Introduction to Communication Systems – Analog Modulation

22AIE211 Introduction To Communication & IoT

Communication system

The **communication system** is a system which describes the information exchange between two points. The process of transmission and reception of information is called communication.

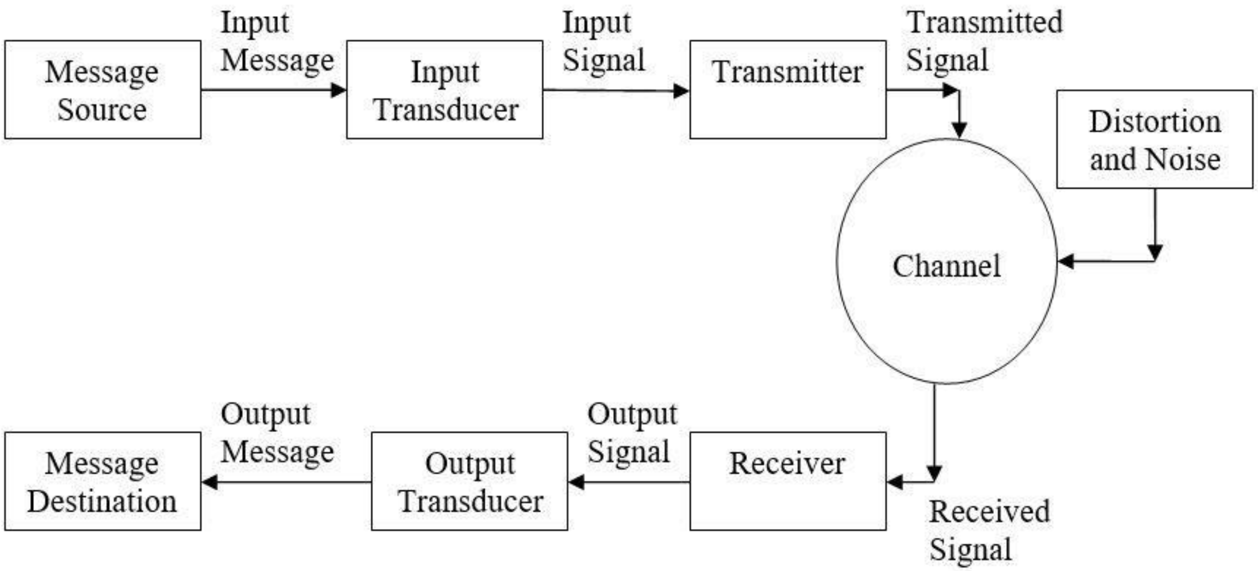


Fig. Block diagram of communication system

(i) Information Source

- Information originates in the information source.
- can be in the form of audio, video, temperature, picture, pressure, etc.
- produces required message which has to be transmitted.

(ii) Input Transducer

- A transducer is a device which converts one form of energy into another form.
- The message from the information source may or may not be electrical in nature. In a case when the message produced by the information source is not electrical in nature, an input transducer is used to convert it into a time-varying electrical signal.
- Example: in case of radio-broadcasting, a microphone converts the information or message which is in the form of sound waves into corresponding electrical signal.

(iii) Transmitter

- The function of the transmitter is to process the electrical signal from different aspects.
- signal processing such as restriction of range of audio frequencies, amplification and modulation of signal are achieved.
- Example: in radio broadcasting the electrical signal obtained from sound signal, is processed to restrict its range of audio frequencies (upto 5 kHz in amplitude modulation radio broadcast) and is often amplified.

- Consist of devices such as amplifier, antenna, mixer, modulator, filter etc.
    - **Amplifier -** increases the amplitude or the strength of the transmitted signal.
    - **Modulator -** As the original message signal cannot be transmitted over a large distance because of their low frequency and amplitude, they are superimposed with high frequency and amplitude waves called carrier waves. This phenomenon of superimposing of message signals with a carrier wave is called modulation.
    - **Antenna -** radiate and receive electromagnetic waves, used in both transmitters and receivers.

(iv) The Channel and The Noise

- Channel - the medium through which the message travels from the transmitter to the receiver(wired or wireless)
- many channel impairments(Noise, attenuation and distortion) affect channel performance to a pronounced level.
- Noise - unwanted signal which tend to interfere with the required signal.

