MODULE 5

COMMUNICATION SYSTEMS

Communication Systems (Text-2) 6 Hr: Introduction, Elements of Communication Systems, Modulation: Amplitude Modulation, Spectrum Power, AM Detection (Demodulation), Frequency and Phase Modulation. Amplitude and Frequency Modulation: A comparison.

INTRODUCTION

Definition: "Communication refers to the transmission of information from one point to other point in terms of electric signals and also it involves storing, sending, receiving and processing of information by electric means."

Communication includes radio telephony and telegraphy, broadcasting, point to point and mobile communication, computer communication, radio telemetry, fax Machine and Satellite television etc.

A BRIEF HISTORY OR EVOLUTION OF COMMUNICATION SYSTEM

The various means by which the mankind communicated with each other can be listed as follows

- The simplest communication recorded since the days of Greeks from one point to other point over a distance is through fire and smoke signals.
- Carrier pigeons were also adopted for communication purposes.
- A very common mode of communication is "telephone".
- Nowadays satellite and fiber optics have made communication more sophisticated.

ELEMENTS OF COMMUNICATION SYSTEMS/ BLOCK DIAGRAM OF COMMUNICATION SYSTEMS

The communication system involves some basic signal processing operations in the transmission of information, irrespective of the mode and nature of transmission. The block diagram for the communication system is shown below in Fig.1.1.

The essential blocks of the communication system is

- Information Source
- Input Transducer
- Transmitter/Modulators.
- Transmission/Communication channel and Noise.
- Receiver/Demodulator.
- Output Transducers
- Destination

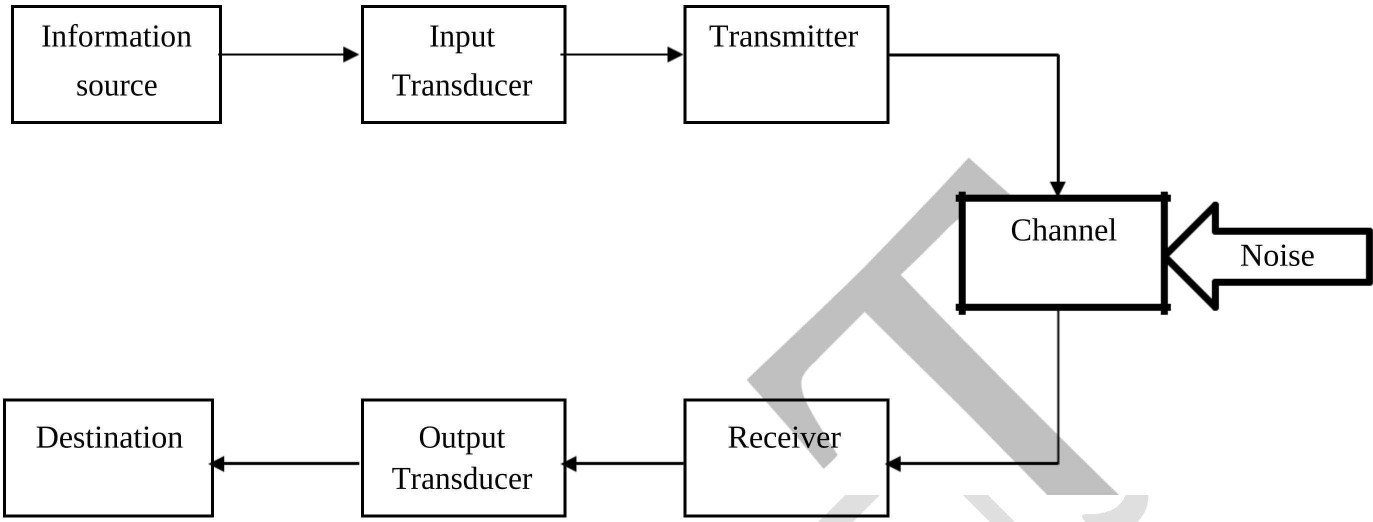


Fig.1.1: Communication system

- Information source:

  The main aim of a communication system is to convey message called information. This message originates from information source. Generally, the source of communication system is an audio signal.

- Input transducer:

  The communication system is designed to transmit only the electrical signals.

  Therefore input transducer is the device that converts audio signals into electrical signals, so that the signals can be transmitted over the communication system.

  Generally, a transducer is a device that converts any physical parameter such as temperature, pressure, floe rate etc.. into an electrical signal like voltage or current and vice versa.

  Thus, the input transducer can be defined as device that converts audio signals into electrical signals. Ex: Microphone.

- Transmitter:

  The output of the transducer is an electrical signal which is called a message signal, which is given as input to the transmitter.

  Transmitter processes the input message signal to make it suitable for sending it over the channel. The transmitter is an electronic part that performs

  - A process called modulation on the message signal to be transmitted. The modulation is a process of altering the characteristics of a high frequency signal called carrier signal in accordance with the message signal.
  - Amplifies the modulated signal.

- Communication channel:

  It is the physical medium or path through which modulated signal is transmitted.

  The term "channel" is often used to refer the frequency range allocated to a particular service.

  Each channel has its own frequency and different applications have different operating frequencies. The channel can be wired link, microwave link or satellite link.

  In the process of transmission of the modulated signal through the channel, the signal will get deteriorated, this is due to noise. Noise is an unwanted energy that gets added to the message signal during transmission over the channel.

  The distortion may be due to the non linearity properties of the electronic device in the transmitter.

- <u>Receiver:</u>

  The signals at the receiver are in modulated form that contains both message and the carrier signals.
  The main function of the receiver is to extract the useful signal from the received signal and deliver to the output transducer.
  The process of extracting message signal from the modulated signal is called demodulation/detection.

  The receiver in addition to the demodulation also performs amplification and filtering.

- <u>Output Transducer:</u>

  The output of receiver is the message signal in the electrical form. The output transducer converts the message signal in the electrical form into the audio signals.

  Thus, output transducer converts electrical signals into audio signals. <u>Ex:</u> Speaker

- <u>Destination:</u>

  Destination may be a person listening the conversation or a computer which receives the data.

<u>MODULATION:</u>

<u>Definition:</u> "The process in which the characteristics of the carrier is varied in accordance with the message signal".

Consider a high frequency sinusoidal carrier wave is represented by the equation (1).

$$c(t)= A_c \sin (\omega_c t+ \ _C) \quad \rightarrow (1)$$

Where,

$c(t)$ - The instantaneous value of the sine wave called carrier.

A_c- Maximum amplitude of the carrier.

ω_c - Angular velocity or angular frequency.[$\omega_c = 2\pi f_c$]

$_c$ – Phase angle in radians

T - Time in seconds

f_c - carrier frequency in hertz

Characteristics of carrier signal like **amplitude (A_c), frequency (ω_c) or phase($_c$)** of a carrier is changed in accordance with the intensity of the modulating signal.

Types of Modulation:

The modulation techniques are classified according which parameter of the carrier is changed.

- **Amplitude modulation**: In AM modulation, the amplitude of the carrier is varied according to the message signal keeping frequency6 and phase constant.
- **Frequency modulation**: In FM, the frequency of the carrier is varied according to the message signal.
- **Phase modulation**: In PM the phase of the carrier is varied according to message signal.

<u>NEED FOR MODULATION</u>

There are many instances when the message signals are incompatible for direct transmission over the medium.

Ex: Voice signals cannot travel longer distance in air, the signal gets attenuated rapidly. To avoid the signal loss or distortion we will go for modulation methods, so we have to use modulation technique for the communication.

The advantage of the modulation technique is given below

- Reduces the height of the antenna.
- Avoids mixing of the signals.
- Increases the range of communication.
- Allows the adjustments in the bandwidth.
- Improves quality of reception.

Reduces The Height Of The Antenna:

The height of the antenna required for transmission and reception of radio waves in communication is a function of wavelength of frequency used.

The minimum height of the antenna is "$\lambda/4$" → (1)

λ is the wavelength where $\boldsymbol{\lambda = c/f}$ → **(2)**

c= velocity of the light. $c=3\times10^{8}$ m/s.

f= frequency in Hz.

