideband signal transmission.
4. It is small in size and lightweight device.

Disadvantages

1. The operational speed of Optocouplers is low.
2. In case of a very high power signal, the possibility of signal coupling may arise.