(v) Receiver

- reproduces the message signal in electrical form from the distorted received signal through demodulation.

(vi) Output transducer

- convert an electrical message signal into its original form.
- For example in radio broadcasting, loudspeaker works as a transducer i.e. converts the electrical signal in the form of original sound signal.

Wired & Wireless Communication

Wired Communication

- the medium is a physical path like Co-axial Cables, Twisted Pair Cables and Optical Fibre Links etc. which guides the signal to propagate from one point to other.
- called Guided Medium.

Wireless Communication

- doesn't require any physical medium but propagates the signal through space.
- Since, space only allows for signal transmission without any guidance, the medium used in Wireless Communication is called Unguided Medium.
- the transmission and reception of signals is accomplished with Antennas.
- Eg: Television and Radio Broadcasting, Satellite Communication, Radar, Mobile Telephone System (Cellular Communication), Global Positioning System (GPS), Infrared Communication, WLAN (Wi-Fi), Bluetooth, ZigBee

Modulation

- process in which a very high-frequency carrier wave is used to transmit the low-frequency message signal so that the transmitted signal continues to have all the information contained in the original message signal.

Need of Modulation

- The message signals have a very low frequency due to which these signals cannot be transmitted over long distances. Hence such low-frequency message signals are modulated over the high-frequency carrier signal due to the following reasons:
  - Practical Length of Antenna
  - Effective Power Radiated By Antenna
  - Narrow Banding of Signal
  - Frequency Multiplexing

Need of Modulation

Practical Length of Antenna

- For the effective transmission of a signal, the height $\boldsymbol{h}$ of the antenna should be comparable to the wavelength $\boldsymbol{\lambda}$ of the signal
- the height of the antenna $\boldsymbol{h}$ should be $\boldsymbol{\lambda / 4}$ in length so that the antenna can sense the variations of the signal properly.
- The low-frequency message signal has a very high value of $\boldsymbol{\lambda}$ which will require a very high antenna (practically not possible).
- ***For example:*** *If we have to transmit a signal of* **20 kHz** *then* $\boldsymbol{\lambda = C / f}$ *and height of the antenna* $\boldsymbol{h \approx \lambda}$ *where* **C** *is the wave velocity, here* $\boldsymbol{C = 3 \times 10^8}$ ***m/s***.

  $$h \approx \lambda = (3 \times 10^8) / (20 \times 10^3)$$

  $\boldsymbol{h = 15}$ ***km.*** (practically not possible).

- Hence, we need to modulate the message signal over the high-frequency carrier signal so that we can have a practical value for the height $\boldsymbol{h}$ of the antenna.

As frequency increases height of antenna decreases

Effective Power Radiated By Antenna

- Power radiated by an antenna $\propto (l / \lambda)^2$ where l is the length of the antenna and λ is the wavelength of the signal which is to be transferred through the antenna.
- when signals having a low frequency and high wavelength is transmitted directly, the power radiated by the antenna is very low and the signal will vanish after traveling some distance.

Narrow Banding of Signal

- An audio signal usually has a frequency range (20 Hz to 20 kHz), if it is directly transmitted then the ratio of highest to the lowest frequency becomes (20 kHz / 20 Hz) = 1000. But if this audio signal is modulated over a carrier signal of frequency 1000 kHz then the ratio of highest to the lowest frequency becomes:

$$\textit{(1000 kHz + 20 kHz) / (1000 kHz + 20 Hz)} \cong 1.2$$

Hence, we need modulation to convert a wideband signal into a narrow band signal.

Frequency Multiplexing

- It is practically not possible to distinguish between the different audio signals when transmitted simultaneously through a single antenna as all of them lie in the same spectral range. Hence, each of these signals is translated to a low-frequency range before transmission which makes it quite easier to recover them and distinguish each of them from one another at the receiver's end.

Signals in Modulation Process

Message or Modulating Signal

- The signal which contains a message to be transmitted, is called as a message signal.
- It is a baseband signal
- it is also called as the modulating signal.

Carrier Signal

- high frequency signal, which has a certain amplitude, frequency and phase but contains no information.
- It is an empty signal and is used to carry the message signal.

Modulated Signal

- The resultant signal after the process of modulation is called as a modulated signal.
- This signal is a combination of modulating signal and carrier signal.