From the above equations 1 & 2 we can easily notice that at low frequency, wavelength is high and hence height of the antenna is more.

> Ex1: Let us consider frequency f=15 kHz.
> Height of the antenna= $\lambda/4$.
> $\lambda/4 = (C/F) \times (1/4)$
> $= ((3\times10^{8}) / (15k)) \times (1/4)$
> = **5000 meters**
> **5000 meters** height of the antenna is unthinkable and impracticable.

> Ex2: Let us consider frequency is 1M Hz.
> Then height of the antenna is $\lambda/4 = (C/F) \times (1/4)$
> **=75 meters.**

This height of the antenna is practical and such antenna can be installed.

Avoids mixing of the signals:

All the audio signals are concentrated within the range of 20 Hz to 20k Hz. The transmission of signals from various sources causes the mixing of signals and then it is difficult to separate these signals at the receiver end.

Let consider the 3 signals which is having the frequency range 0 to 20K Hz and these signals are transmitted without modulation then these signals result in overlap of the 3 signals. Hence detection of the signal becomes difficult.

This can be eliminated by taking different carrier frequencies for different signals and then modulated at the receiver and selects the required signal by avoiding of mixing of the signals.

Increases the range of Communication:

At low frequencies, the signal radiation is poor and it gets attenuated. Therefore the information signals cannot be transmitted directly over long distance. Modulation effectively increases the frequency of the signal to be transmitted and thus increases the distance over which signals can be transmitted faithfully.

Allows multiplexing of signals:

Multiplexing means transmission of two or more signals simultaneously over the same channels. The modulation permits the multiplexing to be used. The different signals from different stations can be separated at the receiver because of the carrier frequencies for these signals are different this is commonly known as tuning the receiver to the desired station. By tuning process the desired signals are selected and at the same time, other signals are rejected.

Allows Adjustments In The Bandwidth:

The signal to noise ratio in the receiver is a function of the signal bandwidth. The signal to noise ratio can be improved by proper control of the bandwidth at the modulation stage.

Improves The Quality Of Reception:

The signal communication using modulation reduces the effect of noise to great extent. Reduction of noise improves the quality of reception.

AMPLITUDE MODULATION (AM)

In amplitude modulation, the amplitude of the high frequency carrier signal is varied in accordance with the message signal.

The carrier and the message signals are multiplied and the resultant is the amplitude modulated wave. The block diagram of the modulator is shown in the fig.1.2.

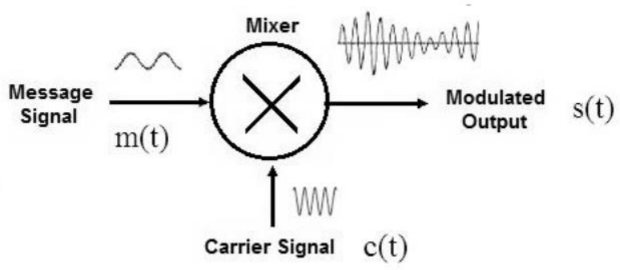


Fig 1.2: Amplitude modulation

Fig.1.3 shows a modulated signal with varying amplitude, along with message signal and carrier signal.

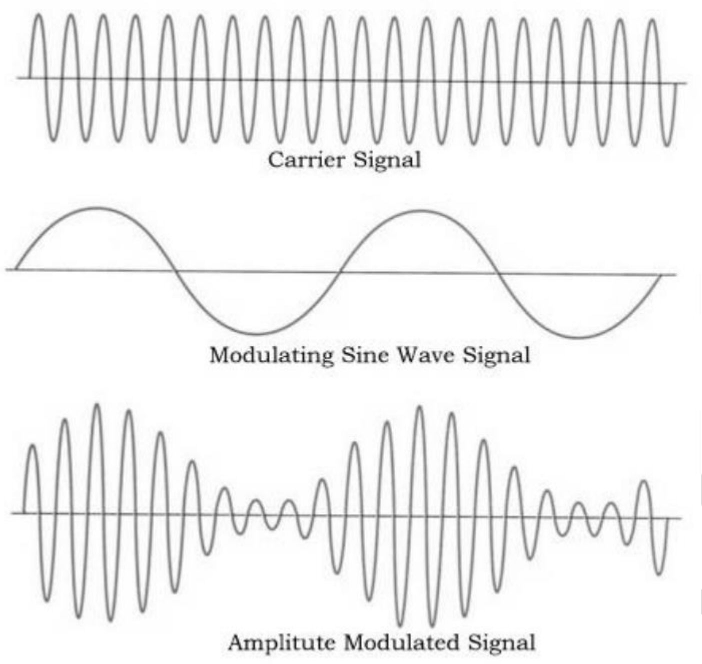


Fig 1.3: Waveforms of amplitude modulator

Expression for the amplitude modulated wave

Let the carrier signal can be represented as $c(t)= A_C\sin(2\pi f_c t)$ → (1)

Where, $c(t)$= Instantaneous value of sine wave called carrier

A_c=maximum amplitude of the carrier signal.

f_c = frequency in hertz.

t= time in seconds.

Let the message signal can be represented as $m(t)= A_m\sin(2\pi f_m t)$ → (2)

Where, $m(t)$= sine wave called message signal

A_m=maximum amplitude of the carrier signal.

f_m= frequency in hertz.

t= time in seconds.

Let the amplitude modulated signal can be represented as $s(t)= A \sin(2\pi f_c t)$ → (3)

Where, A= peak value of the modulated signal.

Note: the frequency of the modulated signal is same as that of the carrier signal.

In AM, the amplitude of the modulated signal varies in accordance with the instantaneous value of the message signal.

$A=A_C+m(t)$ → (4)

Substitute the equation (2) in equation (4)

$A=A_C+ A_m\sin(2\pi f_m t)$

$$A=A_C\left(1+\frac{A_m}{A_C}\sin 2\pi f_m t\right)$$

$$A = A_C(1 + k \sin 2\pi f_m t) \quad \rightarrow (5)$$

Where $k = \frac{A_m}{A_C}$ is called as modulation index.

Substitute equation (5) in equation (3)

$s(t)=[A_C(1 + k \sin 2\pi f_m t)]\sin 2\pi f_c t$

$s(t)=A_C \sin(2\pi f_c t) + k \sin(2\pi f_m t) \sin(2\pi f_c t)$ → (6)

We know that

$\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)]$

Using above trigonometric relation we can simplify the equation (6) as

$s(t)=A_C \sin(2\pi f_c t) + \frac{kA_c}{2}[\cos 2\pi(f_c - f_m)t - \cos 2\pi(f_C + f_m)t]$

$s(t)=A_C \sin(2\pi f_c t) + \frac{kA_c}{2}\cos 2\pi(f_C - f_m)t - \frac{kA_c}{2}\cos 2\pi(f_C + f_m)t$ → (7)

Carrier Lower side band Upper side band

The equation (7) is the final expression for the AM wave, we have three terms here, the first term is known as the carrier signal, second and third terms known as side bands. The first term contains frequency and amplitude A .
The second term has a frequency$(f_c - f_m)$ and this is known as lower side bands (LSB), since the frequency of this term is lower than the carrier frequency.
The third terms known as upper side band with frequency $(f_c + f_m)$. The frequency is higher than the carrier signal. Second and third term will have the amplitude $\frac{}{2}$

The frequency spectrum of the amplitude modulated wave is shown below

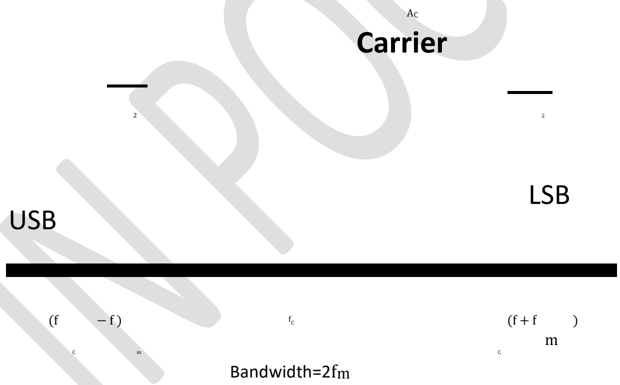


Fig 1.4: Spectrum of amplitude modulated wave

Bandwidth: It is defined as the range of frequencies occupied by the modulated wave. The LSB is at frequency $(f_c - f_m)$ and USB is at frequency $(f_c + f_m)$, then
Bandwidth=USB –LSB = $(f_c + f_m) - (f_c - f_m) = 2f_m$

