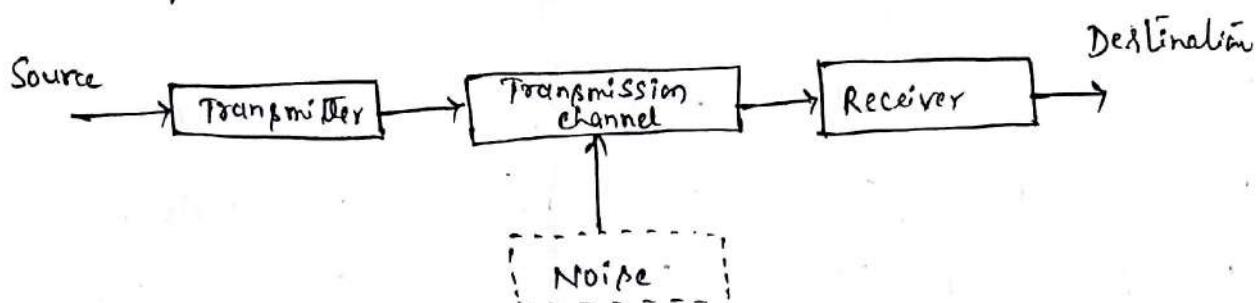


Communication SystemsIntroduction :-

The purpose of a communication system is to transmit information-bearing signals through a communication channel. The basic blocks of communication system are : 1) Transmitter 2) Channel and 3) Receiver

- The transmitter puts the information from the source onto the channel.
- The channel is the medium connecting the transmitter and the receiver and the transmitted information travels through this channel until it reaches the destination.
- The original message signals usually contain frequencies in the low frequency or audio frequency range



General Block Diagram for a communication system

- The transmission processes the input signal to produce a suitable transmitted signal suited to the characteristics of the transmission channel.
- Signal processing for transmission almost always involves modulation and may also include coding.
- The transmission channel is the medium that bridges the distance from source to destination. Ex:- Pair of wires, Coaxial Cable, Radio wave or laser beam.
- Every channel introduces some amount of transmission loss or attenuation, so the signal power progressively decreases with increasing distance.

- Simplex transmission : One-way
- Full-Duplex transmission (FDX) : Allows simultaneous transmission in both directions.
- Half-Duplex Transmission (HDX) : Allows transmission in either direction but not at the same time.

Frequency Band Allocation

Frequency	Range	Some of the uses
Very Low Frequency (VLF)	10 - 30 kHz	Telegony
Low frequency (LF)	30 - 300 kHz	Marine Navigation
Medium Frequency (MF)	300 - 3000 kHz	Broadcasting
High Frequency (HF)	3 - 30 MHz	Long Distance
Very High Frequency (VHF)	30 - 300 MHz	TV, Radar
Ultra High Frequency (UHF)	300 - 3000 MHz	Short Distance
Super High Frequency (SHF)	3 - 30 GHz	Satellite
Extra High Frequency (EHF)	30 - 300 GHz	Government

Radio :-

AM Broadcast

Medium wave (MW) 535 - 1605 kHz

Short wave (SW) 3 - 30 MHz

FM Broadcast 88 - 108 MHz

Television:-

VHF (Lower) Band I 47 - 68 MHz

VHF (Upper) Band II 174 - 230 MHz

VHF (Lower) Band III 470 - 598 MHz

VHF (Upper) Band IV 606 - 870 MHz

Satellite :-

UHF	300 MHz - 1 GHz
L Band	1 - 2 GHz
S-Band	2 - 4 GHz
C-Band	4 - 8 GHz
X-Band	8 - 12 GHz
Ku-Band	12 - 18 GHz
K-Band	18 - 27 GHz
Ka-Band	27 - 40 GHz

Modulation :-

- Defined as the process of Combining a low-frequency Signal with a very high frequency Carrier wave.
- Characteristic of the Carrier signal is varied in accordance with the amplitude of message signal.
- If the Carrier is a sinusoidal wave, then the process is termed as Continuous - wave modulation process.
- The message signal or the baseband signal is called the modulating signal.
- The resultant wave of the modulation process is known as the modulated signal.
- Modulation is performed at the transmitting end of the communication s/m.
- At the receiving end of the system, the Original signal is restored by a process known as demodulation, which is the reverse of the modulation process.

Need For Modulation :-

1. Modulation allows to reduce the size of antenna.
2. Allows several broadcasting stations to transmit simultaneously at different Carrier frequencies.

- It permits Multiplexing i.e. Several signals can be transmitted through the same channel without any mixing.
- Modulation reduces noise and interference effects.
- Modulation improves Signal-to-Noise Ratio.

Two Important modulation Schemes :- Amplitude Modulation and Frequency Modulation.

Amplitude Modulation :-

- In amplitude modulation, the amplitude of the carrier wave is varied in accordance with the instantaneous amplitude of message signal.

Let the modulating or message signal be

$$e_m(t) = E_m \sin \omega_m t \quad \rightarrow \textcircled{1}$$

$E_m \rightarrow$ peak value, $\omega_m \rightarrow$ Angular frequency of the modulating signal

Let the carrier signal be

$$e_c(t) = E_c \sin \omega_c t \quad \rightarrow \textcircled{2}$$

$E_c \rightarrow$ peak value, and $\omega_c \rightarrow$ Angular frequency of the carrier signal.

Then the resulting modulated wave is,

$$e_{am}(t) = (E_c + K_a e_m(t)) \sin \omega_c t \quad \rightarrow \textcircled{3}$$

where $K_a \rightarrow$ Proportionality Constant

Substituting $e_m(t)$ in $e_{am}(t)$ we get

$$e_{am}(t) = (E_c + K_a E_m \sin \omega_m t) \sin \omega_c t$$

$$= E_c \left(1 + \frac{K_a E_m}{E_c} \sin \omega_m t \right) \sin \omega_c t$$

$$= E_c (1 + m_a \sin \omega_m t) \sin \omega_c t \quad \rightarrow \textcircled{4}$$

