18EES101J - BASIC ELECTRICAL AND ELECTRONICS ENGINEERING.

UNIT - IV

TRANSDUCERS

* Tranducer functions and Requirements.
* classification Active and Passive
* Displacement : capacitive, Inductive, Variable Inductance.
* Linear Variable Differential Transformer
* Electromechanical : Pressure, Flow, Accelerometer Potentiometer etc..
* Strain Gauge
* chemical : pH probes, Electro galvanic sensor etc..
* Electroacoustic : MIC, Speaker, Piezo electric, sonar, ultrasonic
* Tactile, Geophones, Hydrophones
* Electro optical : LED, Laser, Photodiode, Photoresistor, Phototransistor
* Photo conductive cell, Photovoltaic cell, Solar cell.
* LED, infrared emitters, LCD, optocouplers
* Thermoelectric : Resistance Temperature Detectors
* Thermo couple * Thermistor * Electrostatic : Electrometer
* Electromagnetic : Antenna, Hall effect, Magnetic catridge etc..
* Radioacoustic : Geiger Muller, Radio receiver, Radio transmitter.

Transducer:-

A 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 gives electrical energy as output is known as electrical transducer.

O/P electrical signal may be voltage, current or frequency and production of these signals is based upon resistive, capacitive, inductive effects.

For measuring non-electrical quantities, a detector is used which usually converts the physical quantity into a displacement.

The displacement transducers converts mechanical force into displacement and then into electrical parameters. Here the mechanical elements used for converting this applied force into displacement are called force summing devices.

Transducer

Active

↓

Self Generating type, develop their own voltage or current

Passive

Externally powered transducers, derive power from external source.

* opto electronic transducer such as photoconductive cell, use the principle of converting light energy to electrical energy

Basic Requirements of a transducer:

i) Linearity:-

The i/p - o/p 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 o/p signals when the same i/p is applied at different times under same environmental conditions.

iv) High stability and Reliability.

The o/p from the transducer should not be affected by temperature, vibration and other environ-mental variations and there should be minimum error in measurements.

v) Good Dynamic response:-

In Industrial, aerospace and biological applications, the i/p to the transducer will not be static but dynamic in nature, ie., the i/p will vary with time. The transducer should respond to the change in i/p as quickly as possible.

vi) Convenient Instrumentation:-

The transducer should produce a sufficiently high analog o/p signal with high S/N ratio, so that the

o/p 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.

Examples of Active and Passive transducers:-

Active Transducers	Passive Transducers.
i) Thermocouple	i) Resistance
ii) Piezoelectric transducer	ii) Potentiometric devices
iii) Photovoltaic cell	iii) Resistance strain gauge
iv) Moving coil generator	iv) Resistance thermometer
v) Photoelectric cell	v) Thermistor
	vi) Photoconductive cell
	vii) Inductance
	viii) LVDT
	ix) Capacitance
	x) Voltage and current devices using Hall effect.
	xi) Photo emissive cell
	xii) Photo Multiplier tube.

CAPACITIVE TRANSDUCER:-

The capacitance of a ||el plate capacitor is given by

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

Where, A = Area of each plate / m^2

d = distance b/w ||el plates in m

ε_0 = dielectric constant → Permittivity of free space. in F/m

ε_r = Relative dielectric constant (Permittivity)

$X_L = \omega L$

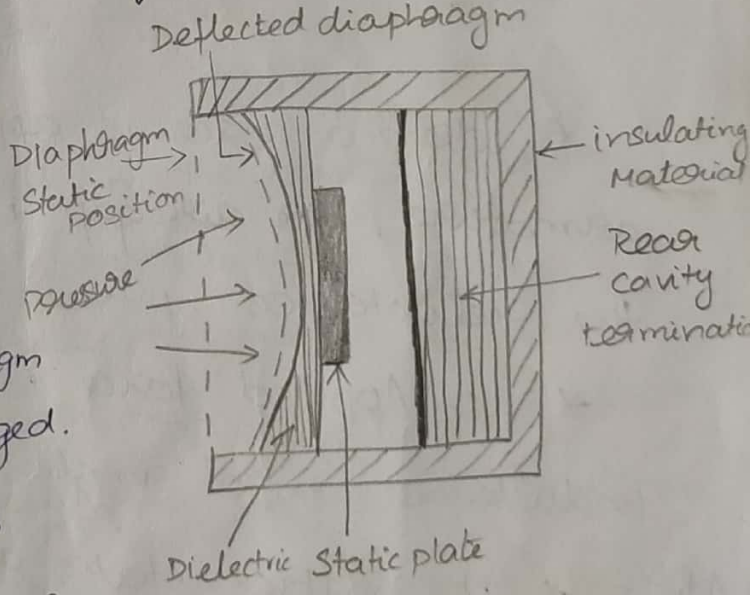
$X_C = \frac{1}{\omega C}$

The capacitance is ∝ Area of plate ⇒ $C \propto A$.

$$C \propto \frac{1}{d},$$

∴ Any variation in A or d causes variation in capacitance.

This principle of variation of d is used in capacitive transducer.



* When a force is applied to a diaphragm which acts as one plate of capacitor, the distance b/w the diaphragm and the static plate is changed.

* The Resulting Changed is measured with AC bridge or an oscillator.ckt.

* The oscillator ckt measures the change in frequency which is a measure of the magnitude of applied force.

