Introduction to Digital and Analog Communication Systems

Why Digital?

- Less expensive circuits
- Privacy and security
- Small signals (less power)
- Converged multimedia
- Error correction and reduction

Why Not Digital?

- More bandwidth
- Synchronization in electrical circuits
- Approximated information

Information

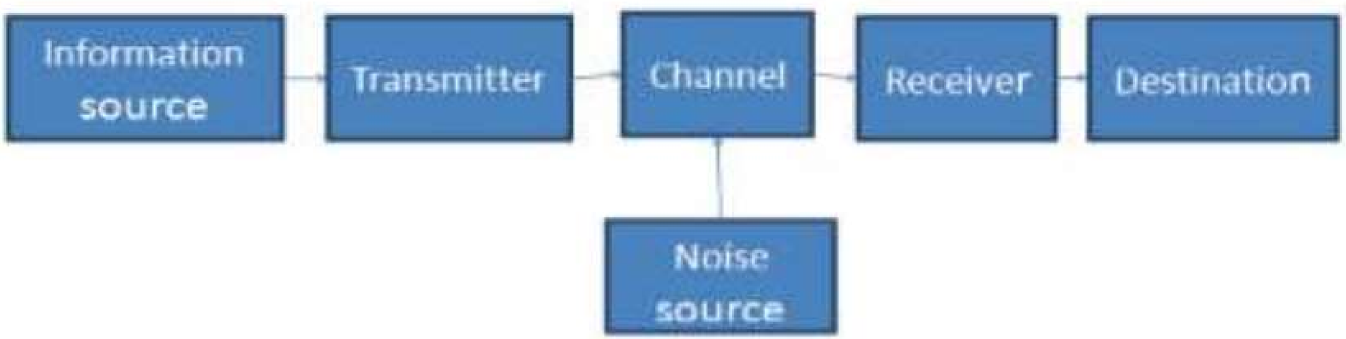
- Electronic communication systems are inherently analog.
- The process of communication is inherently discrete.
- Limitations
  - Noise or uncertainty
  - Changes in system characteristics

Elements of Communication System:

Communication: It is the process of conveying or transferring information from one point to another.

(Or)

It is the process of establishing connection or link between two points for information exchange.



Information source:

The message or information to be communicated originates in information source.

Message can be words, group of words, code, data, symbols, signals etc.

Transmitter :

The objective of the transmitter block is to collect the incoming message signal and modify it in a suitable fashion (if needed), such that, it can be transmitted via the chosen channel to the receiving point.

Channel :

Channel is the physical medium which connects the transmitter with that of the receiver.

The physical medium includes copper wire, coaxial cable, fibre optic cable, wave guide and free space or atmosphere.

Receiver:

The receiver block receives the incoming modified version of the message signal from the channel and processes it to recreate the original (non-electrical) form of the message signal.

Signal, Message, Information

Signal:

It is a physical quantity which varies with respect to time or space or independent or dependent variable.

(Or)

It is electrical waveform which carries information.

Ex: $m(t) = A\cos(\omega t+\varphi)$

Where, A= Amplitude or peak amplitude(Volts)

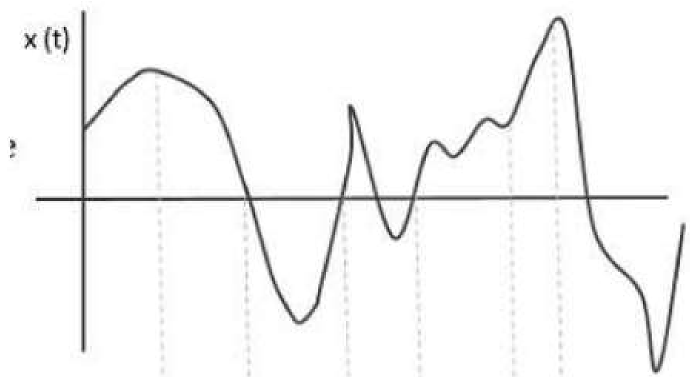
w = Frequency (rad/sec)

φ = Phase (rad)

Types of Signals

- Analog or Continuous Signal
- Digital Signal

Analog or Continuous Signal: If the amplitude of signal continuously varies with respect to time or if the signal contains infinite number of amplitudes, it is called Analog or continuous signal.



Types of Signals

Digital Signal: If the signal contains only two discrete amplitudes, then it is called digital signal.

- With respect to communication, signals are classified into,
- Baseband signal
- Bandpass signal

Baseband signal: If the signal contains zero frequency or near to zero frequency, it is called baseband signal.

Ex: Voice, Audio, Video, Bio-medical signals etc.

Types of Signals

Bandpass signal: If the signal contains band of frequencies far away from base or zero, it is called bandpass signal.

Ex: AM, FM signals.

Message: It is sequence of symbols.

Ex: Happy New Year 2020.

Information: The content in the message is called information. It is inversely proportional to probability of occurrence of the symbol.

- Information is measured in bits, decits, nats.

Limitations of Communication System

- **Technological Problems**:

To implement communication systems, Tx, Rx, channel are required which requires hardware. Communication system is expensive and complex.

- **Bandwidth & Noise**:

The effect of noise can be reduced by providing more bandwidth to stations but due to this less number of stations can only be accommodated.

- **Signal to Noise Ratio (SNR)**:Noise should be low to increase channel capacity but it is an unavoidable aspect of communication system.