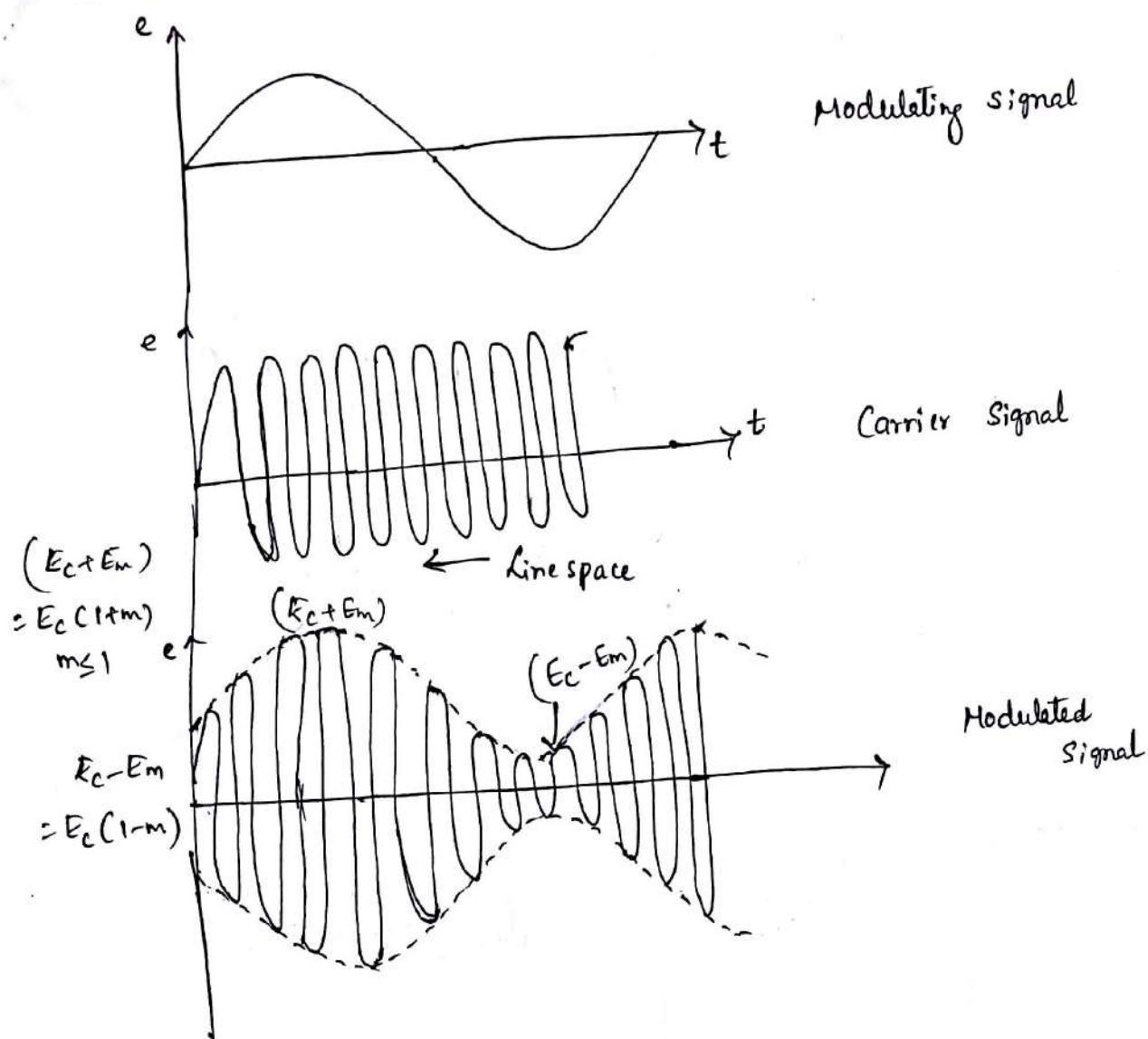
where,

$$m_a = \frac{K_a E_m}{E_c} \rightarrow \text{Modulation Index.} \rightarrow \textcircled{5}$$

{Determines the depth of Modulation}

Amplitude Modulation:

(3)



Frequency Spectrum of Am Wave

From eqn (4)

$$e_{am}(t) = E_c \sin \omega_c t + m a E_c \sin \omega_c t \sin \omega_m t$$

$$= E_c \sin \omega_c t + \frac{m a E_c}{2} [\cos(\omega_c t - \omega_m t) - \cos(\omega_c t + \omega_m t)]$$

$$\text{Since } \sin A \cdot \sin B = \frac{1}{2} (\cos(A-B) - \cos(A+B))$$

$$e_{am}(t) = E_c \sin \omega_c t + \frac{m a E_c}{2} \cos(\omega_c - \omega_m)t - \frac{m a E_c}{2} \cos(\omega_c + \omega_m)t$$

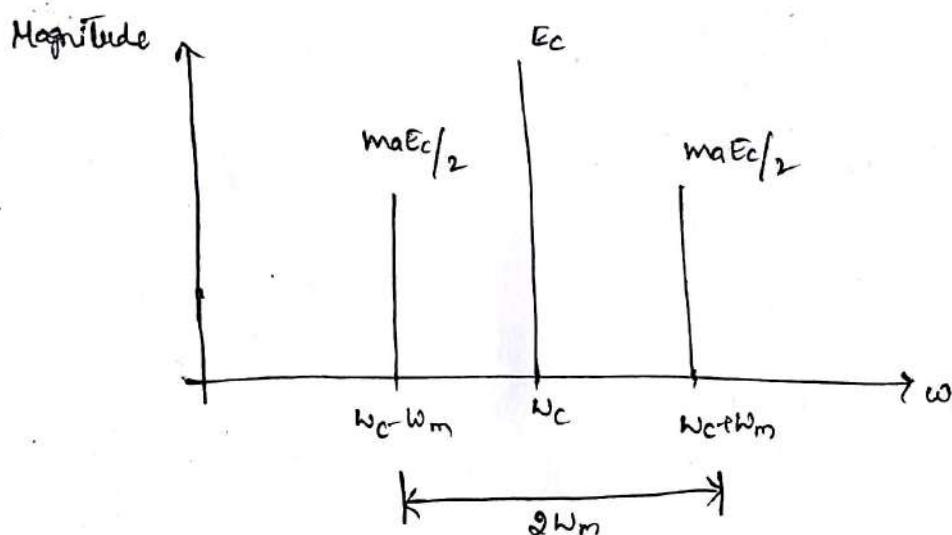
→ (6)

Eqn ⑥ shows that an amplitude modulated wave consists of three sinusoidal components & namely,

1. Carrier wave of angular frequency ω_c and amplitude E_c .
2. Lower side Band (LSB) of $\omega_c - \omega_m$ and amplitude $\frac{m_a E_c}{2}$
3. Upper side Band (USB) of $\omega_c + \omega_m$ and amplitude $\frac{m_a E_c}{2}$

→ A graph with frequency along x-axis and magnitude along Y-axis is called Magnitude spectrum.

The magnitude spectrum of AM signal is illustrated below.



The Bandwidth (BW) of AM wave is obtained as

$$\text{BW in rad/sec} = (\omega_c + \omega_m) - (\omega_c - \omega_m) = 2\omega_m \rightarrow ⑦$$

BW expressed in Hz is

$$\text{Bandwidth in Hz} = (f_c + f_m) - (f_c - f_m) = 2f_m \rightarrow ⑧$$

Where,

f_c = frequency of Carrier Wave in Hz

f_m = frequency of modulating wave in Hz.

From eqn(7) and eqn(8) it is proved that, the bandwidth of an AM wave is twice the frequency of modulating signal.

Spectrum power :-

The power of the AM signal is the sum of power of spectral components, i.e., Carrier and Sidebands.

i.e., Total power of AM signal = $P_c + P_{USB} + P_{LSB}$ → (9)

→ The rms power dissipated across a resistance is the ratio of the square of the rms voltage across the circuit to the resistance.

$$P = \frac{V^2}{R}$$

Assuming Unit Resistance (i.e., $R=1\Omega$), the power of Carrier is

$$P_c = \left(\frac{E_c}{\sqrt{2}}\right)^2 \rightarrow (10) \quad \left(\frac{E_c^2}{2}\right)$$

Similarly, power of LSB,

$$P_{LSB} = \left(\frac{m_a E_c}{2\sqrt{2}}\right)^2 = \left(\frac{m_a^2 E_c^2}{8}\right) \rightarrow (11)$$

and power of USB,

$$P_{USB} = \left(\frac{m_a E_c}{2\sqrt{2}}\right)^2 = \left(\frac{m_a^2 E_c^2}{8}\right) \rightarrow (12)$$

The total power of an AM wave is

$$\begin{aligned} P_t &= P_c + P_{LSB} + P_{USB} = \frac{E_c^2}{2} + \frac{m^2 E_c^2}{8} + \frac{m^2 E_c^2}{8} \\ &= \frac{E_c^2}{2} + \frac{m^2 E_c^2}{4} \\ &= \frac{E_c^2}{2} \left(1 + \frac{m^2}{2} \right) \\ P_t &= P_c \left(1 + \frac{m^2}{2} \right) \longrightarrow \textcircled{13} \end{aligned}$$

Example 1:-

A carrier wave represented by $e_c(t) = 20 \sin 6280t$ is modulated by a sinusoidal signal $e_m(t) = 1.2 \sin(314t + 90^\circ)$. What is the BW required for the transmission of the AM signal?

Solution:- Given that, $\omega_c = 2\pi f_c = 6280$ and $\omega_m = 2\pi f_m = 314$

$$f_c = \frac{6280}{2\pi} \quad \text{Therefore, } f_c = 1000 \text{ Hz}, \quad f_m = 50 \text{ Hz} \quad !$$
$$f_m = \frac{314}{2\pi}$$

from eqn ⑧ required BW of AM transmission

$$\therefore 2 \times f_m = 2 \times 50 = \underline{\underline{100 \text{ Hz}}}$$

Example 2:- An AM transmitter transmits a 80% modulated signal with a carrier power of 120W. Find the total transmitted power.

Solution:- Given that $m_a = 80\% = 0.8$, $P_c = 120 \text{ W}$

From eqn ⑬, $P_t = P_c \left(1 + \frac{m^2}{2} \right)$

$$\therefore P_t = 120 \left(1 + \frac{0.8^2}{2} \right) = \underline{\underline{158.4 \text{ W}}}$$

(5)

Example 3:- An AM transmitter transmits 100W power, with a depth of modulation of 70%. If carrier & lower side bands are transmitted, how much percentage of power is saved.