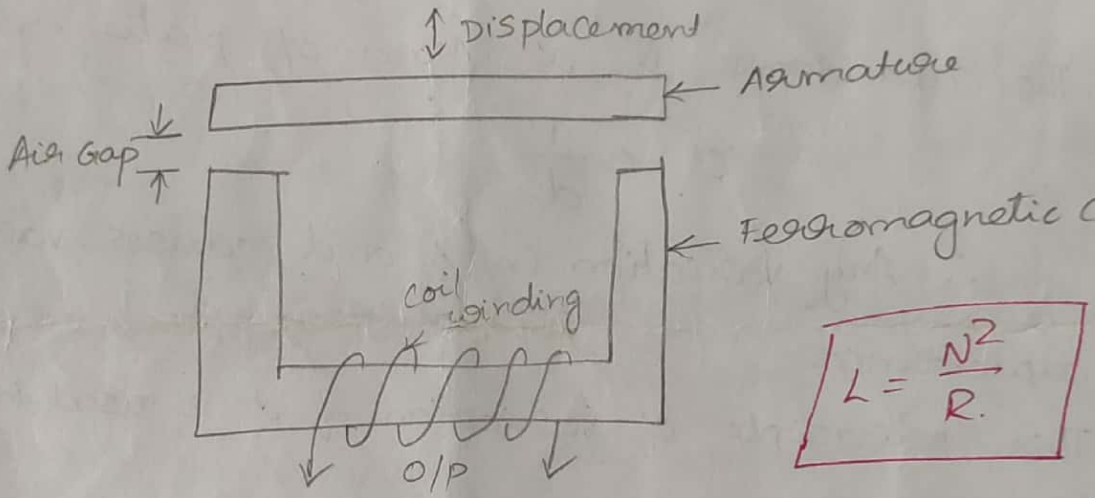
* In capacitor microphone, the same principle is used in which sound pressure varies the capacitance blw the fixed plate and a movable diaphragm.

Adv:* The capacitive transducer can measure both static and dynamic changes.

Drawback:-

* It is sensitive to temperature variations.

Inductive Transducer:-



* When a force is applied to the ferromagnetic armature, the air gap is changed thereby varying the reluctance of the magnetic ckt.

* ∴ Applied force is measured by change in inductance in a single coil.

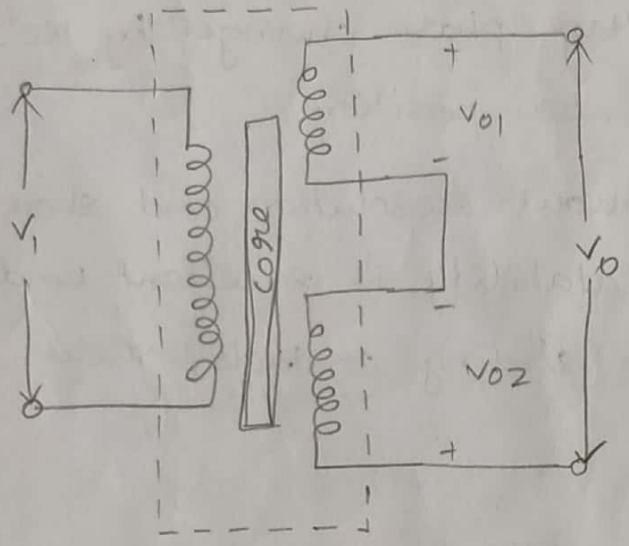
Adv:- * It enables static and dynamic measurements

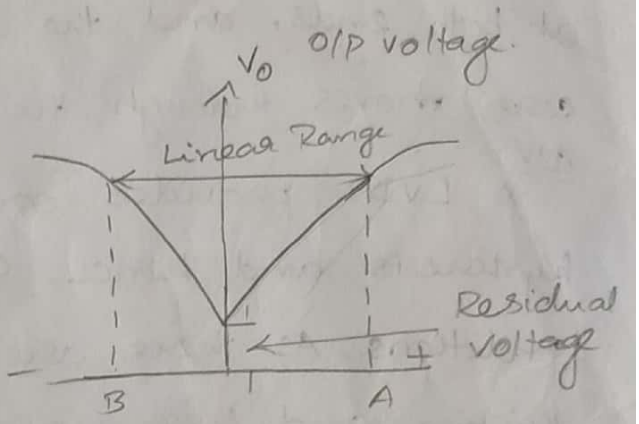
Drawback:-

It has limited frequency response.

Linear Variable Differential Transformer (LVDT)

* LVDT is most widely used inductance transducer.





* It consist 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_{01} and V_{02} are induced in the secondary coils.
* As these coils are connected in series opposition, the O/P voltage $V_0 = V_{01} - V_{02}$.
* If the core is placed ideally in the central position, $V_{01} = V_{02}$ and hence the O/P voltage $V_0 = 0$.
* In practice due to incomplete balance, a residual voltage usually remains with the core in this position.
* 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 o/p voltage produced by the displacement of the core is linear over a considerable range but flattens out at both ends, and the voltage phase changes by 180°. as the core moves through the center position.

Adv :-

* 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.

Disadvantages:-

* 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.

Thermistor:

* The thermistor or thermal resistor is a two-terminal semiconductor device whose resistance is temperature sensitive.
* The value of the resistors ↑ses with ↓se in temperature.
* Materials for thermistor :- cobalt, nickel, copper iron, uranium, manganese.
* The thermistor has very high temperature co-efficient of resistance, making it an ideal temperature transducer.

It is of the order 3 to 5 % Per °c

* The temperature co-efficient is normally negative.