Modulation

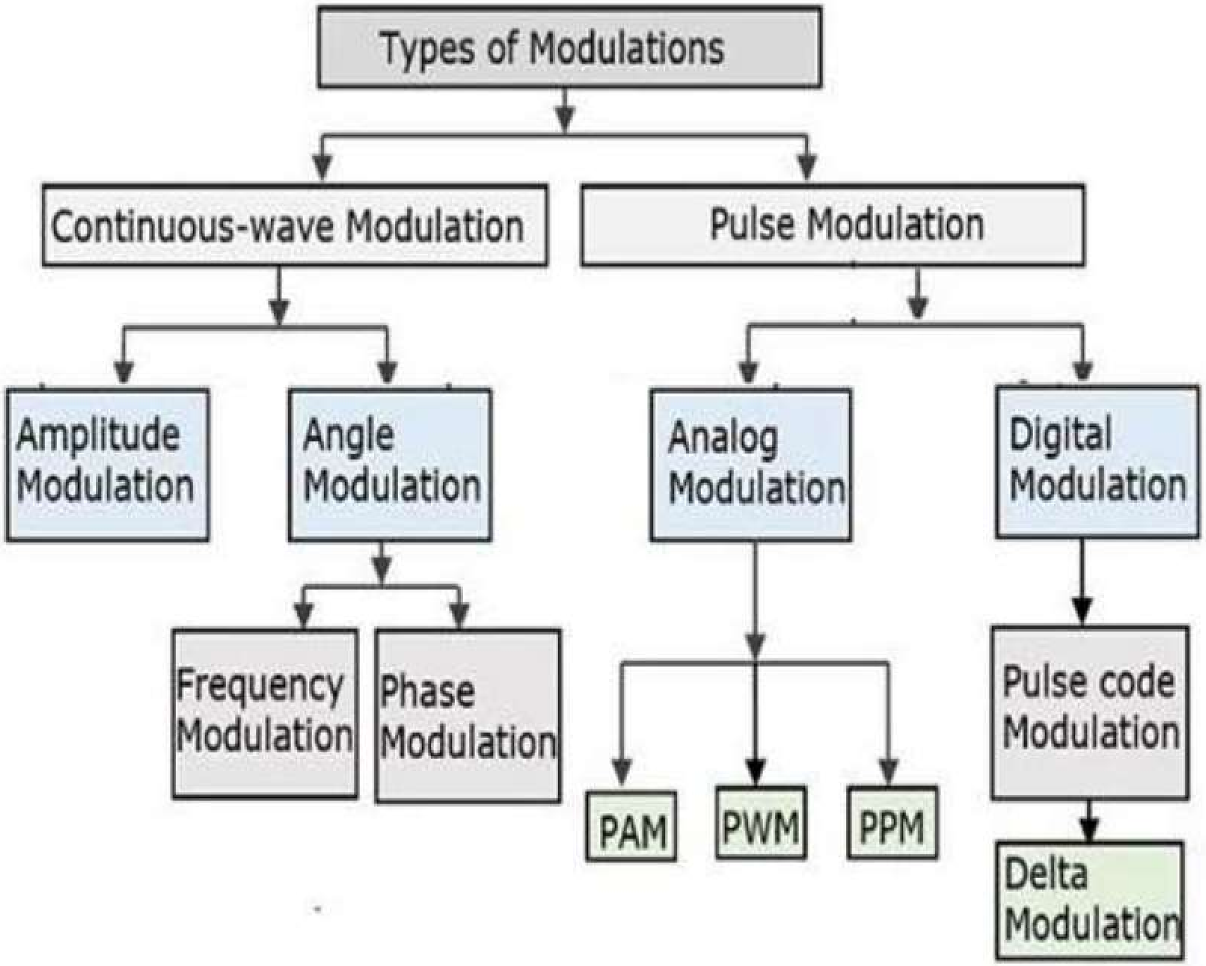
It is the process of varying the characteristics of high frequency carrier in accordance with instantaneous values of modulating or message or baseband signal.

(Or)

It is a frequency translation technique which converts baseband or low frequency signal to bandpass or high frequency signal.

Modulation is used in the transmitter.

Types of Modulation



Types of Modulation

- **Amplitude Modulation**: Amplitude of the carrier is varied in accordance with the instantaneous values of modulating signal.

- **Frequency Modulation**: Frequency of the carrier is varied in accordance with the instantaneous values of modulating signal.

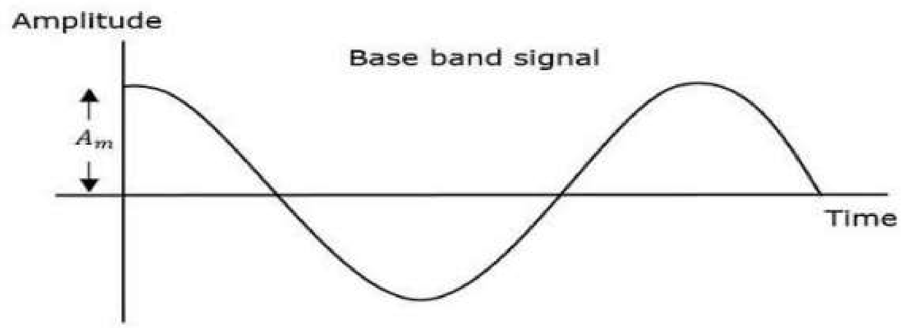
- **Phase Modulation**: Phase of the carrier is varied in accordance with the instantaneous values of modulating signal.