Solu:- Given That $P_t = 100\text{W}$, $M_a = 70\% = 0.7$

$$\text{W.R.T} \quad P_t = P_c \left(1 + \frac{m_a^2}{2} \right)$$

$$\therefore 100 = P_c \left(1 + \frac{0.7^2}{2} \right)$$

$$\therefore P_c = \frac{100}{1.245}$$

$$\therefore \text{carrier power} = \underline{\underline{P_c = 80.32\text{W}}}$$

$$\therefore \text{Saved upper side Band power, } P_{USB} = \frac{m_a^2 P_c}{4} = \frac{(0.7)^2 \times 80.32}{4}$$

$$P_{USB} = \frac{0.49 \times 80.32}{4}$$

$$= \underline{\underline{9.8392\text{W}}}$$

power required to transmit carrier and one sideband $= P_c + P_{LSB}$

$$= 80.32 + 9.8392$$

$$= \underline{\underline{90.15\text{W}}}$$

$$\% \text{ power saving} = \frac{\text{Power Saved}}{\text{Power Transmitted}} \times 100\%$$

$$= \frac{9.8392}{90.15} \times 100\%$$

$$= \underline{\underline{10.91\%}}$$

Frequency Modulation :-

→ Defined as the process by which the frequency of carrier wave is varied in accordance with the instantaneous amplitude of message signal.

Let the modulating (⑥) message signal be

$$e_m(t) = k_m \sin \omega_m t$$

and the carrier signal be

$$e_c(t) = k_c \sin \omega_c t$$

The instantaneous frequency of FM signal is given by

$$f = f_c (1 + k_f k_m \sin \omega_m t) \rightarrow ①$$

where, $k_f \rightarrow$ Proportionality Constant.

The instantaneous magnitude of FM signal is given by

$$e_{fm}(t) = A \sin \phi$$

$$\text{where } \phi = \int \omega dt = \int \omega_c (1 + k_f k_m \sin \omega_m t) dt$$

$$= \omega_c \int (1 + k_f k_m \sin \omega_m t) dt = \omega_c \left[\int 1 dt + \int k_f k_m \sin \omega_m t dt \right]$$

$$\omega_c \left[t + k_f k_m \left(-\frac{\cos \omega_m t}{\omega_m} \right) \right] = \omega_c t - \frac{k_f k_m \omega_c \cos \omega_m t}{\omega_m}$$

$$= \omega_c t - \frac{k_f k_m \omega_c}{\omega_m} \cos \omega_m t$$

$$= \omega_c t - m_f \cos \omega_m t$$

$$\text{where, } m_f, \text{ modulation index of FM} = \frac{k_f k_m \omega_c}{\omega_m} \rightarrow ②$$

∴ Frequency Modulated Wave

$$e_{fm}(t) = A \sin (\omega_c t - m_f \cos \omega_m t) \rightarrow ③$$

- (6)
- Since Eqn ③ is a Sine of Sine function, it can be expanded using Bessel function. The expression obtained by Bessel function contains infinite number of frequency terms. Therefore, ideally the BW of FM is infinity. Functionally the BW of FM is very high.
 - Very high frequency terms in the expression are neglected because they have low amplitudes.

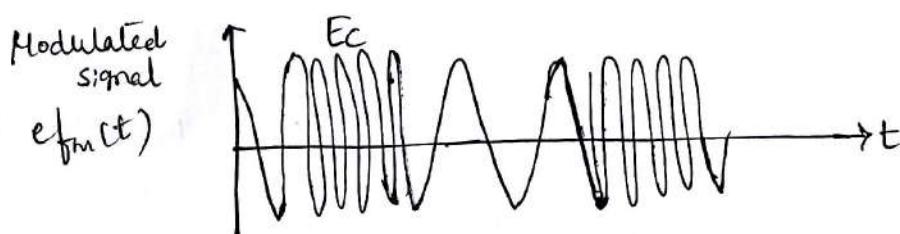
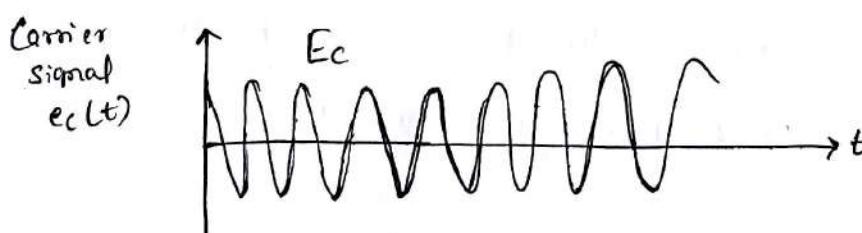
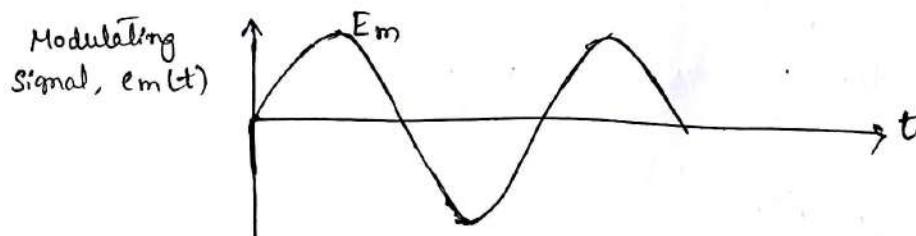
Frequency Deviation and Modulation Index

Eqn ② can be rewritten as,

$$\text{Modulation Index for FM, } m_f = \frac{K_f E_m f_c}{f_m} = \frac{\delta}{f_m} \rightarrow ④$$

where, $\delta = K_f E_m f_c$ is called frequency deviation.

Frequency Deviation is the variation of the frequency of the modulated signal from the frequency of the carrier signal.



Frequency Modulation waveforms

Comparison Between AM and FM :-

FM has several advantages compared to AM. They are

1. All transmitted power in FM is useful whereas in AM most of it is in carrier which does not carry any useful information.
2. FM is highly immune to noise due to the following reasons.
 - (a) Amplitude limiters are used in FM receivers which remove any amplitude variation occurred due to noise.
 - (b) FM is used in VHF and UHF range where noise is less. AM uses MF and HF range in which noise is more.
3. In FM, there is a guard band between adjacent channels so that co-channel interference is less.
4. In FM, only a fraction of a watt of audio power is required to produce 100% modulation while a larger power is required in AM.
5. The amplitude of FM wave remains constant which is independent of modulation index, whereas in AM it is dependent on modulation index.

Disadvantages of FM :-

1. FM requires much wider channel, i.e., FM contains infinite side bands and so bandwidth requirement is very high compared to AM.
2. In FM, complex and expensive transmitting and receiving equipment is required.
3. Since the reception is limited to line-of-sight, the area covered by FM is much smaller than AM.

Comparison of AM and FM

(7)

Amplitude Modulation

- 1) AM has smaller BW.
- 2) AM comparatively utilizes lower carrier frequency.
- 3) AM has less transmission efficiency.
- 4) AM has poor noise performance.
- 5) AM covers more area.

Frequency Modulation

- FM has larger BW.
- FM utilizes higher carrier frequency.
- FM has better transmission efficiency.
- FM has better noise performance.
- FM covers less area.

Phase Modulation :-

→ Phase modulation is a modulation scheme in which the phase angle of the carrier signal is varied in accordance with the instantaneous amplitude of the message signal.

Suppose, the modulating signal is

$$e_m(t) = E_m \sin \omega_m t$$

and Carrier Signal is

$$e_c(t) = E_c \sin \omega_c t$$

Then The phase-modulated signal is

$$e_{pm}(t) = E_c \sin(\omega_c t + K_p e_m(t))$$

where $K_p \rightarrow$ The proportionality constant, Also

$$e_{pm}(t) = E_c \sin(\omega_c t + K_p E_m \sin \omega_m t)$$

$$e_{pm}(t) = E_c \sin(\omega_c t + m_p \sin \omega_m t)$$

where, $m_p = K_p E_m$, the modulation index.

- Phase modulation can be considered as a special case of FM in which the carrier frequency modulation is given by the time derivative of the phase modulation.
- PM is used as an intermediate stage for generating FM. Many of the digital transmission coding schemes like WiFi and GSM use PM.