* The resistance at any temperature T, is given approximately by.

$$R_T = R_0 \exp \beta\left(\frac{1}{T} - \frac{1}{T_0}\right)$$

where,

R_T → thermistor resistance at temperature T(k),

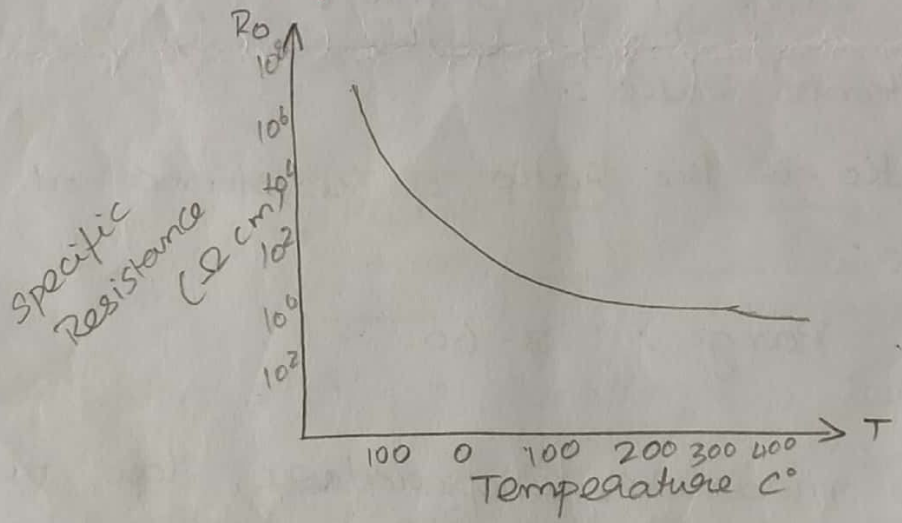
R_0 → thermistor resistance at temperature T_0(k),

β → a constant determined by calibration.

At high temperatures, the equation reduces to

$$R_T = R_0 e^{(\beta/T)}$$

Resistance - temperature curve:



* The curve is non-linear, the drop in resistance from 5000 to 10Ω occurs for an increase in temperature from 20 to 100°C.

* The temperature of the device can be changed internally or externally.

eg: Increase in current ↑se the temperature of the device and thus the resistance decreases.

Externally applied heat source will increase the temperature and thus resistance drops.

Parameter characterizing Thermistor.

i) Time constant :-

The time constant is the time for a thermistor to change its resistance by 63% of its initial value for zero - power dissipation.

Range :- 1 to 50s.

ii) Dissipation constant :-

The dissipation factor is the power necessary to increase the temperature of thermistor by 1°C

Range : 1 to 10 mW/C°

iii) Resistance Ratio :-

Resistance Ratio is the ratio of resistance at 25°C to that at 125°C.

Range :- 3-60.

Uses :-

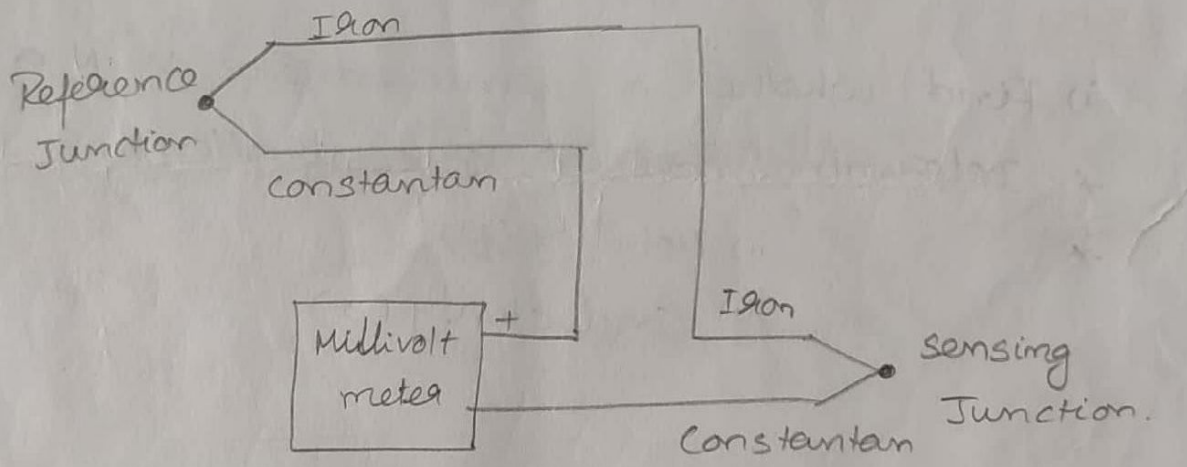
* used to measure, temperature, flow, pressure, liquid level, voltage (or) power level, vacuum, composition of gases and thermal conductivity.
* In compensation n/w.

Thermocouple :-

* A thermocouple is a Junction b/w two dissimilar metals (or) semiconductors that generates a small voltage, typically in the millivolt range, with co-efficient of about 50 μV/C°.

* various thermocouple materials and methods of construction are used depending upon the temperature, environment and required sensitivity.

Thermocouple circuits :-



* It Consist of 2 Junctions i) Reference
ii) sensing;
maintained at different temperatures.

* Each Junction is made up of 2 dissimilar metals

* Reference Junction is maintained at constant temp say 0°C

* o/p voltage depends upon the temperature of sensing junction.

* o/p is very small volt; so it is necessary to amplify the o/p for calibration and measurement.

Uses:

Iron - constantan thermocouple → measuring temp upto 760°c.

Chromel - Alumel thermocouple → measuring temp upto 1370°c

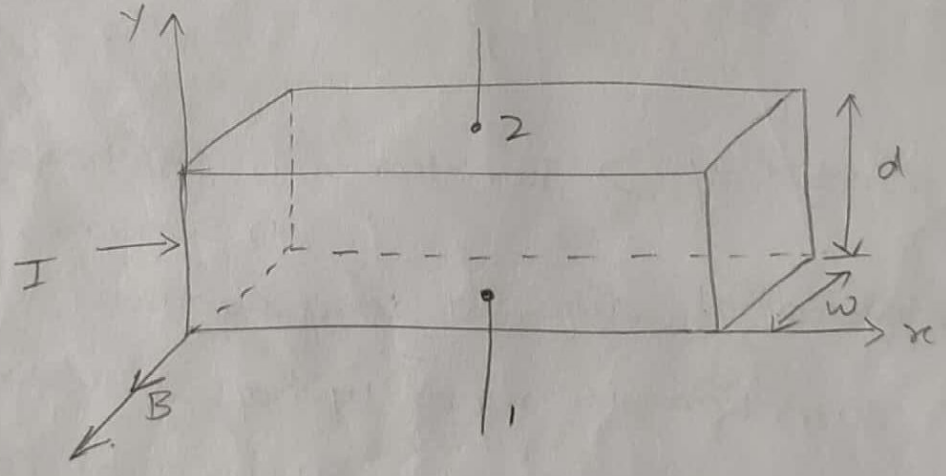
Hall effect:

* When a transverse magnetic field B is applied to a metal or a semiconductor carrying a current I, an electric field E is induced in the direction perpendicular to both I and B. This phenomenon is known as Hall effect.