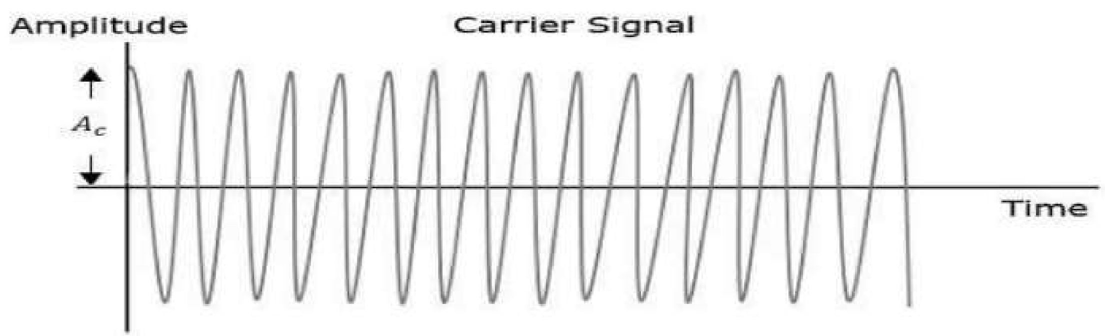
Benefits or Need of Modulation

- To reduce the length or height of antenna
- For multiplexing
- For narrow banding or to use antenna with single or same length
- To reduce noise effect
- To avoid equipment limitation or to reduce the size of the equipment.

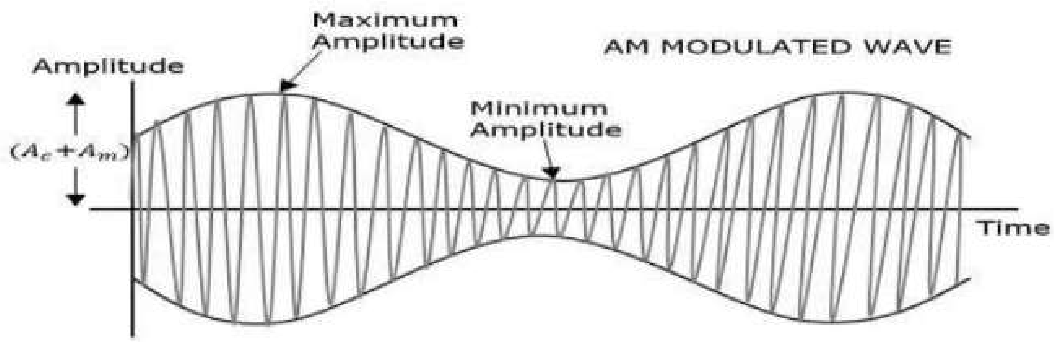
Amplitude Modulation

The amplitude of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.





Amplitude Modulation



The carrier signal is given by,

$$C(t) = Ac\ Cosw_c t$$

Where, Ac= Maximum amplitude of the carrier signal.

W= 2πfc= Frequency of the carrier signal.

Modulating or baseband signal is given by,

$$X(t) = Am\ Cosw_m t$$

Where, Am = Amplitude of the baseband signal.