Types of Modulation

MODULATION TYPES

ANALOG MODULATIONS

- **AM** (Amplitude Modulation)
- **FM** (Frequency Modulation)
- **PM** (Phase Modulation)

DIGITAL MODULATIONS

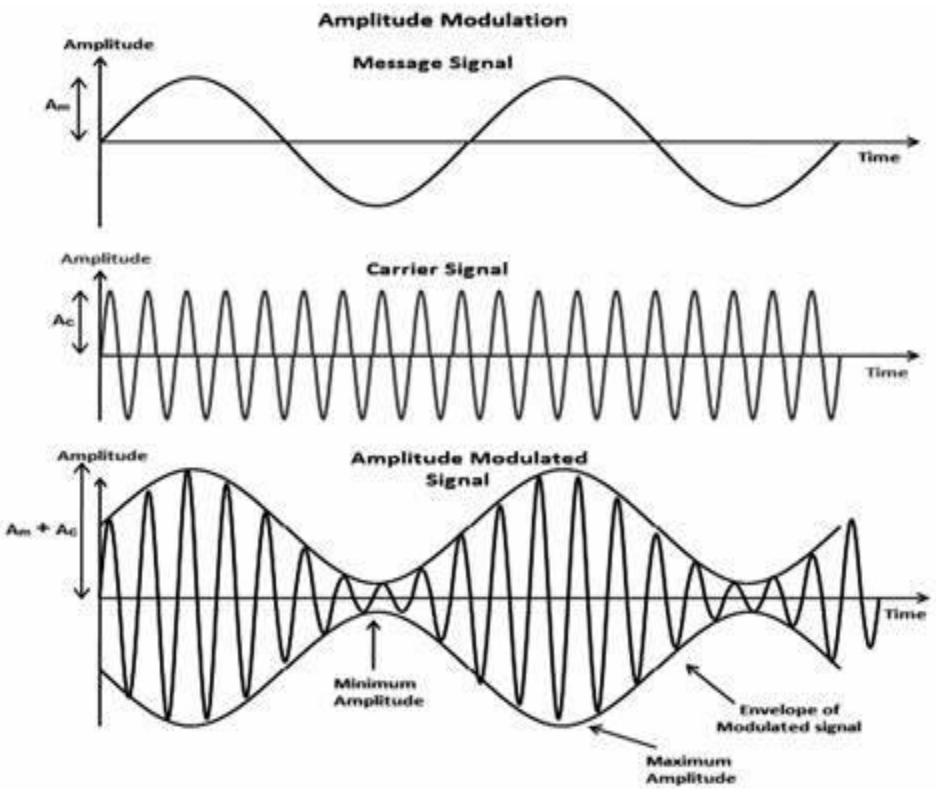
- **ASK** (Amplitude Shift Keying)
- **FSK** (Frequency Shift Keying)
- **PSK** (Phase Shift Keying)
- **APSK** (Amplitude-Phase Shift Keying)
- **QAM** (Quadrature-Amplitude Modulation)

Analog Modulation

- Sine wave (carrier) is described by 3 parameters- amplitude, frequency and phase.
- Let the carrier signal be, x(t)=$A_c sin(2\pi f_c t + \Phi)$
- *So we can have*
  - *Amplitude modulation*
  - *Frequency modulation*
  - *Phase modulation*
- Frequency and phase combined are known as angle modulation

Amplitude Modulation

- the amplitude of high frequency carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal.



Amplitude Modulation

- Modulating signal is analogous to a sine or cosine wave and represented as:

$$m(t)= A_m sin(\omega_m t), \text{ where } \omega_m = 2\pi f_m$$

- *Carrier signal,* $C(t)= A_c sin(\omega_c t), \text{ where } \omega_c = 2\pi f_c$
- *Modulated signal,* $C_m(t) =(A_c + m(t)) \sin \omega_c t$

$$=(A_c + A_m \sin \omega_m t) \sin \omega_c t$$

$$=A_c(1+(A_m/A_c)\sin(\omega_m t))\sin(\omega_c t)$$

($A_m/A_c= \mu$, modulation index/modulation factor/ modulation coefficient / degree of modulation)

$$=A_c\sin(\omega_c t) + A_c\mu\sin(\omega_m t)\sin(\omega_c t)$$

$$= A_c\sin(\omega_c t) + (A_c\mu/2) \times [\cos(\omega_c-\omega_m) - \cos(\omega_c+\omega_m)]$$