Expression for the modulation index

Modulation index is defined as the ratio of peak amplitude of the message signal to the peak amplitude of the carrier signal. It is denoted by the symbol 'k'

$$k = \frac{A_m}{A_C} \rightarrow (1)$$

Consider the message signal is given by ( ) = 2 from the modulated signal S(t), the highest peak of the modulated signal is given by

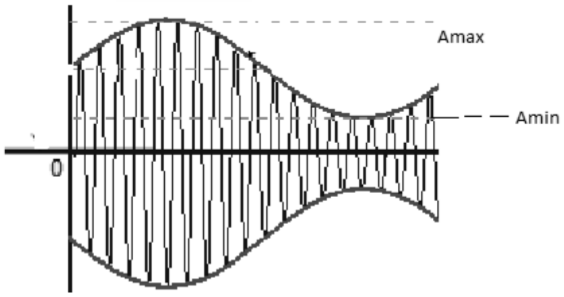


Fig 1.5: Amplitude modulated wave

Then, $A_{max} = A_C + A_m \rightarrow (2)$

Let the lowest peak on the positive side be

Then, $A_{min} = A_C - A_m \rightarrow (3)$

Add equation (2) and (3)

$$A_{max} + A_{min} = 2A_C$$

$$A_C = \frac{1}{2}[A_{max} + A_{min}] \rightarrow (4)$$

Subtracting equation (3) from (2)

$$A_{max} - A_{min} = 2A$$

$$A = \frac{1}{2}[A_{max} - A_{min}] \rightarrow (5)$$

Substitute equation (4) and (5) in equation (1)

$$k = \frac{A_m}{A_C} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

$$k = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

Power consideration in an AM wave

The expression for the AM wave is given below

$s(t) = A_C \sin(2\pi f_C t) + \frac{kA_C}{2} \cos 2\pi(f_C - f_m)t - \frac{kA_C}{2} \cos 2\pi(f_C + f_m)t$

It contains the three terms. The first term is known as the carrier signal, second and third terms are known as side bands.

Each term contains the power. Therefore the total power can be found as the sum of the power present in the individual terms.

The total power transmitted is given by

$$= ++ \rightarrow (1)$$

We know that power, p= 2 The peak value must be divided by √2 the rms value of the signal. The rms (root mean square) value must be used in the power calculation P=

The power in the carrier is

$= \sqrt{2}$ [ ]

Where, R is the resistance of the load.

The power in the lower side band is given by

→ (2)

→ (3)

The power in the upper sideband is given by

$[\quad]^2$

→ (4)

The total power in the modulated wave can be found as the sum of the above three power components.

Substitute the equations (2), (3), (4)

$= \frac{2}{}$ $+ [\quad]^2$

$P = \frac{A^2_c}{2R} + \frac{k^2 A^2_c}{2\,2R}$

$P = \frac{A^2}{2R} [1 + \frac{k^2}{2}]$ → (5)

The term $\frac{A^2}{2R}$ can be replaced by P

$P = P [1 + \frac{k^2}{2}]$ → (6)

If the modulation index is unity, i.e. k=1 in equation (6)

$P_t = P_c[1 + \frac{1}{2}]$

Thus, the total power in the modulated wave is 1.5 times the power in the carrier. **Expression for efficiency of AM wave**

The efficiency of the modulated wave can be defined as the ratio of power in the side bands to the total power in the modulated wave.

$$\eta = \frac{\text{power in the side bands}}{\text{total power in the modulated wave}} = \frac{+}{\quad} \rightarrow (1)$$

Let Pc is the power in the carrier.

WKT =

Let PUSB and PLSB be the power in the lower and upper side bands respectively.

$$= \frac{[\quad]^2}{8}$$

The total power can be expressed as

$$P_t = P_c[1 + \frac{k^2}{2}]$$

Substitute the above relations in equation (1)

$$\eta = \frac{[\quad]^2 + [\quad]^2}{P_c[1+\frac{k^2}{2}]}$$

$$= \frac{P}{P[1+\frac{k^2}{2}]}$$

$$\boxed{= \frac{k^2}{2+k^2}} \rightarrow (2)$$

If the modulation index is unity, k=1 in equation (1)

$$= \frac{}{+} = 0.333$$

Thus for unity modulation index we get a maximum efficiency of 0.333 = 33.33%

Current in the amplitude modulation

The modulated wave connected to an antenna which transmits power. Due to the amplification of signal to the antenna a current flows through it. The current in the antenna can be related to the power transmitted by the antenna

Let I_c is the rms current through the antenna when the unmodulated carrier is connected to the antenna. The power transmitted by the carrier can be found as:

$$P_c = (I_c)^2 R \rightarrow (1)$$

Where, R is the resistance of the antenna.

Let I_T is the current flowing through the antenna when the modulated wave is connected to the antenna. The power transmitted is due to both carrier and sidebands and is referred as total power.

$$P_T = (I_T)^2 R \quad \rightarrow (2)$$

WKT $P_T = P_c[1 + \frac{k^2}{2}]$

Substitute equations (1) and (2) I the above expression, we get

$$(I_T)^2 R = (I_c)^2 R[1 + \frac{k^2}{2}]$$

$$(I_T)^2 = (I_c)^2 [1 + \frac{k^2}{2}]$$

Angle Modulation:

In the angle modulation, phase or frequency of the carrier wave is varied in accordance with the message signal. The amplitude of the carrier is kept constant.

- Phase modulation.
- Frequency modulation.

FREQUENCY MODULATION:

It can be defined as the "process in which the frequency of the carrier is changed in accordance with the intensity of the message signal and by keeping the amplitude constant". Fig below illustrates the principle of frequency modulation.

The modulating and carrier signals are assumed to be sinusoidal of amplitude Vm and Vc respectively.

The angular frequencies of modulating and carrier signals are ωm and ωc respectively.

The frequency modulated wave is as shown in fig(c). The frequency of the carrier changes with variation in the amplitude of the modulating signal.

When the modulating signal voltage is zero at point A, C and E in fig(1.5)(b), the carrier frequency is unchanged.

When the modulating voltage approaches its positive peak as at point B, the carrier frequency is increased to a maximum as shown by the closely spaced cycles in fig(1.5)(c).

During the negative peak of the modulating voltage as at point D, the carrier frequency is reduced to minimum as shown by the widely spaced cycles in fig(1.5)(c).

Thus, the process of FM makes the frequency of the carrier to deviate from its center frequency 'fc' by an amount ±Δf, where Δf is termed as frequency deviation.