Modulation Index

Modulation index or depth of modulation is given by,

$$m_a = [Amax\text{-}Amin/\ Amax+Amin] = A_m/A_c$$

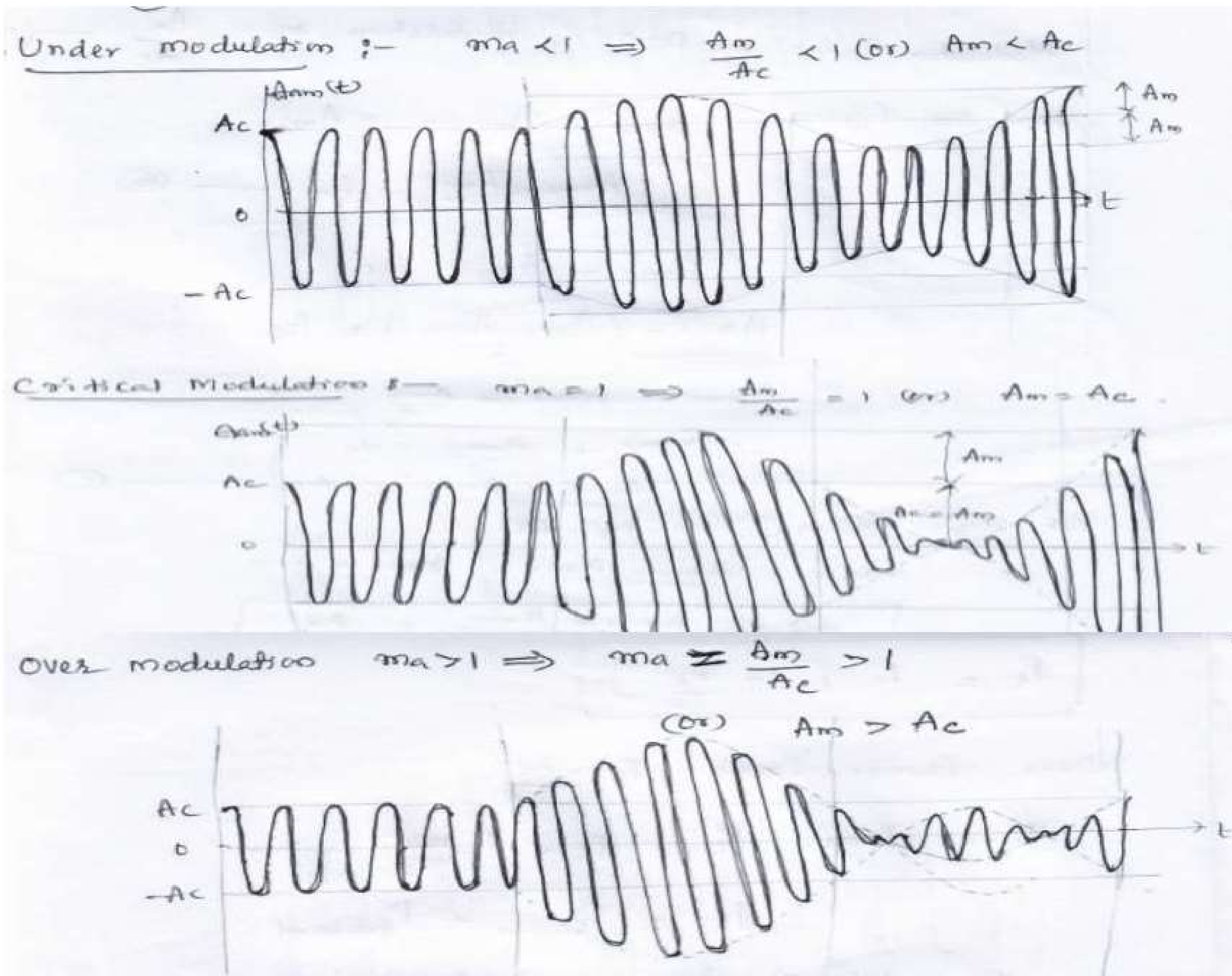
Percentage of modulation index is,

$$\%m_a = [Amax\text{-}Amin/\ Amax+Amin]X100 = [A_m/A_c\ ]X100$$

Types of AM with respect to modulation index:

- Under Modulation (m_a <1)
- Critical Modulation (m_a =1)
- Over Modulation (m_a >1)

Types of AM



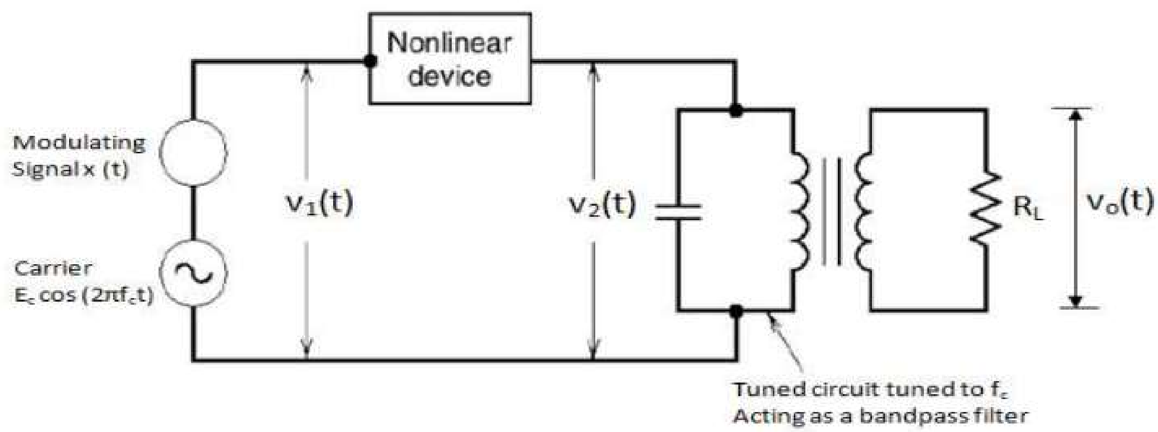
Under modulation :- ma < 1 ⇒ Am/Ac < 1 (or) Am < Ac
Am(t)
Ac
0
−Ac
Am
Am
t
Critical Modulation :- ma = 1 ⇒ Am/Ac = 1 (or) Am = Ac
Ac
0
Am
Ac = Am
t
Over modulation ma > 1 ⇒ ma = Am/Ac > 1
(or) Am > Ac
Ac
0
−Ac
t

Generation of AM Wave

Square Law modulator:

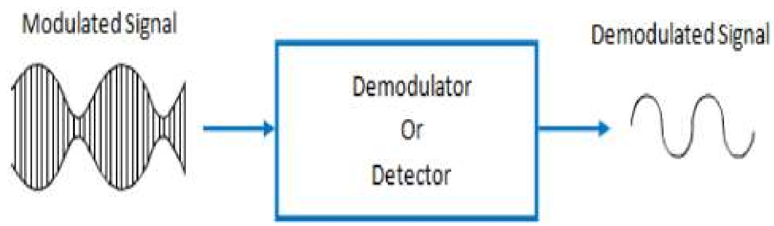
This circuit consists of,

- A non-linear device
- Band pass filter
- Carrier source and modulating signal



Detection of AM Wave

Demodulation or detection is the process of recovering the original message signal from the received modulated signal.



Types of AM Detectors:

1. Square Law detector
2. Envelope detector
3. Rectifier detector

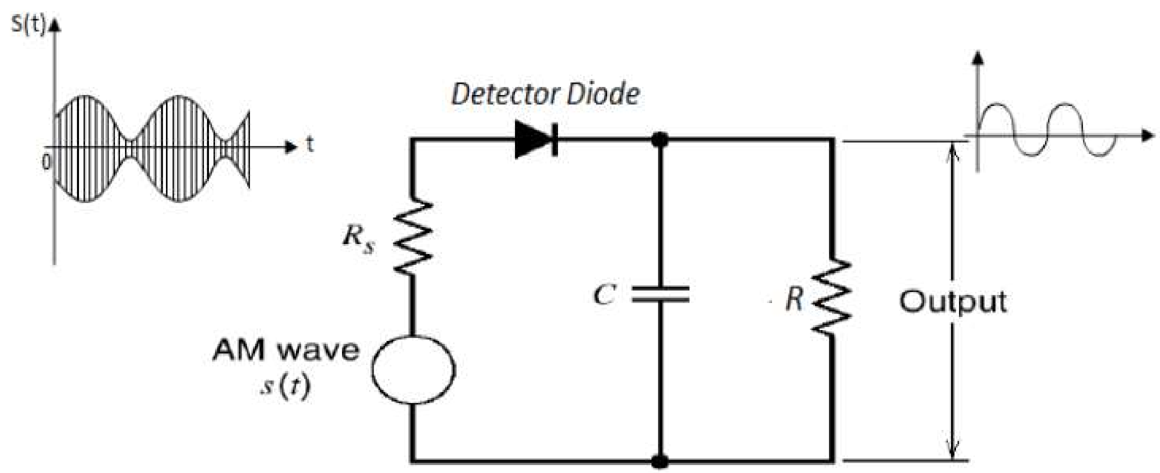
Detection of AM Wave

In order to extract the original message signal, V2(t) is passed through a low pass filter .