$\because \sin A.\sin B = (1/2) \times [\cos(A-B)-\cos(A+B)]$

$$= A_c\sin(\omega_c t) + (A_c\mu/2) \times \cos(\omega_c-\omega_m)- (A_c\mu/2) \times \cos(\omega_c+\omega_m)$$

$$C_m(t) = A_c\sin(\omega_c t) + (A_c\mu/2) \times \cos(\omega_c-\omega_m)- (A_c\mu/2) \times \cos(\omega_c+\omega_m)$$

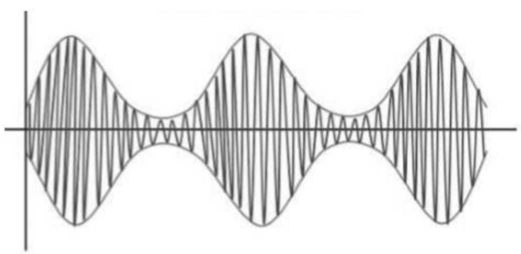
$C_m(t) = A_c \sin(\omega_c t) + (A_c\mu/2) \times \cos(\omega_c - \omega_m) - (A_c\mu/2) \times \cos(\omega_c + \omega_m)$

- From the above equation, we can see that th3 amplitude modulated wave is the sum of three sine or cosine waves.
- there are three frequencies in amplitude modulated wave, ω_c, $\omega_c + \omega_m$ and $\omega_c - \omega_m$ respectively.
- $\omega_1 = \omega_c \Rightarrow f_1 = f_c$
- $\omega_2 = \omega_c + \omega_m \Rightarrow f_2 = f_c + f_m$
- $\omega_3 = \omega_c - \omega_m \Rightarrow f_3 = f_c - f_m$
  - f_c is Carrier wave frequency
  - $f_c + f_m$ is Upper side band frequency
  - $f_c - f_m$ is Lower side band frequency
  - f_m is Modulating signal frequency
- In general $f_c >> f_m$

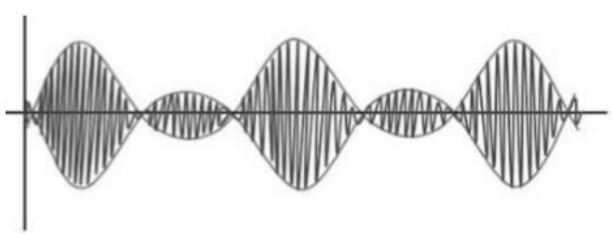
Varying modulation index

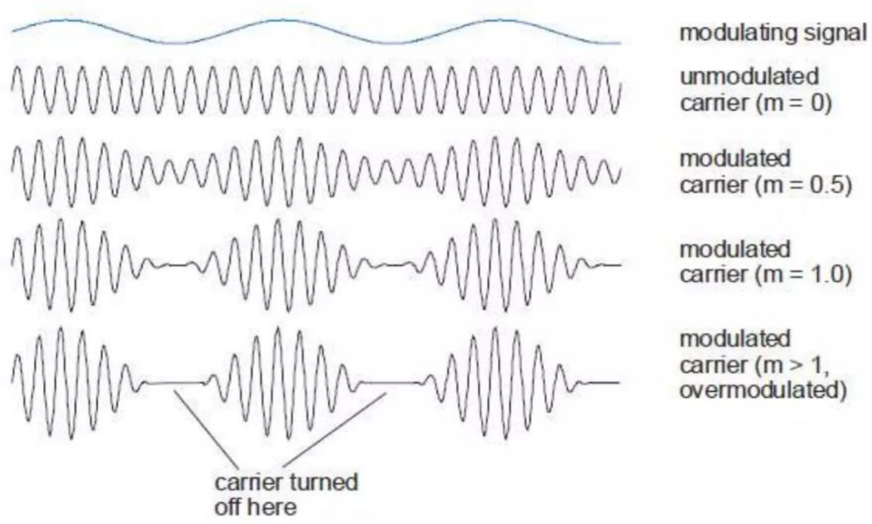
- For perfect modulation, modulation index =1, which implies the percentage of modulation should be 100%.
- if modulation index < 1, it is called as **Under-modulation**. Such a wave is called as an **under-modulated wave**
- If modulation index > 1, then the wave will be an **over-modulated wave**.