Frequency deviation: In FM, the frequency of the carrier is shifted from its unmodulated value(fc) by an amount(Δf) which is proportional to the amplitude of the modulating signal. This shift is called frequency deviation and denoted by δ.

$$\Delta f = \Delta\omega / 2\pi$$

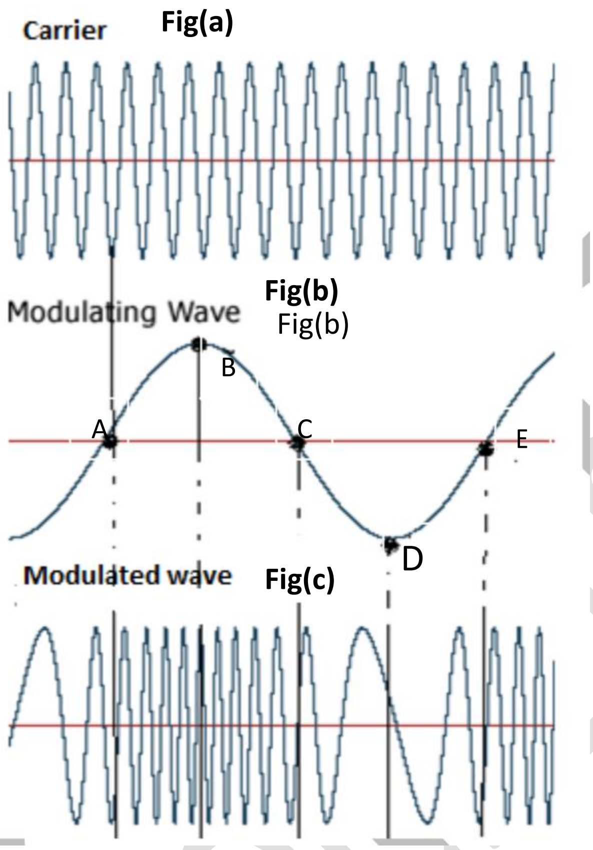


Fig. 1.6 Frequency modulation

Expression for Frequency Modulated Wave

Let the modulating signal be given by an expression

$$m(t)= V_M \cos\omega_m t \quad \rightarrow (1)$$

Let f_c is the frequency of the carrier signal

In FM, the frequency of the carrier signal is altered in accordance with the amplitude of the message signal. Therefore, the frequency 'f' of the modulated wave can be written as

$$f= f_c[1 + k\, m(t)] \quad \rightarrow (2)$$

where, k is a constant. The above equation indicates the variation of frequency in accordance with the amplitude of the message signal.

Substitute equation (1) in equation (2)

$$f= f_c[1 + k\, V_M \cos\omega_m t] \quad \rightarrow (3)$$

"$\cos\omega_m t$" will have value of "+1" and lowest value of "-1". Substituting this in equation (3) we get the maximum and minimum values of 'f'

$$f_{MAX} = f_c\,(1+kV_M) \quad \rightarrow (4)$$

$$f_{MIN} = f_c\,(1- kV_M) \quad \rightarrow (5)$$

In general the maximum frequency deviation of the modulated wave can be expressed as

$f = f_c (1 \pm kV_M)$

The maximum **frequency deviation** in the modulated wave can be found as the difference between "f_{MAX} and f_c" or "f_c and f_{MIN}" values. This is denoted by δ.

Frequency deviation$= \delta = f_{MAX} - f_c$

$\delta = f_c - f_{MIN}$

Substitute the equations (4) and (5) in above relation

$\delta = f_c (1+kV_M)- f_c$

$\delta = kV_M f_c$ → (6)

In general, the expression for frequency modulated wave can be written as

$s(t) = V_c \sin\theta$ → (7)

Where, θ is a variable which is function of frequency

Rewriting the equation (3),

$f= f_c[1 + k V_M \cos 2\pi f_m t]$

Multiply on both sides with 2π

$2\pi f= 2\pi f_c [1 + k V_M \cos 2\pi f_m t]$

$\omega= \omega_c[1 + k V_M \cos 2\pi f_m t]$ → (8)

The value of angular displacement can be found by integrating ω with respect to 't'.

i.e. angular displacement = $\theta=\int$

Substitute the equation (8) in the above expression

$\theta=\int$ [1 + 2]

$\theta=\int 2$ [1 + 2]

$\theta= 2$ [t + 2 2]

$\theta= 2$ t + 2 2 2

Substitute the above equation in the equation (7)

s(t) = Vc Sin [2 t + 2 2]

s(t) = Vc Sin [2 t + 2 2]

Substitute equation (6) in the above expression

s(t) = Vc Sin [2 t + 2]

s(t) = Vc Sin [2 t + kf Sin 2πfmt] → (9)

where, $k_f =$ — k_f is called modulation index in FM

The equation (9) is final expression for frequency modulated wave.

Modulation Index: The modulation index in FM is defined as the ratio of maximum frequency deviation to frequency of the modulating signal.

i.e. Modulation index, $k_f =$

Spectrum of FM wave

The frequency spectrum is a graph representing the amplitude of different components with respect to frequency. The frequency spectrum can be obtained for FM wave by the expression

s(t) = Vc Sin [2 t + kf Sin 2πfmt]

By inspecting above expression, it is not possible to identify different frequency components as the expression is complex. It is a sine function of sine term.

Hence to identify different frequency components present in the above expression, it is expanded using Bessel's function. The resulting expression is as follows:

$S(t)= V_C [J_0 K_f \sin 2\pi f_c t$

$+ J_1 K_f \{\sin(2\pi f_c+2\pi f_m)t - \sin(2\pi fc-2\pi fm)t \}$

$+ J_2 K_f \{\sin(2\pi f_c+2[2\pi f_m])t + \sin(2\pi fc-2[2\pi f_m])t \}$

$+ J_3 K_f \{\sin(2\pi f_c+3[2\pi f_m])t - \sin(2\pi fc-3[2\pi f_m])t \}$

$+ J_4 K_f \{\sin(2\pi f_c+4[2\pi f_m])t + \sin(2\pi fc-4[2\pi f_m])t \}+ -----]$

Upper side bands Lower side bands

In the above expression the terms J_0, J_1, J_2, J_3 ,…. Are called coefficients.

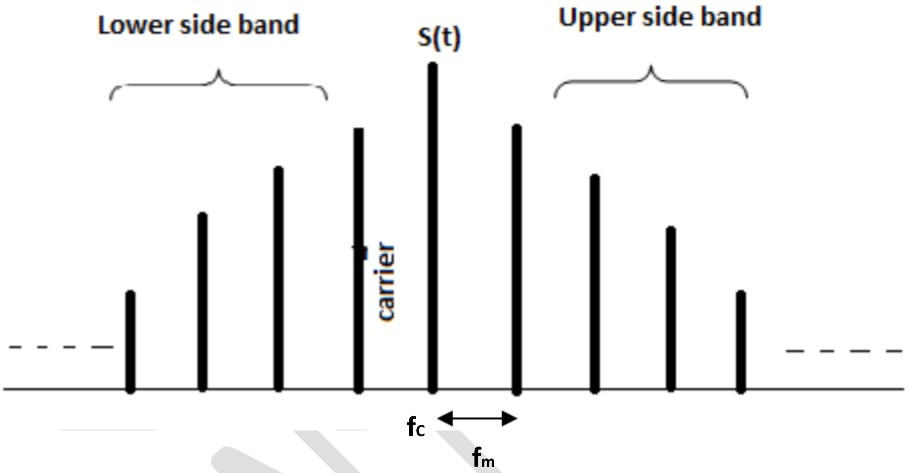


Fig 1.7: Frequency spectrum of FM

The first term represents the carrier and subsequent terms represent the side bands where sideband terms extend up to infinity.

Bandwidth: the bandwidth is defined as the range of frequencies occupied by the modulated wave.

In case of AM signal, bandwidth required is twice the maximum frequency of the modulation which is not same for FM. Here the BW required is very large.

As FM signal has sidebands that extend up to infinity, it is normal accepted practice to determine the bandwidth as that which contains approximately 98% of the signal power. A rule of thumb, often termed **Carson's Rule** states that 98% of the signal power is contained within a bandwidth equal to the deviation frequency plus the modulation frequency doubled, i.e.

$BW= 2(\delta+f_M)$

$k_f =$ — where $\delta = kV_M\, fc$

PHASE MODULATION:

When a message signal is applied to the modulator, the phase angle of the carrier is modified in accordance with the instantaneous value of the message signal. This process of modifying the phase angle of the carrier is called phase modulation.

Let us consider the carrier signal $c(t) = A_c \sin(\omega_c t + \phi_c)$ → (1)
Where, A_c is the amplitude of the carrier.

ω_c is the angular frequency .

ϕ_c is the phase angle of the carrier with respect to a chosen reference.