The output of LPF is,

$$V0(t) = mbAc^2x(t) \text{ ---(3)}$$

Envelope Detector:



Detection of AM Wave

- In rectifier detector, diode acts as rectifier which allows only positive half of the modulated signal to the filter.

- The low pass filter removes all the high frequency components giving envelope at its output.

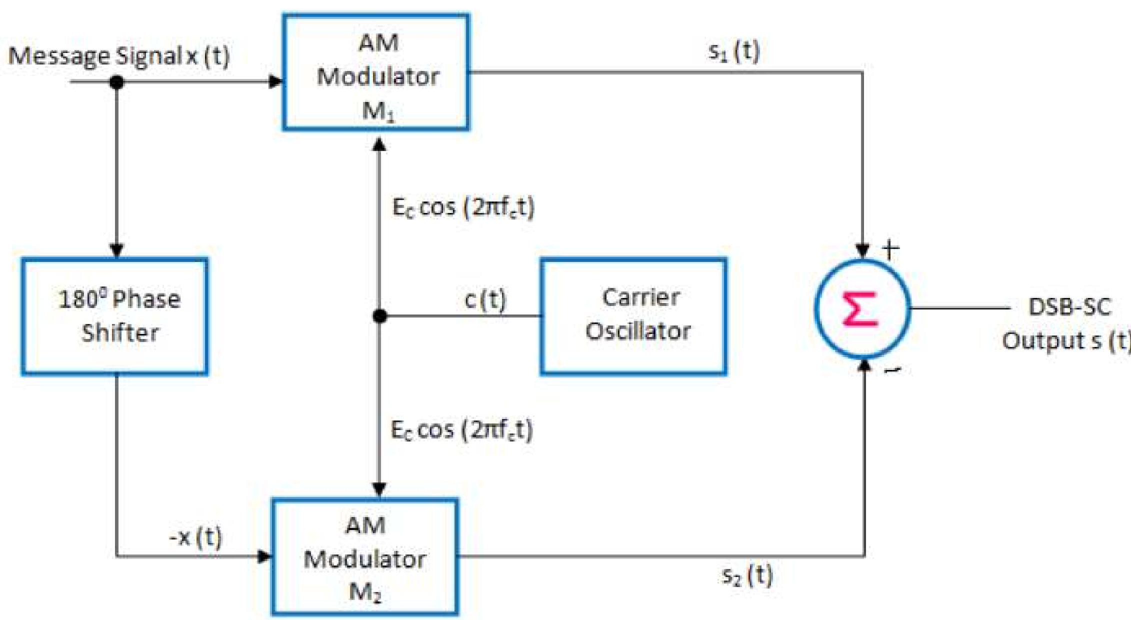
- This envelope will have some dc value which can be removed by passing through capacitor ‘C’.

- The output of rectifier detector is the envelope with zero dc value.