Under-Modulated wave



Over-Modulated wave





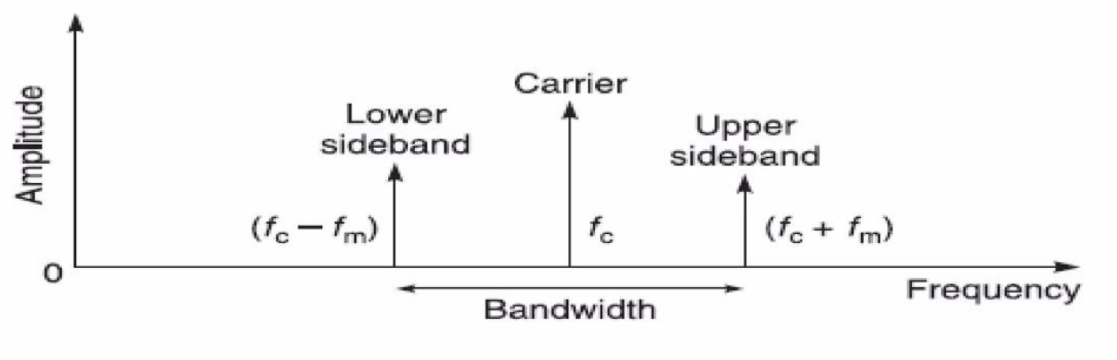
Bandwidth, Power and Efficiency of AM wave

Bandwidth

- Bandwidth (BW) is defined as the difference between the highest and lowest frequencies of the signal.
- Modulation produces 2 new components called sidebands, at frequencies above and below the carrier.
- The spacing in frequency between carrier and sidebands = f_m
- BW = Upper sideband frequency $(f_c + f_m)$ – Lower sideband frequency $(f_c - f_m)$

$= (f_c + f_m) - (f_c - f_m) = f_c + f_m - f_c + f_m = 2f_m$, twice the frequency of modulating signal

Frequency Spectrum



Power

- Power of AM wave is equal to the sum of powers of carrier, upper sideband, and lower sideband frequency components.
- Total Transmitted Power,

$$P_t = P_c + P_s = P_c + P_{USB} + P_{LSB}$$

$$= \frac{A_c^2}{2} + \frac{A_c^2\ \mu^2}{8} + \frac{A_c^2\ \mu^2}{8}$$

$$= \frac{A_c^2}{2}\left(1 + \frac{\mu^2}{2}\right) = P_c\left(1 + \frac{\mu^2}{2}\right)$$

$$\boldsymbol{P_t = P_c\left(1 + \frac{\mu^2}{2}\right)}$$

Efficiency

- $\eta = \frac{P_s}{P_t} = \frac{{}^1/_4 A_c^2\ \mu^2}{\frac{A_c^2}{2}\left(1+\frac{\mu^2}{2}\right)} = \frac{{}^1/_2\ \mu^2}{\left(1+\frac{\mu^2}{2}\right)} = \frac{\mu^2}{(2+\mu^2)}$

$$\eta = \frac{\mu^2}{(2+\mu^2)}$$

Redundancy

- $D = 1 - \eta = 1 - \frac{\mu^2}{(2+\mu^2)} = \frac{2+\mu^2-\mu^2}{(2+\mu^2)} = \frac{2}{(2+\mu^2)}$

$$D = \frac{2}{(2+\mu^2)}$$

Disadvantages of AM

- AM is bandwidth inefficient
- Information is in sidebands : power get wasted in carrier (this type of amplitude modulation is also called Double sideband full carrier (DSB-FC))