Summary of Modulation Schemes

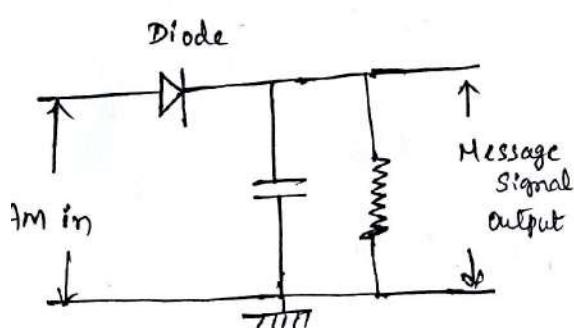
Modulating signal, $e_m(t) = E_m \sin \omega_m t$

Carrier signal, $e_c(t) = E_c \sin \omega_c t$

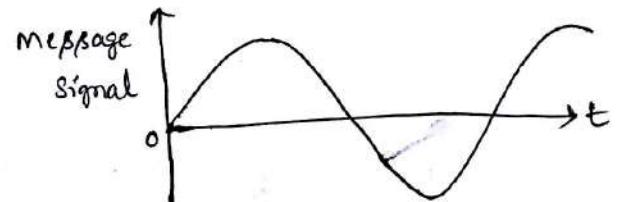
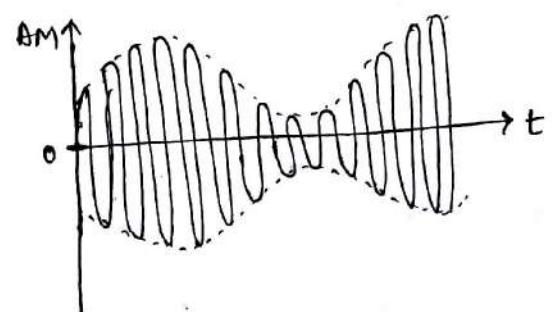
Scheme	Waveform	Modulation Index
AM	$e_{am}(t) = E_c (1 + m_a \sin \omega_m t) \sin \omega_c t$	$m_a = \frac{k_a E_m}{E_c}$
FM	$e_{fm}(t) = A \sin(\omega_c t - m_f \cos \omega_m t)$	$m_f = \frac{k_f E_m f_c}{f_m}$
PM	$e_{pm}(t) = E_c \sin(\omega_c t + m_p \sin \omega_m t)$	$m_p = k_p E_m$

AM Demodulator :-

- Demodulator recovers the message signal from the modulated signal.



AM detector



Input & Output Waveforms

- Diode rectifies the negative cycles of the AM input.
- At each positive peak of AM input, capacitor C charges to peak input voltage.
- Between the peaks capacitor discharges slightly through resistor R but recharges during the next peak.
- As a result, the envelope of the AM wave is obtained at the output of the detector. This circuit is also called Envelope detector.

Introduction :- A transducer is defined as a device that receives energy from one system and transports it to another, often in a different form.

There are two types of transducers.

- Electrical
- Mechanical

Electrical Transducer :-

An electrical transducer is a sensing device by which the physical mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage / current proportional to the input measurand.

An electrical transducer must have the following parameters.

1. Linearity :- The relationship between a physical parameter and the resulting electrical signal must be linear.
2. Sensitivity :- This is defined as the electrical output per unit change in the physical parameter. High sensitivity is generally desirable for a transducer.
3. Dynamic Range ; The operating range of the transducer should be wide to permit its use under a wide range of measurement conditions.
4. Repeatability :- The input/output relationship for a transducer should be predictable over a long period of time. This ensures reliability of operation.
5. physical size; The transducer must have minimal weight and volume, so that its presence in the measurement does not disturb the existing conditions.

✓ Advantages of Electrical Transducers :-

The main advantages of electrical transducers are as follows:

1. Electrical amplification and attenuation can be easily done.
2. Mass-inertia effects are minimized.
3. Effects of friction are minimized.
4. The output can be indicated and recorded remotely at a distance from the sensing medium.
5. The output can be modified to meet the requirements of the indicating & controlling units. The signal magnitude can be related in terms of the voltage current.
6. The signal can be conditioned & mixed to obtain any combination with outputs of similar transducers or control signals.
7. The electrical or electronic system can be controlled with a very small power level.
8. The electrical output can be easily used, transmitted and processed for the purpose of measurement.

Electrical transducers can be classified as

- * Active
- * passive.

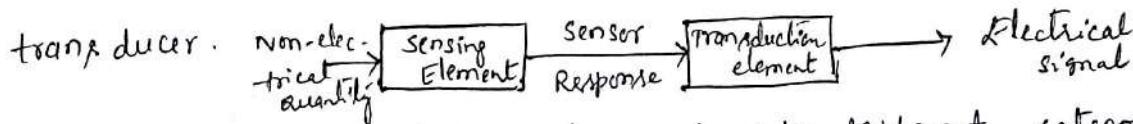
- An active transducer generates an electrical signal directly in response to the physical parameter and does not require an external power source for its operation.
- Active transducers are self generating devices, which operate under energy conversion principle and generate an equivalent output signal.

Examples of active Transducers:- piezo electric sensors (for generation of charge corresponding to pressure) and photo voltaic cells (for generation of Voltage in response to illumination).

✓ Passive transducers operate under energy controlling principles, which makes it necessary to use an external electrical source with them. They depend upon the change in an electrical parameter (R , L and C). (2)

Example :- Strain Gauges (for resistance change in response to pressure), and Thermistors (for resistance change corresponding to temperature variations).

- Electrical transducers are used mostly to measure non-electrical quantities. For this purpose a detector (2) sensing element is used, which converts the physical quantity into a displacement.
- This displacement acts as an electric transducer, which acts as a secondary transducer & give an output that is electrical in nature.
- A transducer which converts a non-electrical quantity into an analog electrical signal may be considered as consisting of two parts., the sensing element and the transduction element.
- The sensing (2) detector element is that part of a transducer which responds to a physical phenomenon (2) to a change in a physical phenomenon.
- ✓ The transduction element transforms the output of a sensing element to an electrical output. This, in a way, acts as a secondary transducer.



Transducers may be further classified into different categories depending upon the principle employed by their transduction elements, to convert physical phenomena into output electrical signals.

- Resistive
- Inductive
- capacitive
- Electro-magnetic
- piezo-electric
- photo-emissive
- photo-resistive
- Potentiometric
- Thermo-electric
- Frequency Generating.

Selecting a Transducer :-

The transducer or sensor has to be physically compatible with its intended application. The following should be considered while selecting a transducer.

1. operating Range : chosen to maintain range requirements and good resolution.
2. Sensitivity : chosen to allow sufficient output.
3. Frequency response and resonant frequency : flat over the entire desired range.
4. Environmental Compatibility : Temperature range, corrosive fluids, pressure, shocks, vibration, size and mounting restrictions.
5. Minimum sensitivity :- To expected stimulus, other than the measurand.
6. Accuracy :- Repeatability and calibration errors as well as errors expected due to sensitivity to other ~~standard~~ stimuli.
7. Usage and ruggedness :- Ruggedness, both of mechanical and electrical intensities versus size and weight.
8. Electrical parameters :- Length and type of cable required, signal to noise ratio when combined with amplifiers and frequency response limitations.

Resistive Transducer :-

The resistance of a metal conductor is given by -

$$R = \frac{SL}{A}$$

$\rho \rightarrow$ Resistivity of the conductor ($\Omega \cdot m$)

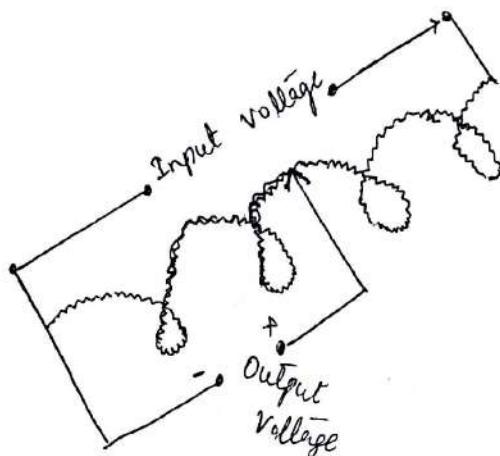
$L \rightarrow$ Length of the conductor (m)

$A \rightarrow$ Area of cross section of conductor (m^2)

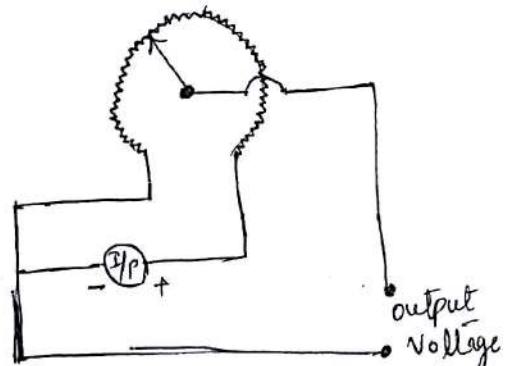
- Resistive transducers are those in which the resistance changes due to a change in some physical phenomenon.
- The change in the value of the resistance with a change θ in the length of the conductor can be used to measure displacement.
- Strain gauges work on the principle that the resistance of a conductor or semiconductor changes when strained. This can be used for the measurement of displacement, force and pressure.
- The resistivity of materials changes with changes in temperature. This property can be used for the measurement of temperature.