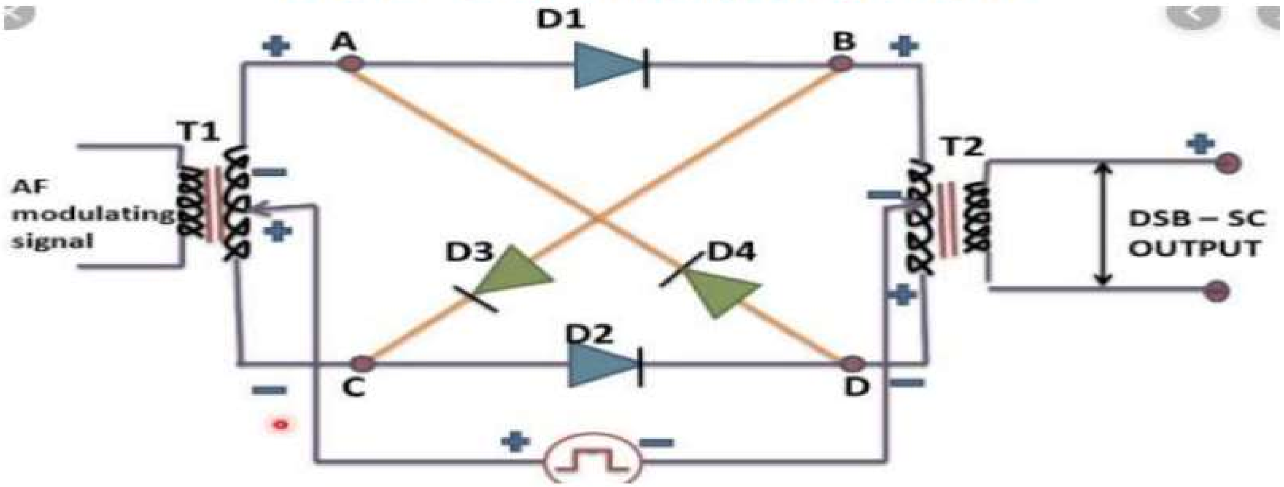
DSB-SC Modulation

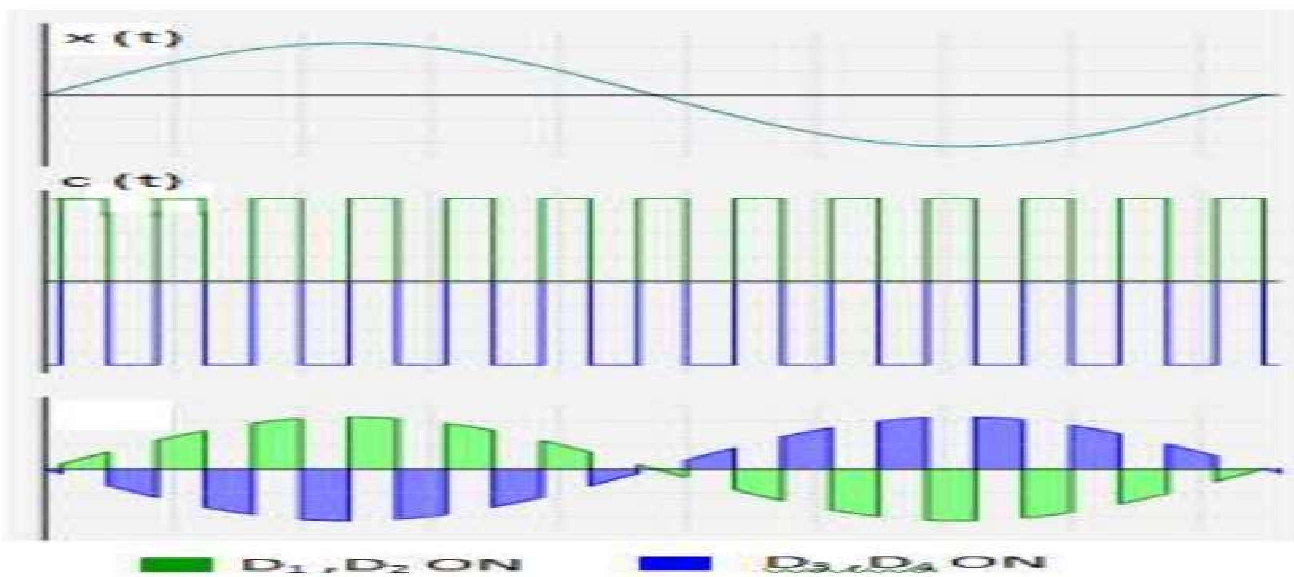
1. **Balanced Modulator**:

It consists of two amplitude modulators arranged in balanced configuration to suppress the carrier completely.



DSB-SC Modulation





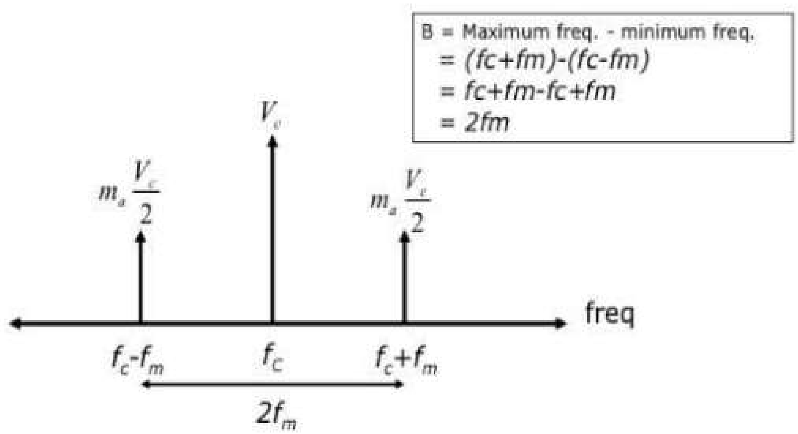
Frequency Domain representation of DSB-SC

The frequency spectrum of DSB-SC is obtained by taking Fourier transform of s(t)

S(f) = F{[1/2AmAc[cos2π(fc+fm)t + cos2π(fc-fm)t]}

$$S(f) = \frac{1}{4}AmAc[\delta(f+fc+fm)+\delta(f-fc-fm)+\delta(f+fc-fm)+\delta(f-fc+fm)$$

This is the spectrum of DSB-SC wave.



Single Sideband-Suppressed Carrier(SSB-SC)

The modulation process in which only one side band is transmitted and with carrier suppression is called Single sideband suppressed carrier (SSB-SC).

Modulating Signal $m(t) = A_m \text{Cos}(2\pi f_m t)$ and Carrier Signal $c(t) = A_c \text{Cos}(2\pi f_c t)$

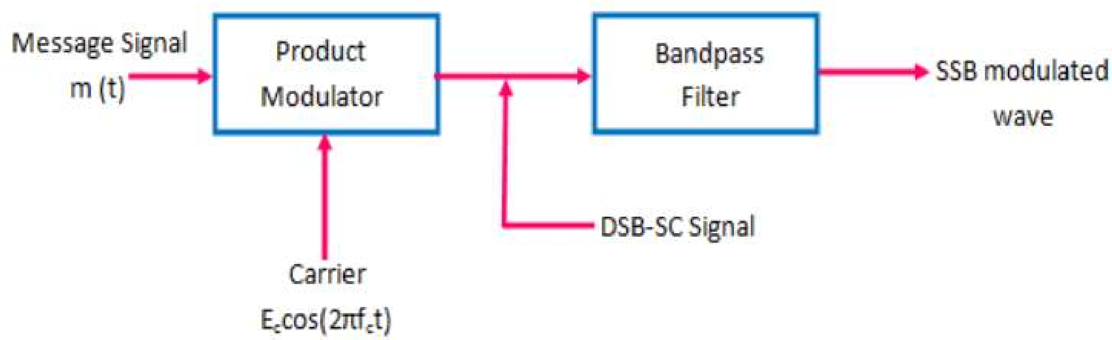
SSB-SC signal can be generated by passing DSB-SC signal through BPF. And DSB-SC signal is generated by multiplying m(t) & c(t).