Applications of Amplitude Modulation

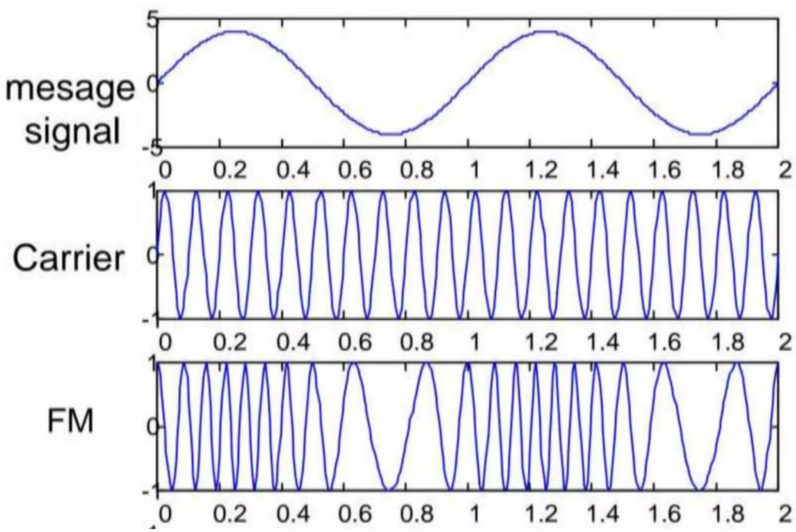
- **Radio Broadcasting**: AM is frequently utilized to send audio signals over great distances in radio broadcasting. The amplitude of a high-frequency carrier wave in AM radio is modulated by the audio signal (music, voice, etc.), which enables the wave to transport audio data.
- **Shortwave Broadcasting**: AM modulation is used in shortwave radio broadcasting to send signals over great distances. Large geographic areas can be covered via shortwave broadcasts, which are frequently utilized for distant locations, emergency communication, and worldwide broadcasting.
- **Wireless Communication**: AM modulation is used in a number of wireless communication systems, including audio transmission systems, wireless intercom systems, and wireless microphones. It offers an easy-to-use and efficient way to wirelessly transmit audio signals.

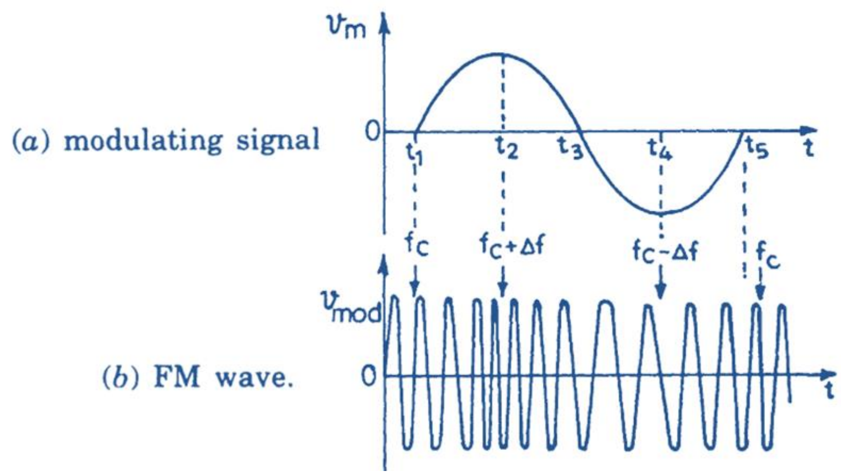
Types of Amplitude Modulation

- Double side band – full carrier (DSB-FC)
  - standard AM used for broadcasting.
  - The carrier conveys no information
- Double side band – suppressed carrier (DSB-SC)
  - Same as AM but without carrier
  - All transmitted power is contained in LSB and USB.
- Single sideband (SSB)
  - Either LSB or USB contains the complete information. Only one sideband is necessary for information transmission.
- Vestigial sideband (VSB)
  - Sideband is partly cutoff or suppressed
  - Limitation of SSB being used for voice signals and not available for video/TV signals leads to the usage of VSB

Frequency modulation

- the frequency of the carrier signal is varied in accordance with the Amplitude of the input modulating signal
- The frequency of a carrier (fc) will increase as the amplitude of modulating (input) signal increases. The carrier frequency will be maximum (f_{cmax}) when the input signal is at its peak. The frequency of a carrier will decrease as the amplitude of the modulating (input) signal decreases.