Potentiometer :-

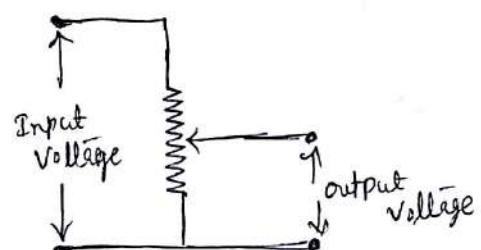
- A resistive potentiometer (POT) consists of a resistance element provided with a sliding contact called a wiper. The motion of the sliding contact may be translatory or rotational.
- Some have a combination of both, with resistive element in the form of a helix as shown in fig.(a), they are known as helipots.



(fig)a; Helipots



Fig(b): Rotational Type



Fig(c); Translatory Type.

- Translatory resistive elements, as shown in fig (a), are linear (straight) devices.
- Rotational resistive devices are circular and are used for the measurement of angular displacement as shown in fig (b).
- Helical resistive elements are multi-turn rotational devices which can be used for the measurement of either translatory or rotational movement.
- A potentiometer is a passive transducer since it requires an external power source for its operation.

Advantage of Potentiometers

- They are inexpensive.
- Simple to operate and are very useful for applications where the requirements are not particularly severe.
- They are useful for the measurement of large amplitudes of displacement.
- Electrical efficiency is very high, and they provide sufficient output to allow control operations.

Disadvantages:-

- When using a linear potentiometer, a large force is required to move the sliding contacts.
- The sliding contacts can wear out, become misaligned and generate noise.

Resistance pressure Transducer :-

- Resistance pressure transducer is based on the principle that due to the change in pressure, the resistance of the sensing element changes. Then this resistance change is sensed by using the sensing element in the Wheatstone's bridge circuit.

→ If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both the length & diameter of the conductor changes, so the resistivity of conductor changes. This effect is commonly called piezoresistive effect. Hence a resistive strain gauge is alternatively called piezoresistive gauge.

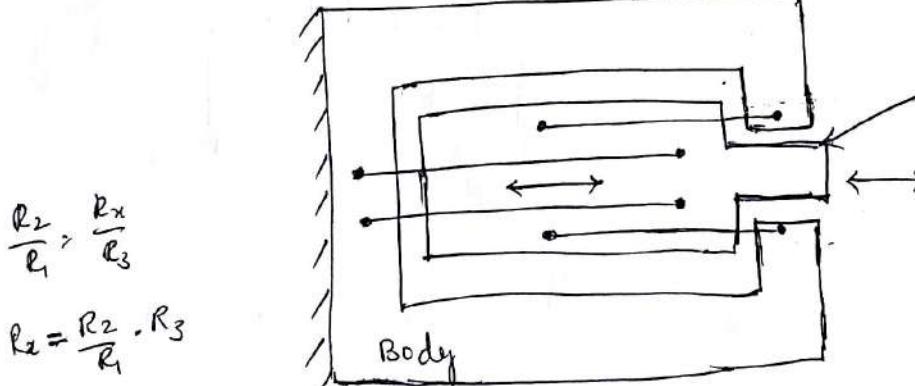
Resistance Wire Gauge

Resistance wire gauges are used in two basic forms, the unbonded type and the bonded type.

Unbonded Resistance Wire Strain Gauge

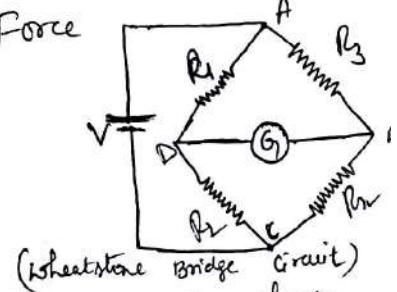
- An unbonded strain gauge consists of a wire stretched between two points in an insulating medium, such as air. The diameter of the wire used is about 25 μm.
- The wires are kept under tension so that there is no sag and no free vibration. Unbonded strain gauges are usually connected in a bridge circuit. The bridge is balanced with no load applied as shown in the diagram.

stationary or Fixed Beam



Main platform
(movable Arm)

Force



- When an external load is applied, the resistance of the strain gauge changes, causing an unbalance of the bridge circuit resulting in an output voltage.

- This voltage is proportional to the strain. A displacement of the beam of 50 μm can be detected with these strain gauges.

Bonded Resistance Wire Strain Gauges

- In bonded resistance wire strain gauge resistive element is cemented to the base which may be a thin sheet of paper, a thin sheet of bakelite or a sheet of teflon.
- The wire is covered on the top with a ^{thin} material, so that it is not damaged mechanically. The spreading of the wire permits uniform distribution of stress.
- The carrier is then bonded or cemented to the member being studied. This permits a good transfer of strain from carrier to wire.

In metallic bonded strain gauge a fine wire element about 25 μ m or less in diameter is looped back and forth on a base \oplus mounting plate. The base is cemented to the member subjected to stress. The grid of fine wire is cemented on a carrier which may be a thin sheet of paper or ~~bakelite~~ bakelite \oplus teflon.

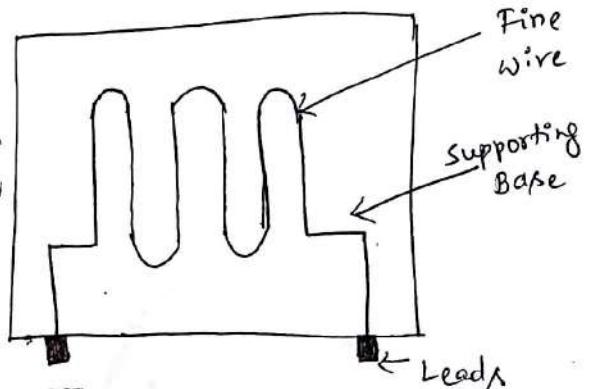
A tensile stress tends to elongate the wire & thereby increase direction of its length and decrease its cross strain. The combined effect is an increase in resistance, as seen from the following equation

$$R = \frac{\rho \times l}{A}$$

ρ = The specific resistance of the material in Ωm

l = the length of the conductor in m

A = The Area of the conductor in m^2



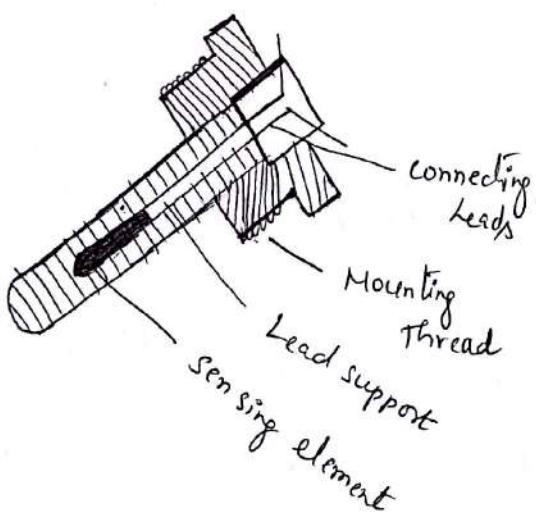
As a result of strain, two physical parameters are of particular interest.