Uses:

i) Find whether a semiconductor is N or P type

* Determine i) carrier concentration.
* ii) Mobility (μ)
  iii) Conductivity (σ).



The Force given,

$$F = eE = Bev$$

e → charge of e^-
B → magnetic field
V → drift velocity.

In N-type semiconductor:-

* The current is carried by electrons.
* It will be forced downwards towards side 1
* So 1 becomes negatively charged with respect to 2.

$\therefore$ Hall Voltage, $V_H = \frac{R_H}{w} BI.$

$R_H \rightarrow$ Hall co-efficient $\Rightarrow R_H = \frac{1}{\rho}$

$w \rightarrow$ width of conductor. $\rho \rightarrow$ charge density.

$\rho = ne \rightarrow n \rightarrow$ electron concentration.

Ptype semiconductor:-

* If the polarity of V_H is positive at terminal 1 with respect to terminal 2.

$\rho = pe$, $p \rightarrow$ hole concentration.

conductivity :- $\sigma = \rho\mu.$

$\mu = \sigma R_H.$

Advantages:-

* They are non contact devices, with high resolution and small in size.

Other applications:-

* Measurement of velocity, RPM, sorting, limit sensing, non-contact current and magnetic field.

STRAIN GAUGE:-

* If a metal conductor is stretched or compressed, its resistance changes because of dimensional changes (l and and cross sectional A) and resistivity change.

* If a wire is under tension its length ↑se from

$$l \rightarrow l + \Delta l.$$

$$R \rightarrow R + \Delta R$$

$$\therefore \text{Strain } S = \frac{\Delta l}{l}$$

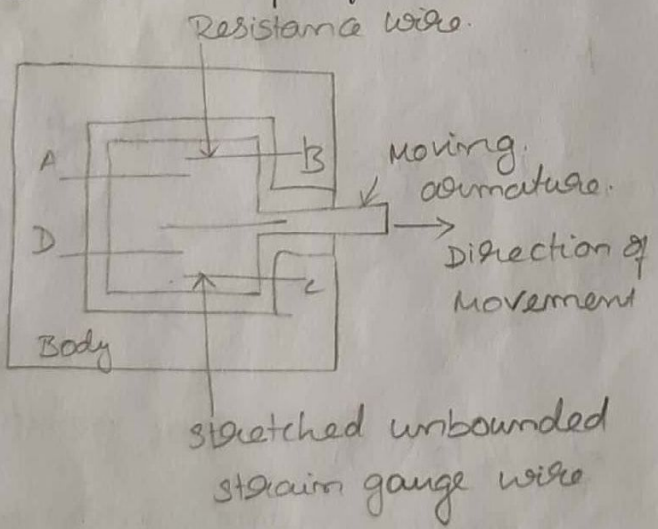
* The sensitivity of a strain gauge is described in terms of a characteristic called gauge factor G,

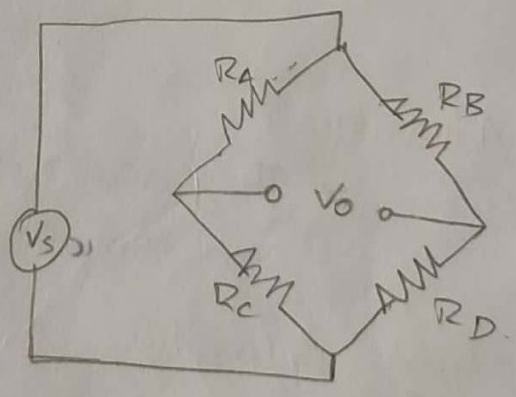
$$G = \frac{\Delta R/R}{\Delta l/l} = \frac{\Delta R/R}{S}$$

Gauge factor G, is defined as the unit change in resistance per unit change in length.

i) unbonded strain Gauge.

The unbonded strain gauge have unbonded wire structure fixed to a force rod which transmiting force to the platform.





* The resistance wire have equal length.

* The armature moves in any one direction.

* Because of the movement of armature the length of the resistance wire A and D ↑ses in length. whereas element B and D decreases in length.

* AS the length varies, Resistance of 4 wires changes and this can be measured with a wheatstone bridge.

* unbalancing the bridge creates the o/p voltage Vo.

Balancing condition of bridge $\Rightarrow \frac{R_A}{R_C} = \frac{R_B}{R_D}$.

* The external force causes variation in resistance of wires

ii) Bonded wire strain gauge:

* A bonded wire strain gauge consists of a grid of fine resistance wire of diameter of about 25 μm. The wire is cemented to base.

* The base may be a thin sheet of paper or very thin Bakelite sheet.

* The wire is covered with a thin sheet of material so that it is not damaged mechanically.

* The base is bonded to the structure under study with an adhesive material.

* It acts as a bonding material.

* It permits a good transfer of strain from base to wire.

Potentiometer:

It is a variable resistor, Types i) carbon
ii) wire wound.

i) carbon potentiometer:

* The construction of carbon potentiometer is as in fig.

* These are manufactured either in film or moulded track types.

* Both consist of an annular ring of carbon resistance formed on a plastic base, over which a movable contact can slide

* There is a slip ring which is also contacted by the movable contact.
* Three terminals are provided, two of them connected to the ends of the carbon track and one to the slip ring.
* A shaft runs through a bush in the center of the base to which the movable contact is attached.
* The assembly is enclosed by a case of sheetmetal over which the resistance value and taper is engraved.
* The taper refers to variation in resistance along the track, which may be i) logarithmic
ii) Linear variation.