$A_{SSB\text{-}SC}(t) = \frac{A_m A_c}{2} \text{Cos}2\pi(f_c + f_m)t$ (or)

$A_{SSB\text{-}SC}(t) = \frac{A_m A_c}{2} \text{Cos}2\pi(f_c - f_m)t$

Generation of SSB-SC

1. Filter or Frequency Discrimination Method:

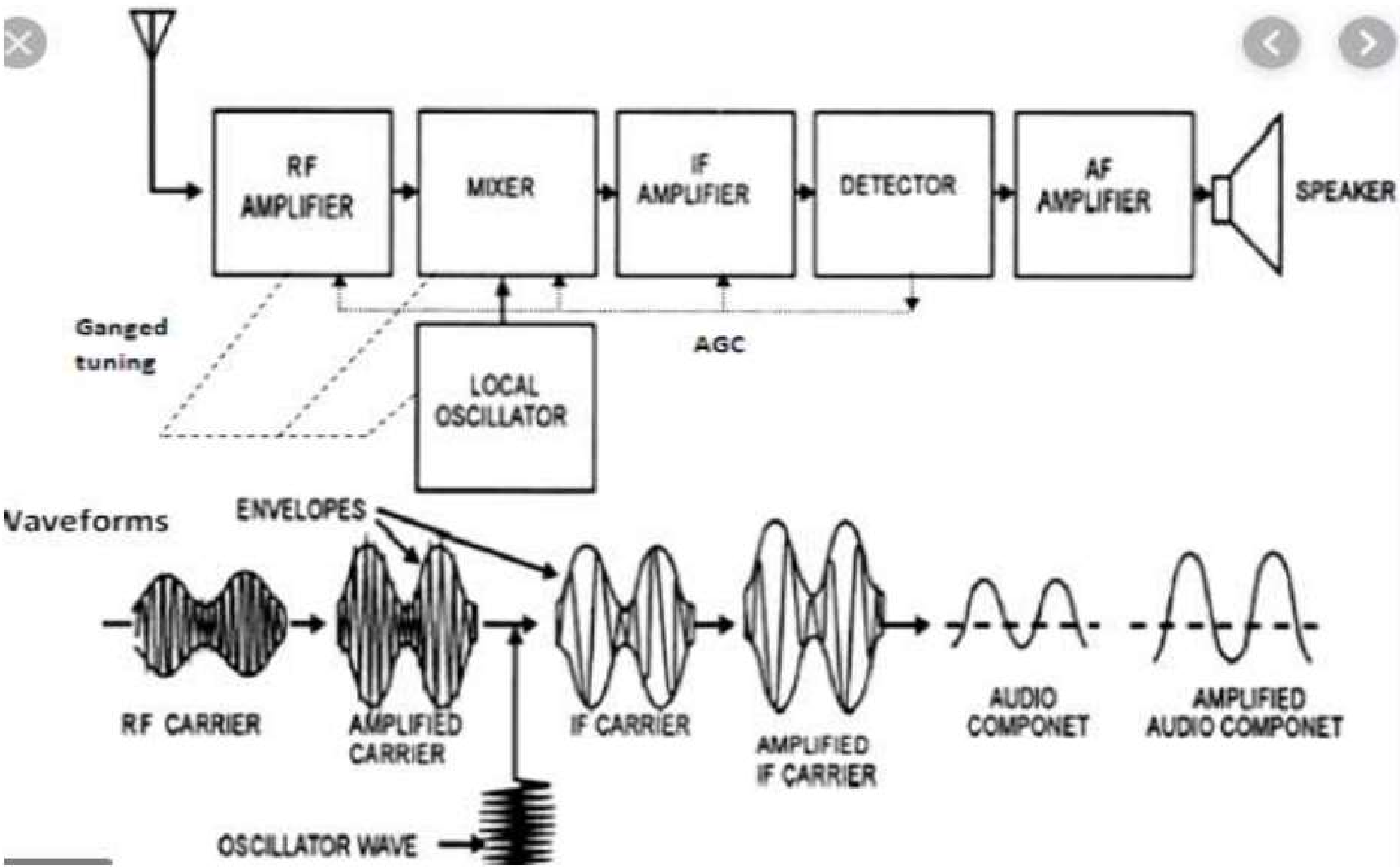


Filter method of generating DSB-SC Signal requires product modulator and BPF as shown in figure.

Here Product Modulator generates DSB-SC Signal which contains two side bands i.e USB & LSB.

By passing DSB-SC Signal through BPF either of sidebands are removed for generating SSB-SC Signal.

Super Heterodyne AM Receiver



Super Heterodyne AM Receiver

Antenna: It is passive device which converts electromagnetic signal into electrical signal.

RF Tuned Amplifier:

- It is broad band amplifier which contain tuning circuit and amplifier.
- Tuning circuit designed to select 110 stations and amplifier provides amplification for 1100 KHz band width.
- RF tuned amplifier is responsible for sensitivity, selectivity, Image signal rejection and noise reduction.

Mixer:

- It is combination of frequency mixer and Band Pass Filter (BPF).
- Frequency generates sum and difference frequency of incoming signal and locally generated signal.
- BPF selects difference frequency at the output whose center frequency is equal to= 455 KHz.

Local Oscillator:

- It is either Colpits or Hartley oscillator.
- It generates carrier frequency 455 KHz greater than the incoming carrier frequency to produce constant or fixed frequency.