- Modulating signal, m(t)= $\boldsymbol{A_m Cos(2\pi f_m t)}$
- *Carrier signal, C(t)=* $\boldsymbol{A_c Cos(2\pi f_c t)}$
- The instantaneous frequency of the FM waveform at any given time is given by, $f_i = f_c + K_f \cdot m(t)$,

  K_f is the frequency sensitivity of the modulator
- Std. eqn of angle modulated wave, $\boldsymbol{s(t)=A_c Cos\, \theta_i(t)}$ ………….*(1)*
- *Instantaneous angular freq,* $\omega_i = \frac{d}{dt}\theta_i(t)$,

$$2\pi f_i t = \frac{d}{dt}\theta_i(t)$$

$$\theta_i(t) = 2\pi \int_0^t f_i \, dt = 2\pi \int_0^t f_c + Kf \cdot m(t) \; dt$$

$$= 2\pi \int_0^t f_c + Kf * A_m Cos(2\pi f_m t) \; dt$$

$$= 2\pi f_c t + \frac{K_f * A_m}{f_m} Sin\,(2\pi f_m t)$$

$$= 2\pi f_c t + \frac{\Delta f}{f_m} Sin\,(2\pi f_m t)$$, Δf is the frequency deviation

$$= 2\pi f_c t + \mu_f Sin\,(2\pi f_m t)$$, μ_f is the modulation index ……………(2)

- Freq. modulated signal $\boldsymbol{s(t)=A_c Cos\,(2\pi f_c t + \mu_f Sin\,(2\pi f_m t))}$ *(Substitute (2) in (1))*

Frequency modulated signal, s(t)=$\boldsymbol{A_c Cos\,(2\pi f_c t + \mu_f Sin\,(2\pi f_m t))}$

Types of FM

FM can be divided into **Narrowband FM** and **Wideband FM**.

Narrowband FM

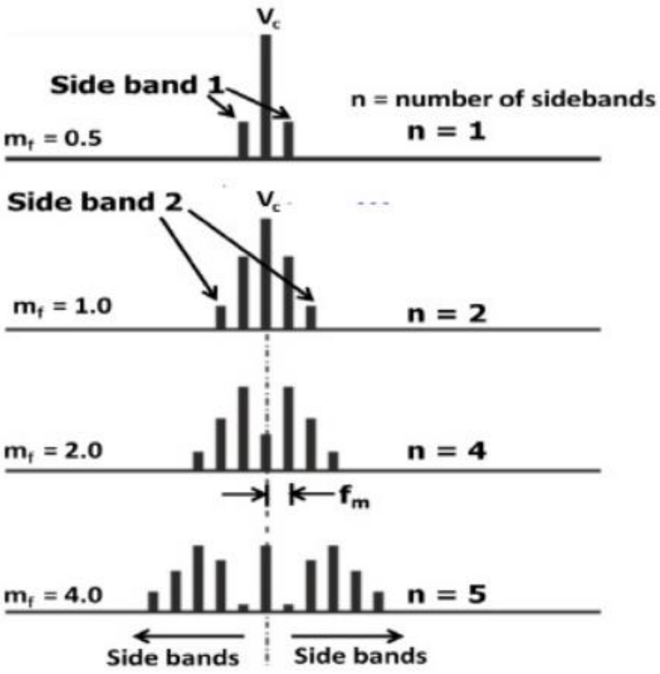
- has a small bandwidth.
- The modulation index is small.
- Its spectrum consists of carrier, USB, and LSB.
- This is used in mobile communications such as police wireless, ambulances, taxicabs, etc.

Wideband FM

- has infinite bandwidth.
- The modulation index is large, i.e., higher than **1**.
- Its spectrum consists of a carrier and infinite number of sidebands, which are located around it.
- This is used in entertainment broadcasting applications such as FM radio, TV, etc.