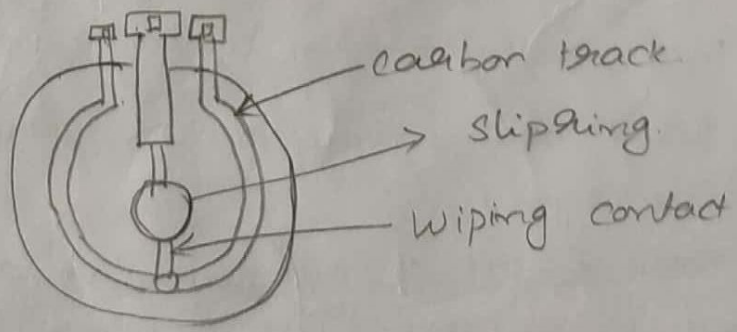
The Track can be film type (or) moulded type.

i) Film type :- A mixture of carbon, graphite and resin in the form of paste is sprayed on to a plastic sheet, with suitable masks in the form of rings.

If non-linear taper is required, the ring width may be varied across the circumference or the spray may be made from different composition mixture.

ii) Moulded track type :- The resistance material and base plate are moulded together with slip ring.

This integral moulding of base, track and terminals gets rid of solders, rivets, weld and provide good humidity resistance and fewer mechanical joints.



ii). Wire wound potentiometers :

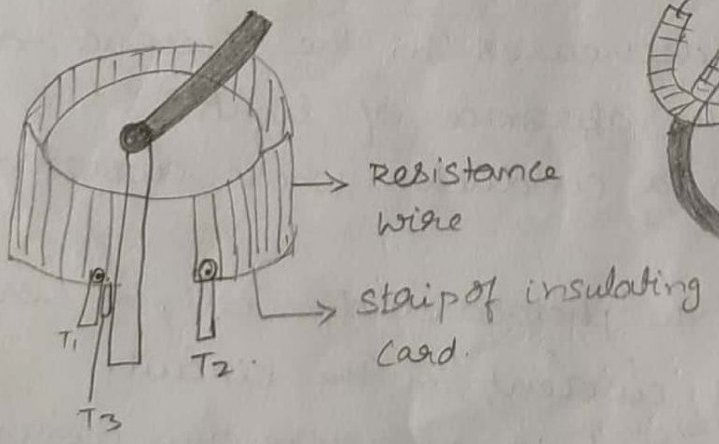
There are 2 types a) single turn
b) Multi turn

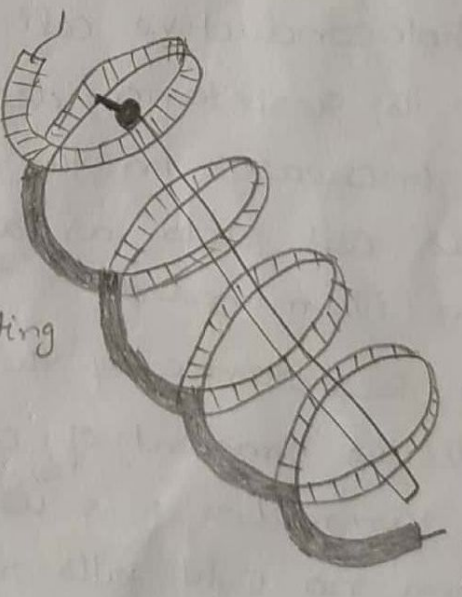
a) single turn :-

* It consist of a flat strip of insulating card made of flexible plastics or anodised aluminium.
* The resistance wire are made up of
  - Copper alloy → Low resistance pots
  - nicked chromium → High resistance pots,

is wound and then the strip is bent round.
* contact by means of a slider metal or beryllium copper, which is spring loaded
* Contact from the slider is made through a slip ring or by a coiled spring.
* The winding is usually of two or three linear resistance sections.
* singleturn pots → Range : 50Ω to 5MΩ
  Power Rating : 2 to 3 W.

uses :-
* used as Gain control element in an amplifier
* AS brightness and contrast control in TV receivers.





b) Multiturn wire wound :-

* Multiture or helical pots have up to 10 turns

* The resistance element is wound on a long strip and then formed into a helix
* The contact is of precision metal and has multiple "fingers". The groove between the helical turns of the element used to guide the contact.
* Because of its construction, the wire wound pot has appreciable stray inductance and capacitance.
* Multi turn pots :- Range :- 50Ω to 250kΩ.
Power Rating :- 5W.

uses:-
used in applications that require precise setting of resistance value.

OPTO ELECTRONIC DEVICES

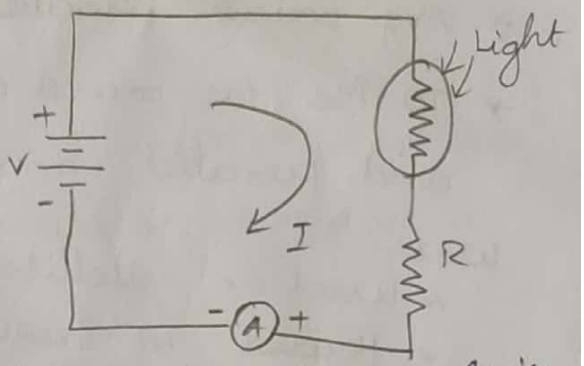
i) Photo conductive cell

* Photo conductive cell or Light Dependent Resistor (LDR)
* It is made of a thin layer of semiconductor material such as cadmium sulfide or lead sulfide.
* The semiconductor layer is enclosed in a sealed housing.
* A glass window in the housing permits light to fall on the active material of the cell.
* Photoconductive cell exhibits the peculiar property that its resistance decreases in the presence of light and increases in the absence of light.
* This cell acts as a conductor whose resistance changes when illuminated.
* The Resistance of the photoconductive cell, in series with R limits the amount of current in the circuit.
* The ammeter A is used to measure the current.
* When no light falls on the cell, its resistance is very high and current is low.