1. The change in gauge resistance.
2. The change in length.

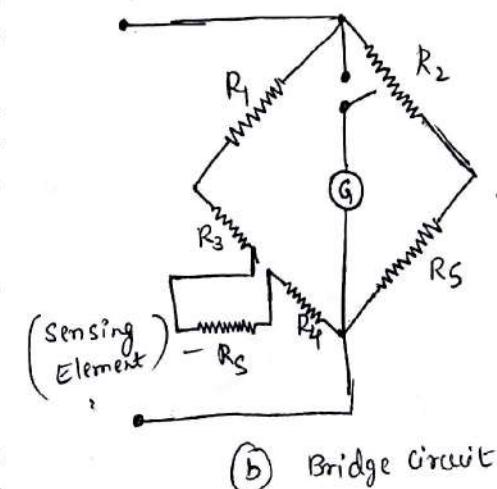
Resistance Thermometer:

(5)

- The resistance thermometer is an instrument used to measure electrical resistance in terms of Temperature, i.e., it uses the change in the electrical resistance of the conductor to determine the temperature.
- The main part of a resistance thermometer is its sensing element. The characteristic of the sensing element determines the sensitivity and operating temperature range of the instrument.
- The sensing element may be any material that exhibits a relatively large resistance change with change in temperature. Also, the material used should be stable for its characteristics.
- To maintain the calibration of a resistance thermometer, it is necessary to consider its stability.
- Another desirable characteristic for a sensing element ~~is~~ is a linear change in resistance with change in temperature.
- The smaller a given sensing element, the less heat required to raise its temperature & the faster its response.
- platinum, nickel and copper are the metals most commonly used to measure temperature. The resistivity of platinum tends to increase less rapidly at higher temperatures than for other metals, hence it is a commonly used material for resistance thermometers.



(a) Industrial platinum Resistance Thermometer



(b) Bridge circuit

Soln:- The gauge factor is given by.

(12)

(Q) $S = \frac{\Delta R/R}{\Delta l/l} = \frac{0.003/100}{\Delta l/10 \times 10^{-2}} = 1$

$\therefore \text{change in length} = \Delta l = \frac{0.001 \times 10^2 \times 10}{100} = 1 \times 10^{-6} \text{ m} = \underline{\underline{1 \mu\text{m}}}$

- (3) A resistance wire strain gauge uses a soft iron of small diameter. The gauge factor is +4. Calculate the poisson's ratio, neglecting piezo-resistive effects.

Soln:- In general, a gauge factor of a resistance wire strain gauge is given by,

$$G = 1 + 2\mu + \frac{\partial S/\delta}{\Delta l/l} \quad \text{where } \mu \text{ is poisson's ratio}$$

As piezo resistive effects to be neglected, we can write

K@ $G = 1 + 2\mu$.

$$\mu = \frac{G-1}{2} = \frac{4-1}{2} = \underline{\underline{1.5}}$$

- (4) A resistance wire strain gauge with a gauge factor of 2 is bonded to a steel structural member subjected to a stress of 200 MN/m². modulus of elasticity of steel is 400 GN/m². calculate the percentage change in the value of gauge resistance due to the applied stress.

Soln:- Young's Modulus = $\frac{\text{Stress}}{\text{Strain}}$

$$\therefore \text{Strain} = \frac{\text{Stress}}{\text{Young's Modulus}} = \frac{\Delta l}{l} = \frac{200 \times 10^6}{400 \times 10^9} = 0.5 \times 10^{-3}$$

Gauge factor is given by, $K = \frac{\Delta R/R}{\Delta l/l} \Rightarrow \frac{\Delta R}{R} = K \left(\frac{\Delta l}{l} \right)$

$$\therefore \frac{\Delta R}{R} = K \cdot (\text{Strain}) = (2)(0.5 \times 10^{-3}) = 10^{-3} \text{ i.e. } \underline{\underline{0.1\%}}$$

Advantages of Resistance Thermometers

(6)

The measurement of Temperature by the electrical resistance method has the following advantages and characteristics.

1. The measurement is very accurate.
2. It has a lot of flexibility with regard to choice of measuring equipment.
3. Indicators, recorders or controllers can also be operated.
4. More than one resistance element can be clubbed to the same indicating/recording instrument.
5. The temperature sensitive resistance element can be easily installed and replaced.
6. Extremely accurate temperature sensing.
7. No necessity of Temperature compensation.
8. Stability of performance over long period of time.
9. They are best suited for remote indication.
10. Resistive element can be used to measure differential temperature.

Limitations of Resistance Thermometer

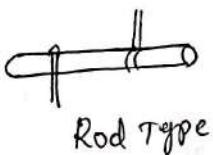
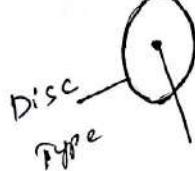
1. High cost
2. Need for bridge circuit and power source.
3. Possibility of self-heating
4. Large bulb size, compared to a thermocouple.

Thermistor ✓ : The resistors depending on temperature are thermal resistors.

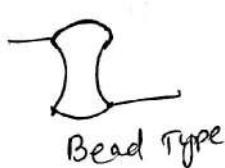
- Resistance thermometers are also thermistors having positive temperature coefficients. But the resistors having negative temperature coefficients (NTC) are called thermistors.
- ~~the resistance~~ of a thermistor decreases as temperature increases, the NTC of thermistors can be as large as few percent degree Celsius change in temperature.
- Thus the thermistors are very sensitive and can detect very small changes in temperature too.

Construction :-

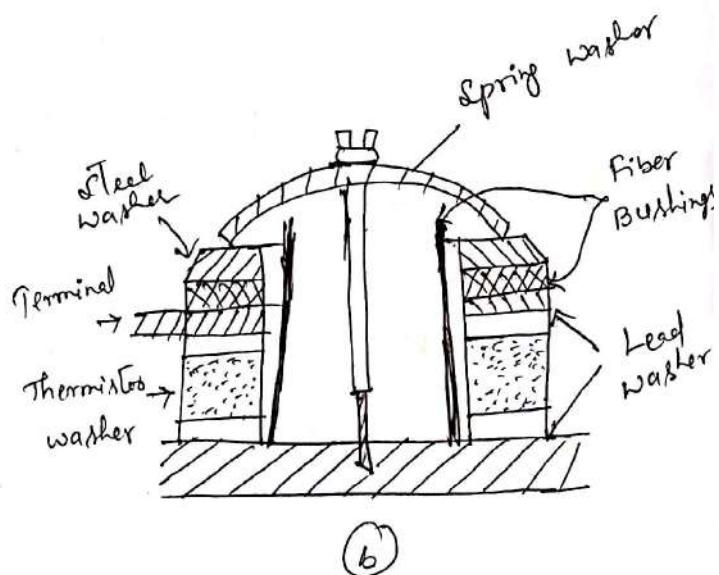
- Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron & uranium.
- Their resistances at ambient temperature may range from 10Ω to 100kΩ.
- Thermistors are available in a wide variety of shapes & sizes as shown in figure.



Washer Type



(a)



(b) Various Configurations of Thermistor

(c) Bush-Type Thermistor

Advantages of Thermistor

1. Small size and low cost.
2. Fast response over narrow temperature range.
3. Good sensitivity in the NTC region.
4. Cold junction compensation not required due to dependence of resistance on absolute temperature.
5. Contact and lead resistance problems not encountered due to large R_{th} (Resistance).

Limitations of Thermistor

1. Non linearity in resistance vs Temperature characteristics.
2. Unsuitable for wide temperature range.
3. Very low excitation current to avoid self heating.
4. Need of shielded power lines, filters, etc due to high resistance.

The mathematical relationship according to which the resistance of thermistor behaves w.r.t. temperature is given by,

$$R_{T_1} = R_{T_2} e^{\left[\beta \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right]}$$

Example :- A thermistor has a characteristic temperature β of 3000K. If its resistance is 100k Ω at 300K, what will be its resistance at 600K?

Solution :- Given, $T_0 = 300K$ $T = 600K$
 $R_0 = 100k\Omega$ $\beta = 3000K$

$$\therefore R_T = R_0 e^{\left[\beta \left(\frac{1}{T_1} - \frac{1}{T_2} \right) \right]} = 100 \times 10^3 e^{3000 \left(\frac{1}{600} - \frac{1}{300} \right)} = 100 \times 10^3 \cdot e^{-5}$$

$$= 673.4945 \Omega$$

Inductive transducers using self inductance as a variable use one coil, while those using mutual inductance as a variable use multiple coils. (8)

The transducers can be designed to provide two outputs, one of which represents inductance and the other, the decrease in inductance. The succeeding stages of the instrumentation system measure the difference b/w these outputs. This is known as differential output.