Bandwidth of Frequency Modulation Signal

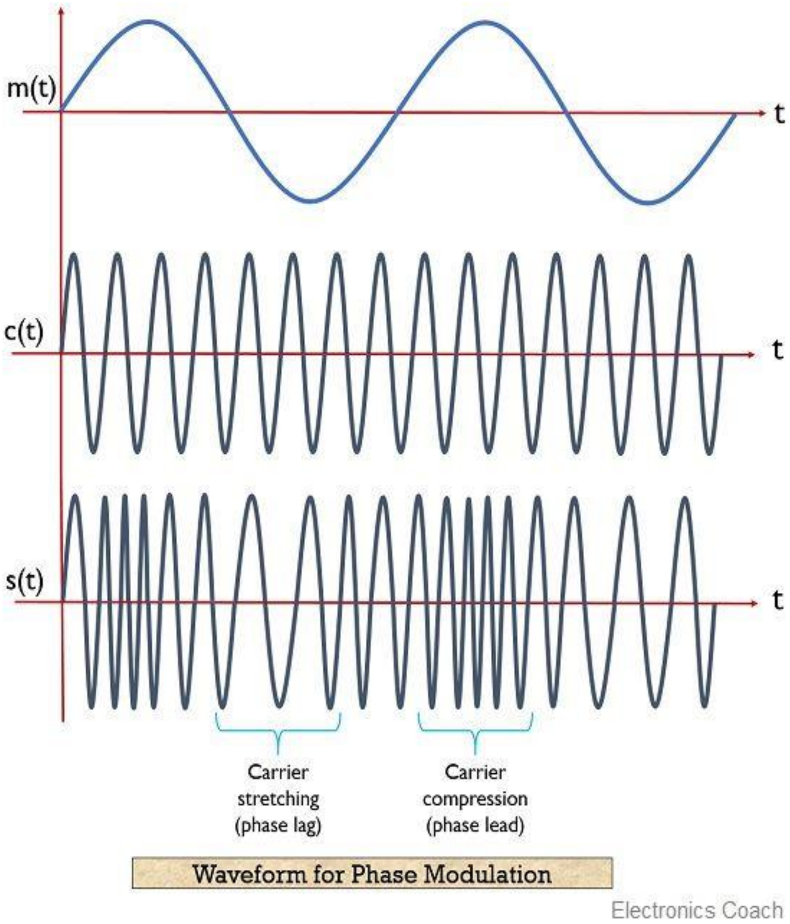
- FM signal spectrum is quite complex and will have an infinite number of sidebands as shown in the figure
- the spectrum expands as the modulation index increases.
- Sidebands are separated from the carrier by fc ± fm, fc ± 2fm, fc ± 3fm, and so on.
- Only the first few sidebands will contain the major share of the power



The bandwidth of FM Signal

Phase Modulation

- the phase of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.
- The amplitude of the carrier signal remains unchanged while phase change occurs.
- With the change in phase, the frequency of the signal also shows variation.
- when the amplitude of the sinusoidal signal starts to increase and reaches the maximum value, then the phase lead of the carrier signal gets increased. Due to this a compression in the carrier signal is noticed. This resultantly increases the frequency of the signal.
- when the amplitude of the modulating signal starts falling and attains a minimum value, then phase lag of the carrier wave occurs. Thereby causing stretching of the signal. Due to this, the frequency of the signal gets decreased.



Expression of Single Tone Phase Modulation

- The message signal, $\mathbf{x(t) = A_m \sin (\omega_m t)}$
- carrier signal, $\mathbf{c(t) = A_C \sin (\omega_c t + \varphi)}$
- The phase deviation is given as

$$\theta(t) \; \alpha \; x(t)$$

$\theta(t) = K_p\, x(t)$, Kp is the deviation sensitivity

(Kp = rad / V)

Phase modulated wave,

$$s(t) = A_C \sin (\omega_c t + \; K_p\, x(t))$$

$$s(t) = A_C \sin (\omega_c t + m_p \sin \omega_m t), \text{where } m_p = K_p\, A_m$$

m_p is the modulation index

Advantages of Phase Modulation

- The process of phase modulation is quite east than frequency modulation.
- This technique is used to determine the speed of the mobile target. Because for this the carrier is required to be constant and this is obtained in case of phase modulation.
- A phase modulated signal is more immune to noise effects.

Disadvantages of Phase Modulation

- In order to raise the modulation index of a phase modulated signal, frequency multipliers are needed.
- The system cost is quite expensive.
- Sometimes phase ambiguity exists when the modulation index exceeds a certain value.

Applications of Phase Modulation

- widely used in the transmission of radio waves.
- also employed in wireless signal transmission like satellite and Wi-Fi transmission etc.

Summary

- Communication system – basic model
- Wired & Wireless Communication
- Modulation & its need
- Amplitude Modulation
- Frequency Modulation
- Phase Modulation