* The voltage drop V_0 across R is relatively low.
* When the cell is illuminated, its resistance becomes very low
* The current increases and voltage V_0 increases.

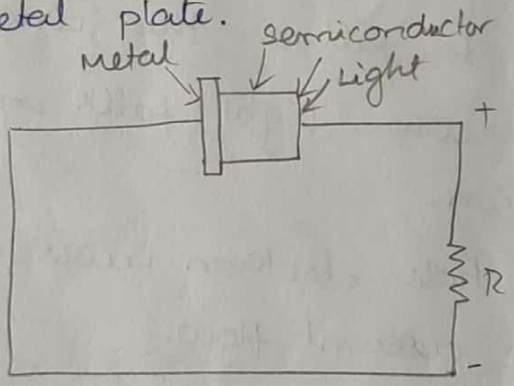
*Uses:-

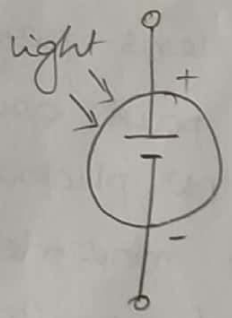
This simple ckt with slight modifications can be used in control circuits to control the current.



Photovoltaic cell:-

* Photovoltaic cell, is light-sensitive semiconductor device, produces a voltage when illuminated which may be used directly to supply small amount of electric power.
* The voltage rises as the intensity of light falling on the semiconductor junction of this cell rises.
* The cell consist of a piece of semiconductor material such as silicon, germanium or selenium which is bonded to a metal plate.





Solar cell:-

* When sun light is incident on a photovoltaic cell, it is converted into electric energy.
* Such a energy converter is called solar cell or solar battery.
* This cell consist of a single semiconductor crystal which has been doped with P and N type materials.
* When light falls on the PN junction, a voltage

appears across the junction.

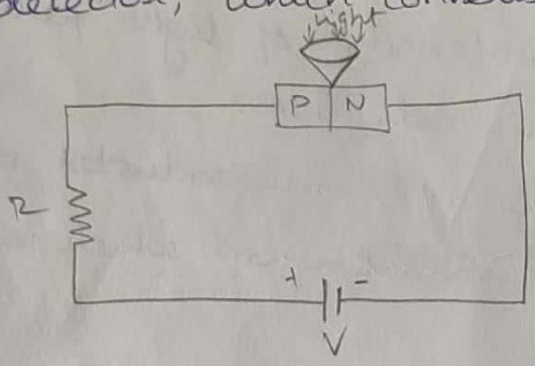
* About 0.6V is developed by the solar cell in bright sunlight.
* Avg power produced by a cell → 30 mW / sq m
* To use the power o/p, banks of cells are used in series and parallel combinations.

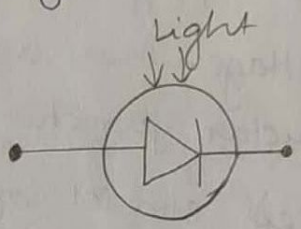
Uses:-

* used in satellites.
* Houses to harvest electrical power.

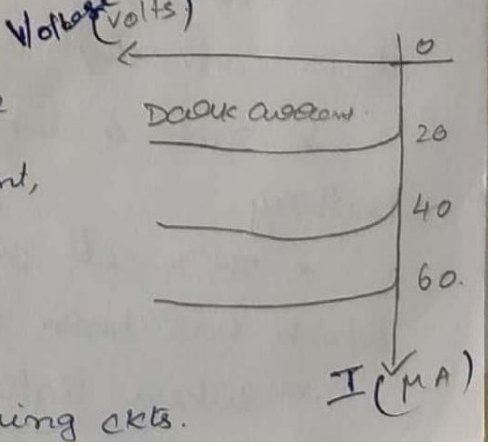
Photodiode :- (Photo detector):-

* Silicon photodiode is a light sensitive device, also called photodetector, which converts light signals to electrical signals





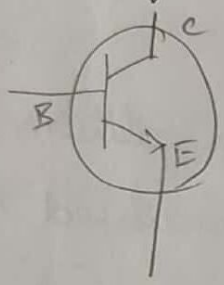
* The lens permits light to fall on the junction, hole-electron pair are created when light falls on reverse biased PN photodiode junction.
* The movement of these hole-electron pairs in a properly connected circuits results in current flow.
* $I \propto$ Intensity of light
* The reverse current increases in direct proportion to the level of illumination.
* Even when no light is applied, there is a minimum reverse leakage current, called dark current.

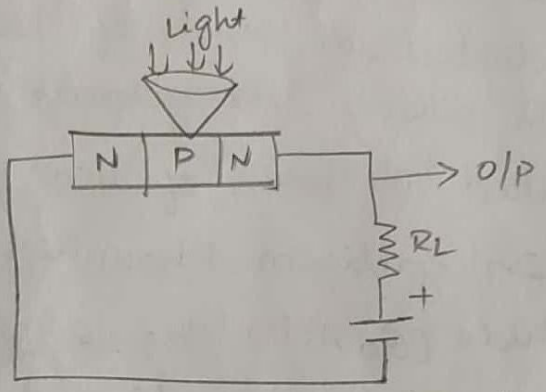


uses → light detectors
→ Demodulators and encoders.
→ optical communications and switching ckts.