Due to the application of the message signal, the phase angle changes sinusoidally. Let ϕ is the phase angle of the carrier after modulation and is expressed as

$$\Phi = \phi_m \sin \omega_m t \quad \rightarrow (2)$$

Where, ϕ_m is the maximum value of the phase angle due to application of modulating signal. This is proportional to the maximum value of message signal.

$\omega_m = 2\pi f_m$ is the angular frequency of message

signal The modulated signal can be expressed as

$$S(t) = A_C \sin(\omega_c t + \phi)$$

Substituting equation in above expression

$$S(t) = A_C \sin(\omega_c t + \phi_m \sin \omega_m t)$$

This equation may also be written as

$$S(t) = A \sin(\omega_c t + k_p \sin \omega_m t)$$

Where, $k_p = \phi_m$ is the modulation index.

AM DETECTION

The modulated signal will contain both message signal and the carrier signal and this modulated signal is transmitted over the channel.

The process of extracting message signal from the modulated signal at the receiver end is called detection or demodulation.

The block diagram of demodulation is given below

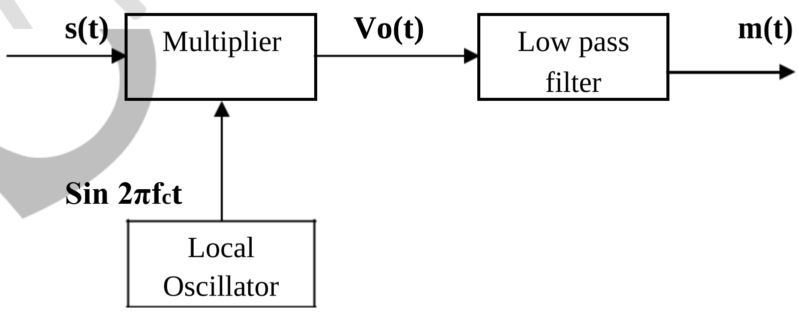


Fig.1.8: Block diagram of AM detection

The demodulator consists of two blocks.

The first block performs the multiplication of modulated wave with the output of a local oscillator.

The local oscillator generates a sine wave of frequency equal to the carrier frequency used in modulation.

The output of the multiplier is passed through a low pass filter. The LPF is a circuit that allows only the signals of low frequency to pass through it and blocks the high frequency signals.

The output of the low pass filter is equal to the message signal.

To find the output of the demodulator

The output of the demodulator can be found by the following two steps

The modulated signal is multiplied with the local oscillator output. The output of multiplier contains both low and high frequency components.

These high frequency components are removed by the low pass filter. The remaining expression is the message signal.

Let S(t) is the modulated signal and is given by

$$S(t) = A_c[1 + k \sin 2\pi f_m t] \sin 2\pi f_c t \quad \rightarrow (1)$$

Let a message signal be $m(t) = A_m \sin 2\pi f_m t$ $\rightarrow$ (2)

The output of the first block is the product of the modulated wave and the local oscillator output

$$V_o(t) = s(t).l(t) \quad \rightarrow (3)$$

Where, l(t) is the output of local oscillator

$$\text{i.e. } l(t) = \sin 2\pi f_c t \quad \rightarrow (4)$$

Substitute equation (4) and (1) in equation(3)

$V_o(t) = A_c[1 + k \sin 2\pi f_m t] \sin 2\pi f_c t \,.\, \sin 2\pi f_c t$

$= A_c[1 + k \sin 2\pi f_m t] \sin^2 2\pi f_c t$

w.k.t. $\sin^2\theta =[\quad]$

by using this trigonometric relation

Vo(t) = $\rightarrow$ (5)

In the above equation the first term is the DC component, second term 2 which is the message signal. The third and fourth term contains cos $4\pi f_c t$ is a high frequency components.

The output of the multiplier block is passed through LPF. The LPF blocks the high frequency signals, thus filtering the third and fourth term.

Therefore, the output of the LPF is

m'(t) = $\rightarrow$ (6)

In the above equation, the first term is DC component which can be removed by a capacitor. Therefore, we get

$$\hat{}(\ ) = \frac{\quad}{2}\ 2 \quad \rightarrow (7)$$

Comparing equation (2) & (7), both have 2 which is the message signal but the magnitudes are different. Hence the message signal is detected from the modulated wave.

Frequency ranges with applications

Frequency range	Application
Super high frequencies (3GHz-30GHz)	RADAR
Ultra high frequencies (300MHz-3GHz)	Communication satellites, cellular phones, personal communication systems
Very high frequencies (30MHz-300MHz)	TV and FM broadcast
High frequencies(3MHz-30MHz)	Short-wave broadcast commercial
Medium frequencies(300kHz-3MHz)	AM broadcast
Low frequencies(30kHz-300kHz)	Navigation, submarine communications
Very low frequencies(3kHz-30kHz)	Submarine communications, navigation
Voice frequencies(300Hz-3kHz)	Audio, submarine communication, navigation
Extremely low frequencies(30Hz-300Hz)	Power transmission

COMPARISON OF FM AND AM:

Frequency Modulation	Amplitude Modulation
This occupies VHF and UHF frequency range. At these frequencies, the noise interference is less.	This occupies MF and HF frequency range, where There is more interference due to noise.
Several transmitters can be operated with same frequency without any interference between the transmitters.	Each transmitter has to be operated with different frequency as there is interference among the Transmitters.
The amplitude variations of the modulated signal caused by noise can be eliminated by the receivers by fitting the receivers with amplitude limiters.	Since the amplitude of the modulated signal varies it not possible to detect noise, hence cannot be eliminated.
There is less interference from the adjacent channels.	The adjacent channel causes interference.
The noise can be reduced by increasing the deviation.	This feature is not possible in AM since the increasing modulation beyond 100% would cause distortion.
The noise in the FM signal can be reduced by increasing the frequency deviation.	It is not possible to reduce the noise as there is a limit on the depth of modulation.
There is no change in the amplitude of the modulated signal, hence power of the modulated signal is independent of depth of modulation.	The power of the transmitted power depends of the depth of modulation.
The FM system is more efficient.	The AM system is less efficient.
This system requires more complex equipment for Modulation and demodulation. This disadvantage.	The modulation and demodulation equipment are simpler.
The FM requires a channel of wider bandwidth. This is a major disadvantage.	The width of the bandwidth is less when compared to FM transmission.
The FM can cover only lesser area.	Comparatively, the AM wave can cover a larger area.

MODULE 5

TRANSDUCERS

Transducers (Text-2)**:** Introduction, Passive Electrical Transducers, Resistive Transducers, Resistance Thermometers, Thermistor. Linear Variable Differential Transformer (LVDT). Active Electrical Transducers, Piezoelectric Transducer, Photoelectric Transducer.

INTRODUCTION

A transducer is a device or combination of device, which converts one form of energy to another form of energy. Usually a transducer converts a signal in one form of energy to a signal in another. Energy types include electrical, mechanical, electro mechanical, acoustic, thermal etc.

<u>Classification of Transducer</u>

Classification of Transducer may be based on

1. Input and Output quantity
2. Role of Transducers
3. Operation of the Transducers

Based on the **input and output quantity** the transducer is of two types

- Sensors
- Actuators

A **sensor** is used to detect a parameter in one form report it in another form of energy often an electrical signal.

Example A pressure sensor detects pressure and converts it into electric signals

Mechanical Quantity | Sensor | Electrical Signal

Fig.1.1: Block diagram of sensor

An **actuator** accepts energy and produces movement (action). The energy supplied to actuators might be electrical or mechanical

Example: An electric motor and a loudspeaker coverts electrical energy into motion of different type

Electrical signal | Actuator | Mechanical Quantity

Fig.1.2: Block diagram of actuator

Based on the **role of transducer** the transducers is two types

- Input Transducer
- Output Transducer

Input transducers can be used for measurement of a quantity these are also called as instruments transducers. Example Microphone

Output transducer is used for delivering power to the load. This is also called as power transducers. Example speaker of a system

Based on **operation of transducers,** classification of transducer is of two types

- Active Transducer
- Passive Transducer

An **active transducer** develop voltage and current as the output without any external energy

Example: Thermocouple, piezoelectric transducer and photoelectric transducer etc. **Passive transducer** is one which develops voltage and current as the outputs with the help of external energy.