Advantages of differential output:

1.

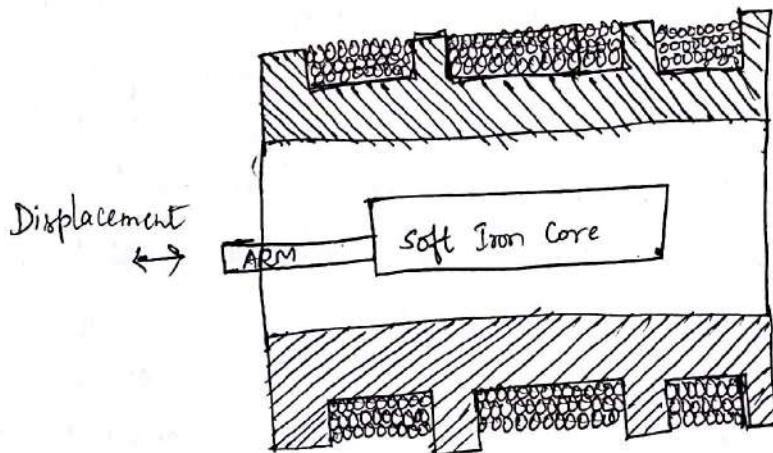
2.

3.

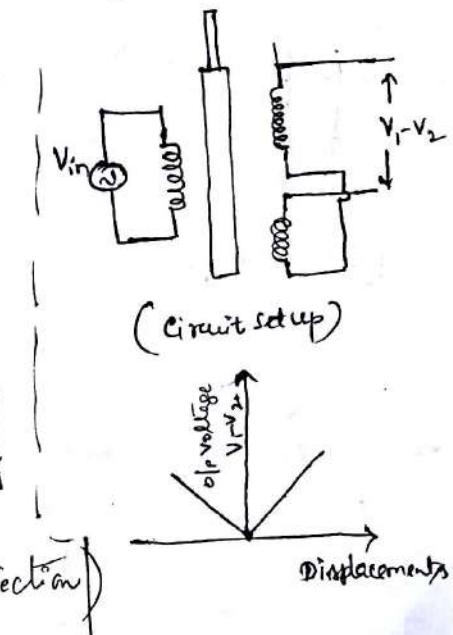
4.

Linear Variable Differential Transducer (LVDT)

The differential transducer transformer is a passive inductive transformer. It is also known as a Linear Variable Differential transformer. (LVDT). (Accurate device for measuring linear displacements)



Construction of LVDT (Cross Section)



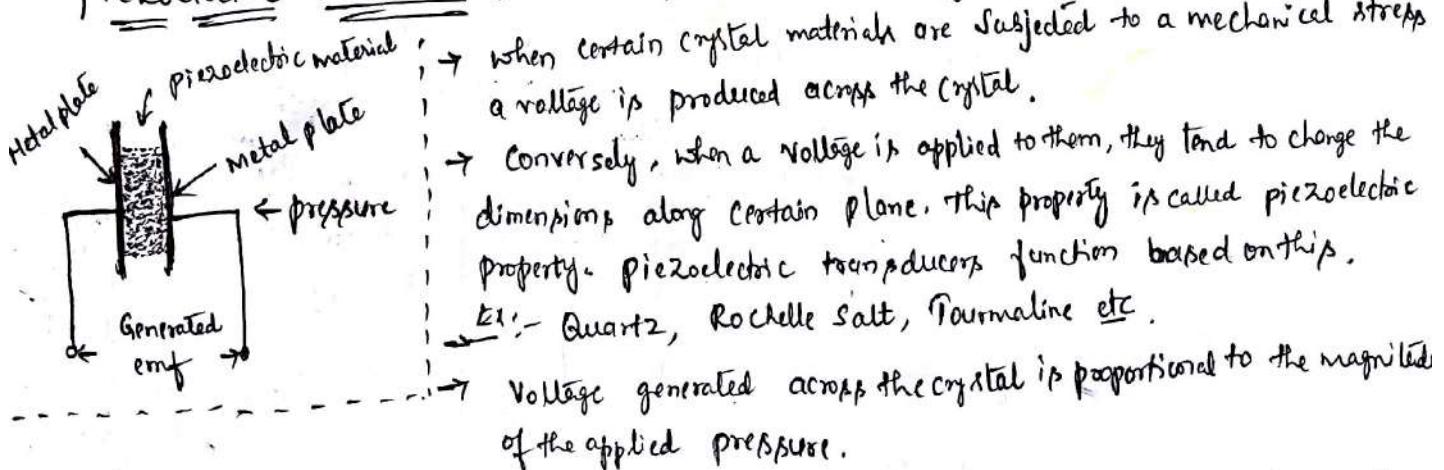
- LVDT consists of a single primary winding & 2 secondary windings.
- The secondary windings have an equal number of turns & placed on either side of the primary winding.
- A movable soft iron core called armature slides within the hollow former & therefore affects the magnetic coupling between the primary & two secondary coils.
- The displacement to be measured is applied to an arm attached to the soft iron core.
- Arm is ~~not~~ connected to the object being measured. It moves up or down inside the tube.
- Secondary windings are connected in series but opposite to generate differential output voltage.
- When the core is in its normal position, equal voltages are induced in the secondary windings.
- If the armature is at the centre of the windings, the induced emf in the two secondary windings will get cancelled each other as they are equal and opposite. resulting Output Voltage Zero.
- As the core is moved slightly to one direction, the induced voltage in one of the secondaries will become greater than in the other. The output voltage changes from maximum to zero and back to maximum again but in the process its phase angle changes by 180° . This enables the LVDT to produce an AC signal whose magnitude represents the amount of movement from the center position & whose phase angle represents the direction of the core.

REVIEW QUESTIONS

✓ Active Electrical Transducers

An active transducer generates an electrical signal directly in response to the physical parameters & does not require an external power source for its operation.

Piezoelectric Transducer: Converts Mechanical energy into electric energy.



- The piezoelectric material is kept between two metal plates. The generated emf according to the pressure variations is picked up using metal wires connected to the metal plates.
- Used to measure, force, pressure, acceleration, torque, strain etc.
- Applications are microphone, vibration sensor ~~and~~ in rockets.

the region and increasing reverse current level.

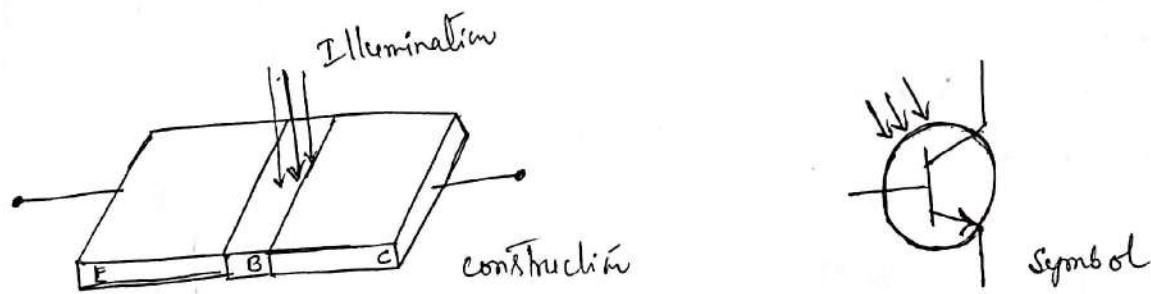
(9)

The photo-transistor :-

= the photo-transistor has a light sensitive collector to base junction.