Phototransistor :-

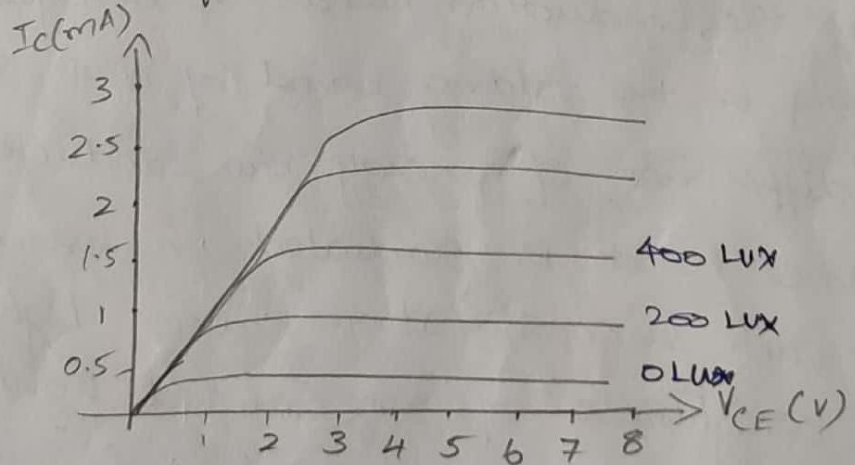
* The current produced by a photodiode is very low which cannot be directly used in control applications.
* Therefore this current should be amplified before applying to ctrl ckts.
* Photo transistor → photo diode + a transistor amplifier.
* When the phototransistor is illuminated, it permits a greater flow of current.





* A lens focusses the light on base - collector junction.
* Although the phototransistor has 3 sections, only 2 leads, emitter and collector leads are generally used.
* The phototransistor is dependent mainly on the intensity of light entering the lens and is less affected by the voltage applied to the external circuit.

Characteristics of phototransistor :-



Display Devices:-

i) Light Emiting Diode (LED):-

* LED → PN junction diode, which emits light when forward biased, → This phenomenon is called electroluminescence.

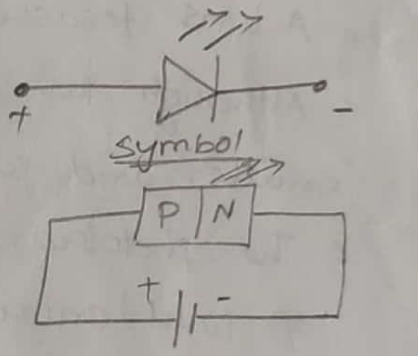
* In all semiconductor devices some amount of energy is radiated in form of heat

* In silicon and germanium, greater percentage of energy is emitted in form of heat.

* In gallium Phosphide (GaP) or gallium aerseride phosphide (GaAsP), the energy is radiated in form of light in visible spectrum.

Working:-

* When LED is forward biased, the electrons and holes move towards the junction and recombination takes place



Forward biased LED

* As a result of recombination, the electrons lying in the conduction bands of N-region fall into the holes lying in the valance band of a P-region.

* The difference of energy b/w conduction band and the valance band is radiated in form of light.

* Thus each recombination causes light emission.

* The brightness of the emitted light is directly proportional to the forward bias current.

Construction:-

* A N layer is grown on a substrate and P-type is deposited on it by diffusion.

* The carrier recombination takes place in P-layer and so it is kept uppermost.

* The metal anode connections are made at the outer edge of the P-layer it is kept ~~uppermost~~. so as to allow more central surface area for the light to escape.

* LED's are manufactured with domed lenses in order to reduce the reabsorption problem.

* A metal film is applied to the bottom of the substrate for reflecting as much light as possible.

* LED's are always encased to protect their delicate wires.

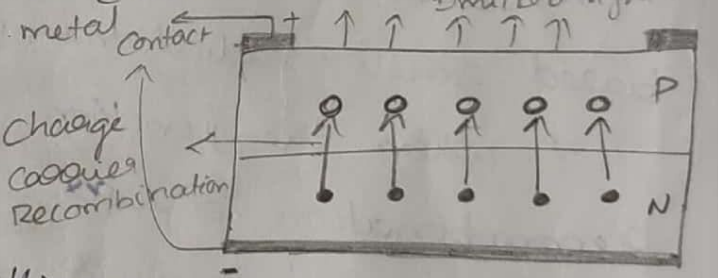
Colours of LED:-

Depending upon the material used, different colours of light are emitted.

i) Gallium arsenide (GaAs) - Infrared (Invisible)

ii) Gallium phosphide (GaP) - Red (or) Green.

iii) Gallium arsenide phosphide (GaAsP) - Red or yellow.



current & voltage req:-

operating voltage :-

1.5 to 3.3 V

current : Few tens of milliamps

Power : 10 to 150 mW.

Life time : 1,00,000 + hrs.

switch ON & off time of LED's : 1 ns. (so it is very fast)

To Protect LED it has to be connected along with a Resistor of 1 KΩ to 1.5 KΩ.

Applications:-

i) used in burglar alarm, Picture phones, multimeters, calculators, digital meters, microprocessors, digital computers, electronic telephone exchange, intercoms, ...

ii) Two-lead LED's are available, which contain 2 LED's which will change its colour from green to red when there is a reversal in biasing.

Injection Laser Diode (ILD):-

* when emitted light is coherent, then such a diode is referred to as ILD.

* ILD has less switch on time than LED.

* ∴ ILD are more suitable for wide-band and high data rate applications.

Disadvantage:- It has a strong temperature dependance.

Infra Red Emitters:-

* Gallium arsenide PN junction diodes, when forward biased emits radiations in Infra Red spectrum.

* when the junction is energised electron hole recombination occurs due to this recombination energy is emitted as infra red radiations.

* Infra red radiation wavelenght : 0.9 μm.

Applications:-

i) used in shaft encoders.

ii) Data-transmission systems.

iii) Intrusion alarm

iv) Card and paper tape readers.