Ex; Resistance temperature detector (RTD), thermistor, LVDT

Difference between active transducer and Passive transducer

active transducer	Passive transducer
They do not require an external source of power for their operation.	They require an external source of power for their operation.
They are self-generating type transducers	They are not self-generating type transducers
They produce electrical parameter such as voltage or current proportional to the physical parameter under measurement.	They produce change in the electrical parametersuch as inductance, resistance or capacitance in response to the physical parameter under measurement.
Example: Thermocouple, photo electric transducer, piezoelectric transducer.	Example: Thermistor, RTD, LDR, LVDT phototransistor.

<u>**Characteristics of Transducers**</u>

Characteristics

A transducer should have the following characteristics for good performance of the system in which transducer are used. The characteristics are listed below.

- **Accuracy & Precision**
- **Repeatability & Reproducibility**
- **Sensitivity & Stability**
- **Dynamic error & Fidelity**
- **Bandwidth & Speed of response.**

ELECTRICAL TRANSDUCERS

A transducer which gives output in electrical form it is known as electrical transducer. Electrical transducer consisting of two elements, the two are closely related to each other. These two parts are sensing or detecting element and transduction element. The sensing or detecting element is commonly known as sensor.

- Active Electrical Transducer
- Passive Electrical Transducer

Fig.1.3: Electrical Transducers

PASSIVE ELECTRICAL TRANSDUCERS

The three passive elements in electric circuit are Resistor, Inductor and Capacitor. The transducers that are based on the variation of these parameters due to application of any external stimulus is known as passive transducer

RESISTIVE TRANSDUCER

It is a type of passive transducer in which the resistance of the transducer is varied due to the application of external stimulus. Hence, these are also called as variable resistance transducers

Application: Used to measure physical quantities like temperature, pressure, displacement, force, vibration etc.

Working principle

The variable resistance transducer works on the principle that the resistance of conductor is directly proportional to the length of the conductor and inversely proportional to the area of conductor (A)

Where ρ is the resistivity or specific resistance of material and is measured in ohm-m (Ωm)

The resistivity of the material varies with the temperature and composition of its medium. This is principle primarily used to measure temperature

RESISTANCE THERMOMETER

This is one of the applications of resistance transducer. Thermometer is an instrument used to measure the temperature. The resistance transducer which is used to measure temperature is called as resistance thermometer

The phenomenon of the resistance thermometer is resistance of material varies with their change in temperature

The resistivity of the metal (conductor) increases with temperature but in semiconductor and insulator generally it decreases

Resistance thermometers also called as **resistance temperature detectors (RTDs)**. RTDs are sensors used to measure temperature by correlating the resistance of RTD elements with temperature.

Construction

RTD elements consist of length of fine coiled wire wrapped around ceramic or glass or mica core. The RTD element is made from a pure material like platinum, nickel or copper. This entire assembly is enclosed in a proactive tube. The RTD is shown below

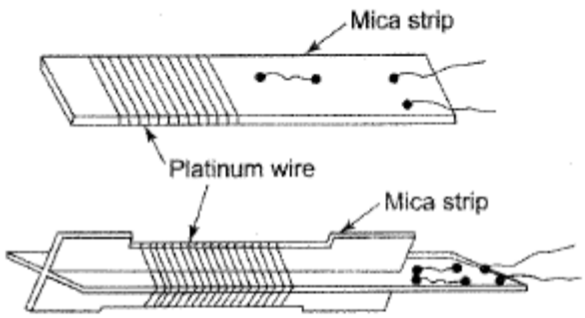


Fig.1.4: Resistance Temperature Detector (Resistance thermometer) Working

As the temperature of material changes, the change in resistance of the material will be due to changes in both length and resistivity

The element (RTD) is made to come in contact with material whose temperature is to be measured. The variation of the resistance of the coil is measured. The variation of resistance of coil is expressed as

$R_T=R_o\ [1+\alpha T]$

Where R_T is the resistance of any temperature T ° C

R_o is the resistance at 0° C

α is called temperature co-efficient

The temperature co-efficient of the resistance is given by

=—

ΔT Change in temperature °c

Fractional change in resistance

ΔR change in resistance

Ro resistance at 0°c

The two terminals of platinum wires i.e. connecting leads are connected to the Wheatstone bridge as shown in figure below. The entire transducer (RTD) is represented by a variable resistance in between the terminal of A and B

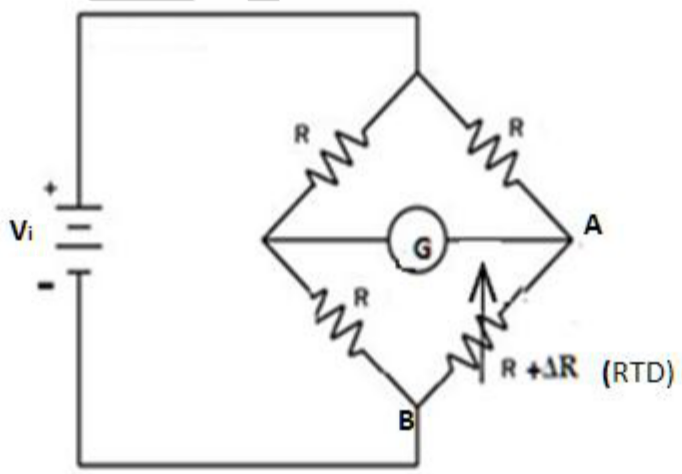


Fig.1.5: RTD connection using Wheat stone bridge

RESISTIVE TRANSDUCERS,

In figure above the variable resistance represents the resistance transducer the other three resistances are of equal values R

There for the balancing of the bridge depends on the resistance of the transducer

At the reference temperature (R_0 at 0º C) the value of resistance of the transducer is R and the bridge is balanced
Due to the change in temperature ΔR is the change in resistance of transducer then the bridge become unbalanced and current flow through galvanometer and is directly proportional to the variation of temperature from the reference value Thus the temperature can be measured

Advantages and Disadvantages of RTD

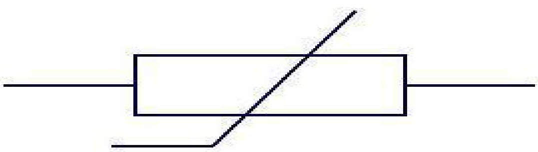
Advantages	Disadvantages
• High Accuracy • Does not require compensation • Designed for fast response • Good sensitivity • High reproducibility • They can be calibrated to detect the actual temperatures to detect the actual temperature to within ±0.25 º C up to 120 º C and ±0.5 º C from 120 º C to 550 º C. They have wide temperature range	• High Cost • Large size as compared to thermocouples • Requires bridge circuit and external power source for measurement • Changes of self-heating due to current through RTD and change in resistance occurs.

THERMISTOR

Thermistor is special type of resistor and full form of thermally sensitive resistor, whose resistance varies more significantly with temperature than in standard resistors.
The resistance increases with the temperature for most of the metals but the thermistors respond negatively i.e. the resistance of the thermistors decrease with the increase in temperature.

Advantages and limitations of thermistors over RTDs
Thermistors differ from RTDs in RTD the material used is pure metals whereas thermistors generally ceramics or polymer is used.
RTDs are useful over larger temperature range
Thermistor achieve high precision within a limited temperature range typically –90º to 130ºc

Thermistor can be classified into two types
If the resistance increases with increasing temperature and the device is called a positive temperature coefficient (PTC) thermistors.
If the resistance decrease with increasing temperature and the device is called a negative temperature co-efficient (NTC) thermistors.