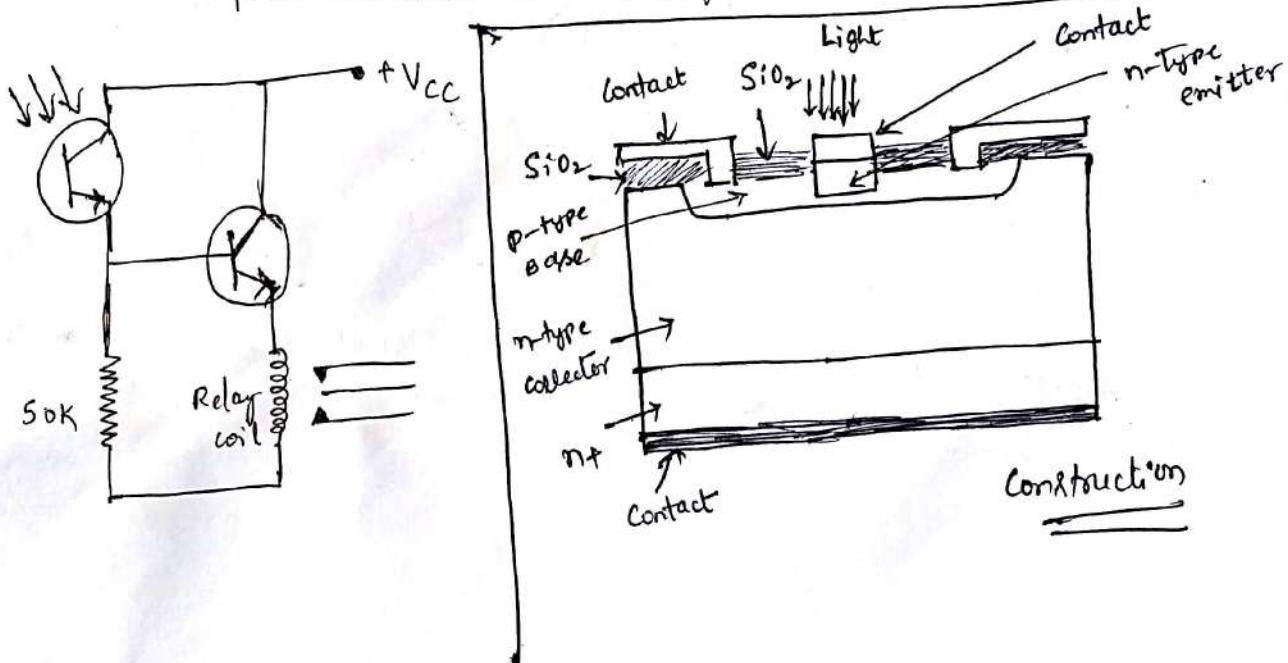
→ A lens is used in a transistor package to expose base to an incident light. When no light is incident, a small leakage current flows from collector to emitter called I_{CEO} . due to small thermal generation. This is very small current, of the order of μA . This is called a dark current.

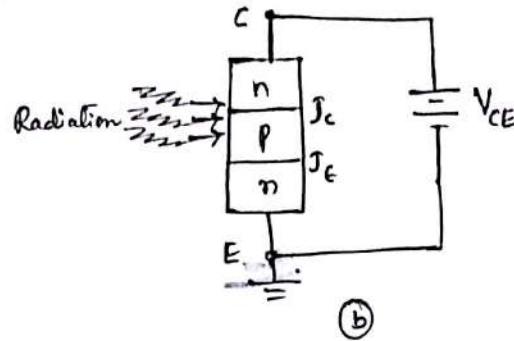
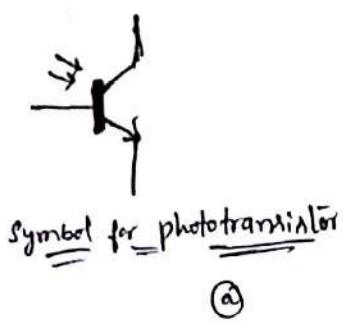
→ When the base is exposed to the light, the base current is produced which is proportional to the light intensity.



Application :-

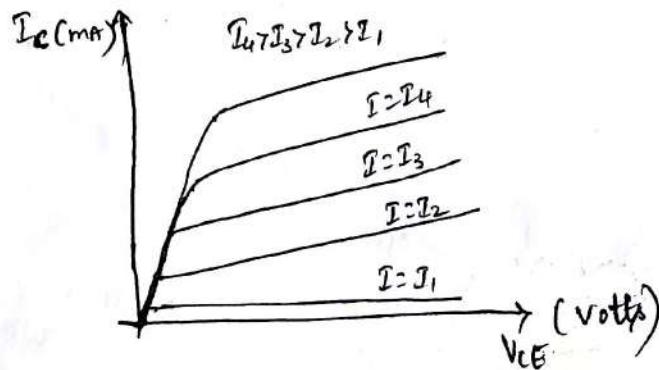
photo-transistor and Relay circuit





Light incident
on collector
Junction.

- The phototransistor is usually connected in CE configuration with the base open and light radiation is concentrated on the region near the collector junction J_c as shown in fig(b).
- The transistor is biased in active region as the emitter junction J_e is slightly forward biased & collector junction J_c is reverse biased.
- When the collector junction J_c is not illuminated, the current flow inside the transistor is only due to the thermally generated minority carriers.
- When the junction is illuminated, additional minority carriers are generated by the photons & these contribute to the reverse current in the same manner as done by the thermally generated minority carriers.



Applications of phototransistor

- Light controlled relay
- Used in optical communication systems at the receiver end to detect the information carried by light.

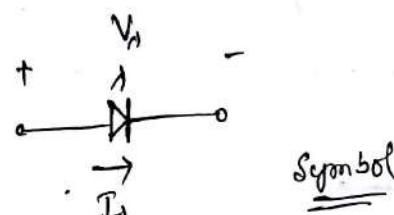
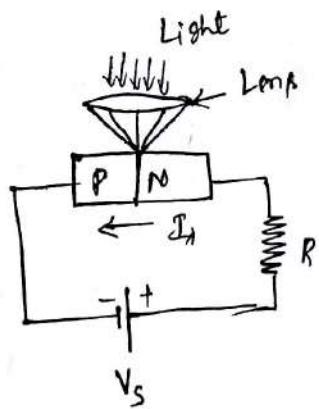
Photoelectric Transducers

(18)

- Converts light energy into electric energy.
- When light energy interacts with an electron, the entire light energy is converted into kinetic energy of electrons resulting current in the material. This phenomenon is known as photoelectric effect.
- Light Sensors are used to measure light intensity. Light Sensors are more commonly known as photoelectric devices or photosensors.

photodiodes :-

- Two terminal p-n junction device which operates in the reverse bias region.
- Works on the principle of absorption of light.
- photodiode has a small transparent window which allows light to strike the p-n junction.



- In photodiode, reverse current increases with the light intensity at the p-n junction.
- If there is no incident light, the reverse current is almost negligible and is called the dark current.
- When the photodiode is illuminated with light (photons) having energy ($h\nu$) greater than the bandgap energy (E_g) of the semiconductor, electron-hole pairs are generated due to the absorption of photons.
- The diode is fabricated such that the generation of electron-hole pairs takes place in or near the depletion region. More number of minority carriers will be pulled through the junction.

→ When an external load is connected, current flows. The magnitude of this current is proportional to incident light intensity.

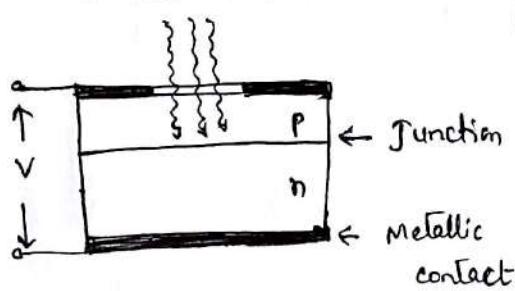
Applications :-

- Light detectors
- Switching
- Demodulation
- Optical Communication.

Solar cell :-

- Solar cell or photovoltaic cell is a p-n junction device which produces electric current from solar radiation.
- It works on the principle of photodiode, except that no external bias is applied and the junction area is kept much larger for solar radiation to be incident.

Incident Sunlight



Construction

Symbol :-



→ It is constructed in the form of an n-type silicon wafer with a very thin layer of p-material on its surface.

→ Silicon is the semiconductor material most commonly used for the construction of solar cell

→ Solar radiation penetrates the thin p-layer to the p-n junction and photons collide with valence electrons generating free electron-hole pairs. This results in increase in minority carrier flow, which is opposite in direction to the conventional forward current of a p-n junction.

increased minority carrier flow, which is opposite in direction to the conventional forward current of a p-n junction.

Applications :-

- Street lights, calculators, watches etc.
- Solar energy is utilized in solar cookers, solar lights, water heaters, power storage etc.