Liquid Crystal Display (LCD):-

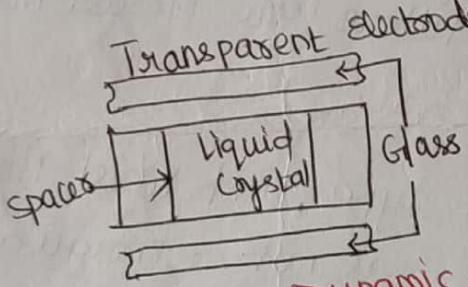
* used to display numeric & alphanumeric characters.
* 2 liquid crystal materials :- nematic (most common) NLC
  cholestoric

NLC:-

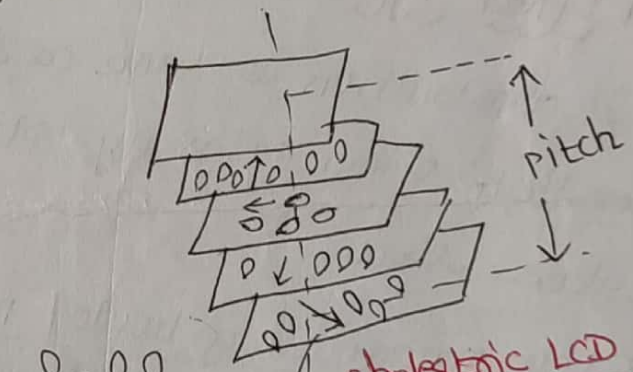
↳ All molecules align themselves approximately parallel to unique axis (director)

↳ liquid is normally transparent, but if it is subjected to strong electric disruption, the liquid may polarise & turn opaque.

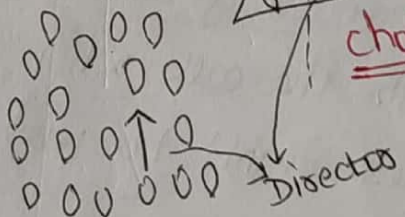
↳ Removal of applied electric field allows crystal to regain its original form & material becomes transparent.



Construction of Dynamic Scattering LCD



Cholestoric LCD



Nematic LCD

Construction of LCD:- Based on construction, there are 2 types of LCD.

(i) Dynamic Scattering Type:-

* Display has 2 glass plates coated with tin oxide (SnO_2) on inside with transparent electrodes.
* In b/w 2 glass plates, lies liquid crystal of 5 to 50 μm thick
* oxide coating is etched on front sheet to produce pattern of characters.

* weak electric field is applied to liquid crystal, which tends to align molecules in direction of field.

* when voltage exceeds, domain structure collapses, flow becomes turbulent & substance becomes inhomogeneous, & liquid crystal scatters light.

*when liquid is not activated, it is transparent. when liquid is activated with more electric field, light is scattered in all directions & cell appears bright. This is called as dynamic scattering.

(ii) Field Effect Type:-

* construction is same as dynamic scattering type, with exception that a thin polarising optical filters are placed inside each glass sheet.

* LCD material is of twisted nematic type, which twist the light passing through the cell. when latter is not energised.

* this allows light to pass through optical filters and cell appears bright.

Liquid crystal cell types

(i) Transmittive Type:-

Both glass sheets are transparent, so that light from real source is scattered in fwd direction when cell is activated

(ii) Reflective Type:-

It has reflective surface on one side of glass sheet. The incident light on front side of cell is dynamically scattered by an activated cell.

current & voltage levels:-

* LCD consume very small amount of energy.
* In 7-segment display, current drawn is 25μA for dynamic scattering cells & 300μA for field effect cells.
* LCD require a.c voltage supply.
* V/g level for scattering LCD's is 30V with 50Hz freq.

Advantages:-

* V/g required are small.
* Low power consumption.
* 7-segment display requires about 140W
  LED needs 40mW.
* Economical.

Disadvantages

* Very slow devices.
* ON & OFF times are quite large.
  ↓ few ms ↓ 10ms
* occupy large area.
* when used in d.c, life span is less.

X

Comparison b/w LED & LCD:-

LED	LCD
* Need more pwr (10-250mW) power/digit.	* Acts as capacitor & consumes less pwr. Needs 10-200μW.
* Due to high pwr requirement, it needs external circuitry to give pwr.	* pwr can be driven directly from IC chips.
* Good brightness level.	* Moderate brightness level.
* Temp range - 40 - 85°C.	* Temp range ⇒ -20 to 60°C
* Life time ⇒ 1,00,000 hrs	* Life time → 50,000 hrs
* Red, orange, yellow, green & white Colours	* Invisible in darkness.
* opr V/g - 1.5V to 5V dc	* opr V/g = 3 to 20 V a.c.
* Response time - 50 to 500 ns	* Response time - 50 to 200 ms
* Viewing angle - 150°.	* Viewing angle → 100°.

Optocouplers:-

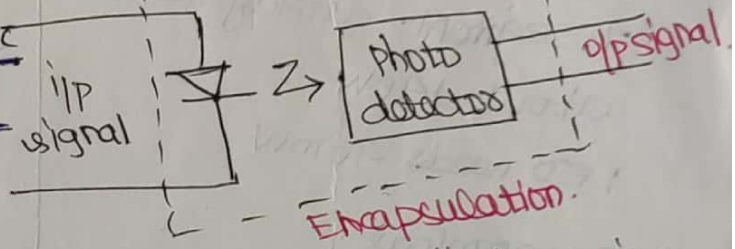
* solid state component which has light emitter, light path & light detector enclosed within & cannot be changed externally.

* As it provides electrical isolation → opto isolator

* Allows signal transfer without coupling wires, capacitors & transformers.

* couples digital (ON/OFF) or analog signals.

* Also called as optoelectronic isolator



↳ It has an infrared LED & photodetector like PIN photodiode, phototransistor Darlington pair

↳ optoisolators transduce i/p V/g to light using LED (GaAs).

↳ that light is transduced back to V/g using light sensitive devices.

↳ wavelength response of each device is made to be identical as possible.

↳ Transparent insulating cap b/w each material to permit passage of light. Very small response time & can txt in MHz range.

↳ Rigid structure allows one way transfer of electrical sgl from LED to photodetector.

Advantages

high isolation resistance of order of $10^{11}\Omega$ with isolation resistance of 2-500V.