Thermistor Symbol

Symbol of thermistor

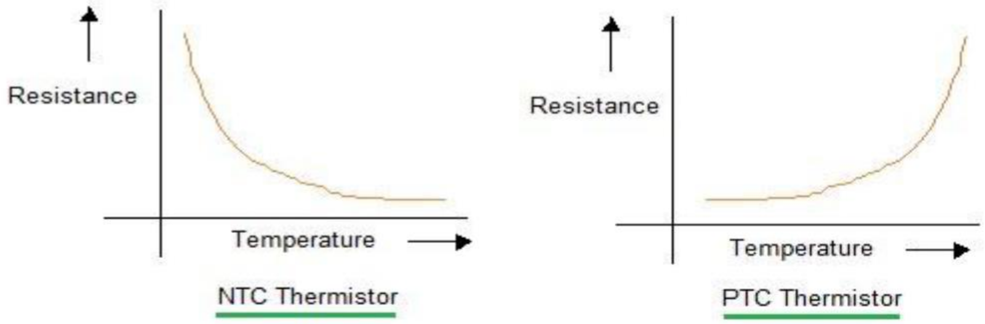


Fig.1.6: Variation of resistance in thermistor i) NTC thermistor ii) PTC thermistor

The resistance of the thermistor can be expressed as

$$R = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)} \quad \text{------------------------------------} \ (1)$$

Where Ro resistance at temperature O K

R Resistance at T K

Constant to be determined experimentally

For large value of T

=Ro

Thermistor are widely used as

- Inrush current limiters
- Temperature sensors
- Self-resetting over current protectors
- Self-regulating heating elements
- Used for measurements of Temperature Flow and Pressure Liquid level.

Advantages and disadvantages of thermistors

Advantages	**Disadvantages**
Small size, low cost	Reverses temperature characteristics is highly non-linear
Fast response over a narrow temperature range	Not suitable for wide temperature range
Comparatively large change in resistance for a given change	Requires Wheat stone bridge circuit and external power source for measurements

in temperature	

LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

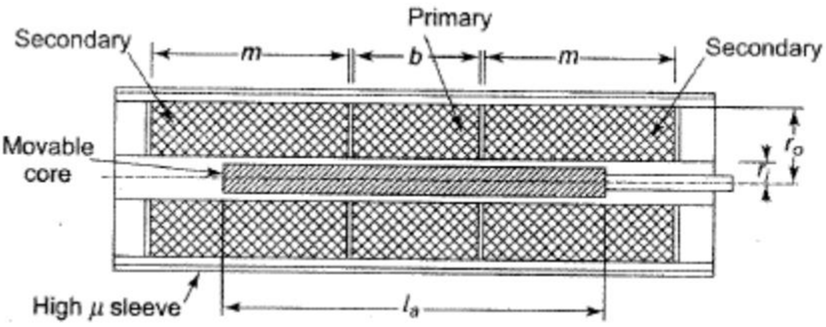


Fig.1.7: Construction of LVDT

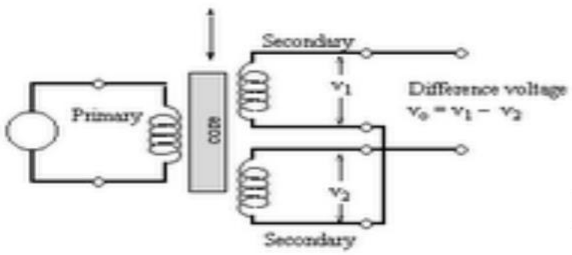


Fig. Equivalent circuit of LVDT

Definition The LVTD is a type of electrical transformer used for measuring linear displacement.

LVTD is also called as differential transformer linear variable displacement transformer.

Principle of LVDT:

LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.

And the way how the energy is getting converted is described in working of LVDT in a detailed manner.

LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides.

The number of turns in both the secondary windings are equal, but they are opposite to each other, i.e., if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil. The two secondary coils are represented as S_1 and S_2.

Esteem iron core is placed in the centre of the cylindrical former which can move in to and fro motion as shown in the figure.

The AC excitation voltage is 5 to 12V and the operating frequency is given by 50 to 400Hz.

Working of LVDT

Let"s study the working of LVDT by splitting the cases into 3 based on the iron core position inside the insulated former.

Case 1: When core is placed centrally it is symmetric with respect to both the secondary windings. Then the induced voltages are equal in the secondary windings. Then two induced voltage will cancel each other and output voltage is zero thus zero output voltage induces that the core is positioned centrally.

Case2:

If the core is moved to left the induced voltage magnitude in the secondary winding 1 will be more than in secondary winding 2 for this case the difference in the two output voltage will not be zero.

Case 3

If the core is moved to right the secondary winding 2 will have higher induced voltage. The output voltage for this case will not be zero and also the polarity of output voltage will be opposite of that for core shifted to left.

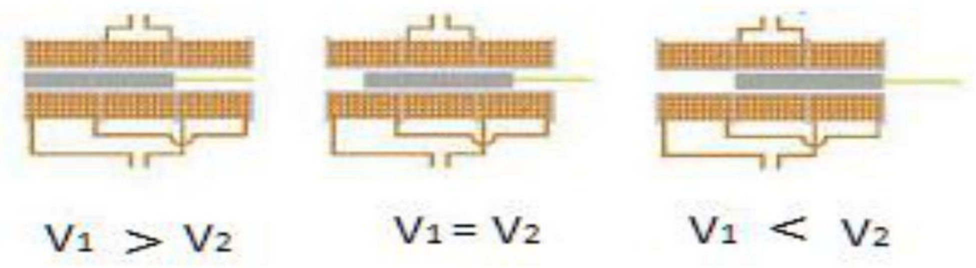


Fig.1.7: Working of LVDT

Advantages and Disadvantages of LVDT

Advantages	Disadvantages
• Insensitive to temperature changes • Ruggedness: Good mechanical life • Electrical isolation is better • High sensitivity and better linearity • Frictional less operation because no physical contact exists between the core and coil structure	• Temperature affects the transducers • The dynamic response is limited by the mass of the core. • They are sensitive to stray magnetic fields. • Comparatively large displacement is necessary for appreciable differential output.

Applications of LVDT

- It is used in all applications where displacement ranging from fractions of a few milli meter to a few centi meter have to be measured.
- Acting as secondary transducer, LVDT can be used as device to measure force, weight and pressure etc.

ACTIVE ELECTRICAL TRANSDUCERS

An active transducer is defined as the transducer which can produce an output voltage without the help of external stimulus.

The different types of active transducer

1) Thermoelectric Transducer
2) Piezoelectric Transducer
3) Photoelectric Transducer

THERMOELECTRIC TRANSDUCER

THERMOCOUPLE

A thermocouple is a temperature measuring device consisting of two dissimilar conductor that contact each other at one or more spots

It produces a voltage when the temperature of one of the spots differs from the reference temperature at other ports of the circuit.

Thermocouples are self-power and required no external form of excitation but limitation is with accuracy.

The content of dissimilar metals will produce an electric potential related to temperature.

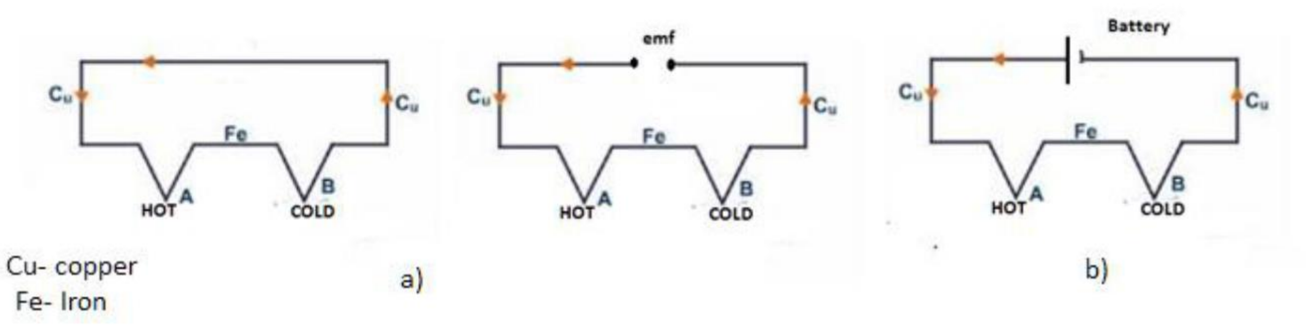


Fig.1.8: Typical thermocouple circuit a) Seebeck Effect b) Peltier Effect

Fig.1.9: A Thermocouple using two metals

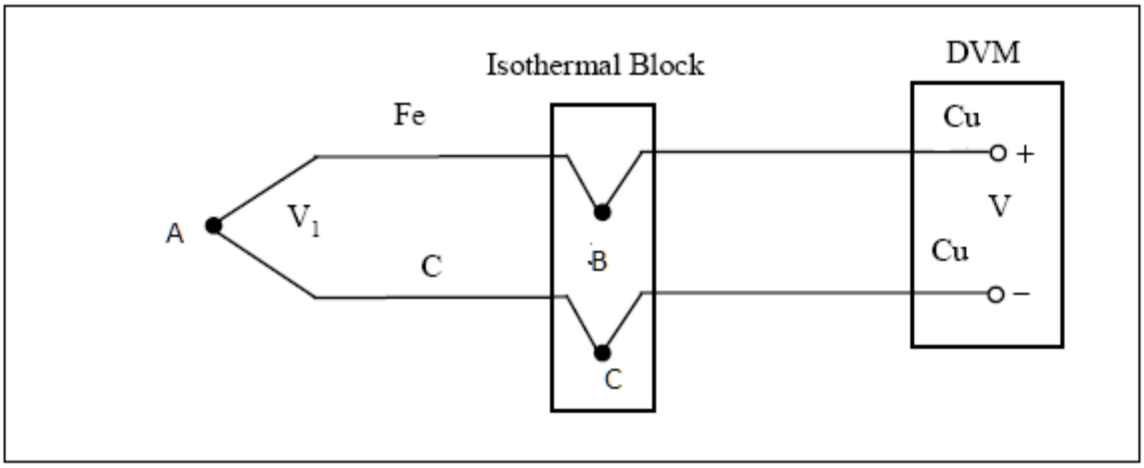


Fig.1.10: A thermocouple using three different metals

Measurement of temperature using thermocouple

In above fig there are three dissimilar metal are used to form three junctions.

The junction "A" is heated and it is called a hot junction the junction "B" and "C" are maintained at low temperature are called cold junctions

Due to the difference in the temperature between the junctions an emf is induces across the terminal box which is measured by using voltmeter.

The magnitude of voltage is proportional to the temperature at the hot junction.

The behavior of thermocouple can be given by Seebeck effect, Peltier effect, Thompson effect.

Seebeck Effect

The Seebeck effect states that if two wires of different metals are connected together to form two junctions are maintained at different temperature then an emf is induced and electric current flows in the wires. The current flows from hot junction to cold junction

Peltier effect

If is the reverse phenomenon of Seebeck effect

The Peltier effect status that if an external emf is applied to the junction formed by two different metals then the heat may be absorbed or liberated depending on two direction of flow of current.

In above fig an external emf is connected which forces current through junction.

Thompson effect

It states that in conductor of same metal if there is a temperature gradient along the length of the conductor then the heat might be observed by conductor depending on the flow of current. If the current flows in the direction of flow of heat the heat is observed by the conductor. If the current flows in the opposite direction of flow of heat the heat is liberated by conductor.

PIEZOELECTRIC TRANSDUCER:

Fig.1.11: A general form Piezoelectric Transducer

It coverts mechanical energy into electrical energy and is based on the piezoelectric effect. The “Piezo” is a Greek word means „press‟ or “squeeze”

The basic phenomenon of piezoelectric effect is the electrical charge is developed on surface of non-metallic material like quartz, Rochelle salt, Tourmaline, Lithium Sulphate (LS), Ammonium Di-hydrogen phosphate (ADP), and Di potassium Tartrate (DKT) etc., when they are subjected to external force (Mechanical stress).

These charges are developed on a face perpendicular to the direction of application of force.

The three modes of operation are thickness expander mode, length expander mode and volume expander mode

The concept of development of charges due to applied force is shown in fig

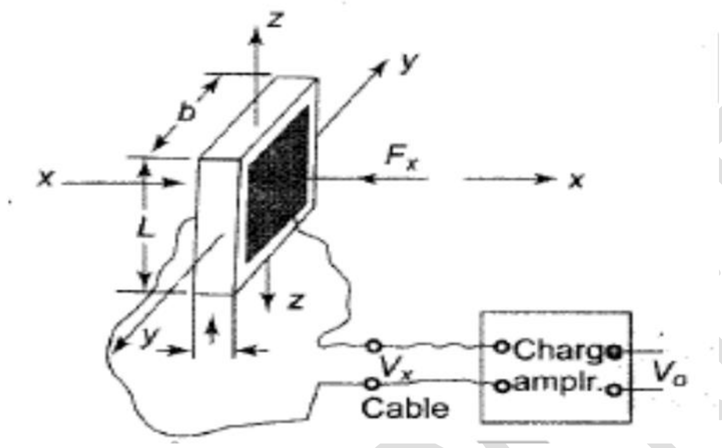


Fig.1.12: Piezoelectric Transducer

Application

A piezoelectric sensor is used to measure pressure, acceleration, strain, force etc.

They are used for quality assurance process control and for research and development in industry.

It has been used in medical, aerospace, nuclear instrumentation.

PHOTOELECTRIC TRANSDUCER

A photo-electric transducers are defined as the materials or devices that convert light energy into electrical current.

Certain material or semiconductor devices absorb energy from the incident light. This energy is transferred to the electronics present in the materials.

The electrons, due to the imparted energy, get activated and the electrons start moving. That is light energy is converted into kinetic energy of the electrons. The movement of the electrons causes the flow current.

We have three types of Photo-electric transducers

- **Photo-emissive transducers**
- **Photovoltaic transducers**
- **Photoconductive transducer**

Metallic cathode and an anode in an evacuated tube is the main part of photo-emissive transducer. The emitted electrons from the cathode are attracted towards the anode, which causes current flow proportional to the wavelength of the radiation and the material of the surface.

The effect of optical radiation on the semiconductor may be observed as a change in either current, developed voltage or resistance.

Photovoltaic cells are passive and the change in the resistance value according to the illumination of light should be measured by suitable circuitry. They are used in exposure meters (light meter).
It is known as light dependent resistor (LDR). Photo diodes and photo transistor are considered to function in both in photo-emissive and photovoltaic mode.

HALL EFFECT TRANSDUCER

Hall effect is one of the galvanometric phenomenon in which interaction between the magnetic field and moving electrical charges results in the development of forces that alter the motion of the charge.
These are very much prominent in semiconductor materials. An thin strip of Bismuth or N-type Germanium is subjected to magnetic field B normal to its surface as shown in figure.

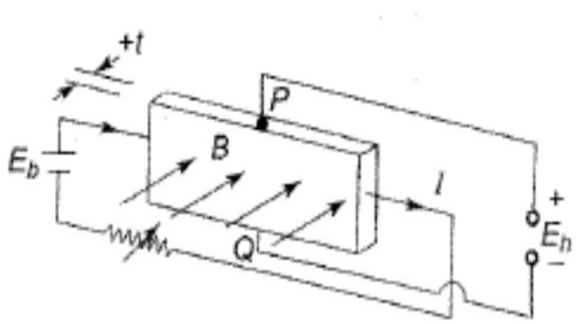


Fig.1.13: Hall Effect Transducer

While it carries a current I along the length of the strip, but normal to B, because of the force from magnetic field the electrons move towards to the edges of the strip with a velocity v.
So the edge surfaces act like charged electrodes and potential difference between two edges known as Hall potential (E_h). E_h is proportional to B and I. It is suitable for measurement of magnetic field.

Application:

It has made it possible without interruption of the circuit and without making any electrical contact with the conductor.

Comparison for primary and secondary transducer

Primary transducer	Secondary transducer
A transducer which converts physical quantity into mechanical signal is called primary transducer	A transducer which converts mechanical quantity into electrical signal is called primary transducer
They do not require any electrical for their operation	They require any electrical for their operation