Super Heterodyne AM Receiver

IF Amplifier:

- It is narrow band, high gain and fixed frequency amplifier which provides amplification for 10 KHz band width at center frequency of 455 KHz.
- It is cascade CE amplifier which provides 90% of total receiver amplification.

Detector or Demodulator:

- It is frequency translator circuit which extracts modulating signal from AM signal.
- Usually Envelope detector is used.
- Fidelity of the receiver is mainly depends on detector or demodulator.

Audio Amplifier:

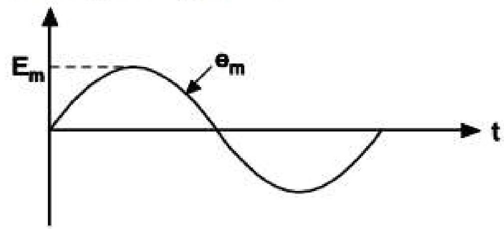
- It is low frequency amplifier which provides amplification at (20- 20K) Hz.
- It contain cascade CE Voltage amplifier followed by Power amplifier.

Loud Speaker:

- It converts Electrical signal into sound or audio signal.

Mathematical Representation of FM

(i) Modulating Signal:



It may be represented as,

$$e_m = E_m \cos \omega_m t \qquad \ldots(1)$$

Here cos term taken for simplicity

where,

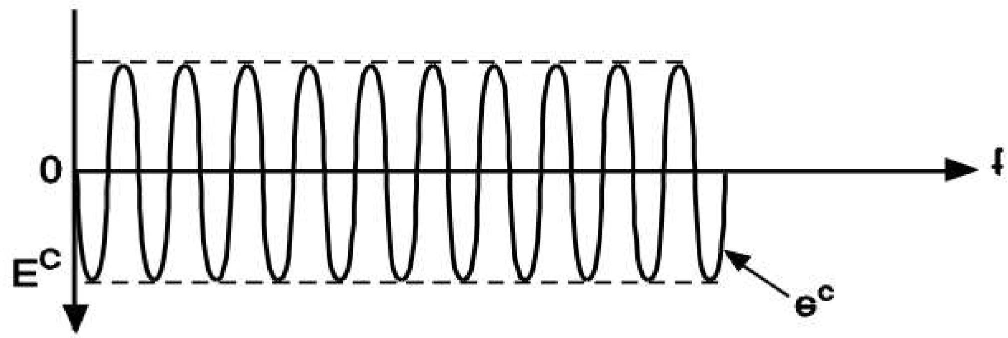
e_m = **Instantaneous amplitude**

ω_m = **Angular velocity**

= $2\pi f_m$

f_m = **Modulating frequency**

(ii) Carrier Signal:



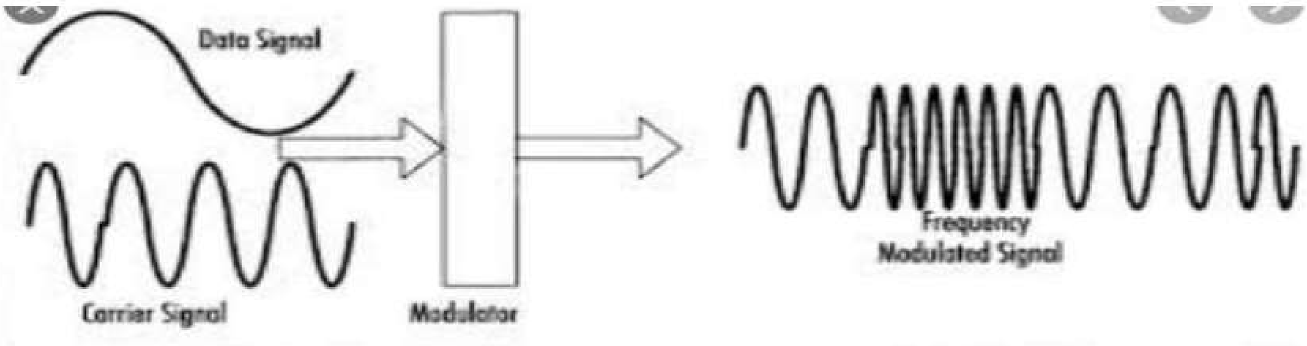
Carrier may be represented as,

$$e_c = E_c \sin(\omega_{ct} + \phi) \qquad \text{-----(2)}$$

where,

e_c	=	Instantaneous amplitude
ω_c	=	Angular velocity
	=	$2\pi f_c$
f_c	=	Carrier frequency
ϕ	=	Phase angle

Frequency Modulation



Frequency modulator converts input voltage into frequency i.e the amplitude of modulating signal m(t) changes to frequency at the output.

Consider carrier signal c(t) =Ac Coswct

The frequency variation at the output is called instantaneous frequency and is expressed as,

$$w_i = w_c + k_f\, m(t)$$

Where, k_f = frequency sensitivity factor in Hz/volt

Frequency Spectrum of FM

Frequency spectrum is a graph of amplitude versus frequency. The frequency spectrum of FM wave tells us about number of sideband present in the FM wave and their amplitudes.

The expression for FM wave is not simple. It is complex because it is sine of sine function.

Only solution is to use **'Bessels Function'.**

Equation (2.32) may be expanded as,

$$
\begin{aligned}
e_{FM} = \quad & \{A\, J_0\,(m_f)\,\sin \omega_c t \\
& + J_1\,(m_f)\,[\sin(\omega_c + \omega_m)\,t - \sin(\omega_c - \omega_m)\,t] \\
& + J_1\,(m_f)\,[\sin(\omega_c + 2\omega_m)\,t + \sin(\omega_c - 2\omega_m)\,t] \\
& + J_3\,(m_f)\,[\sin(\omega_c + 3\omega_m)\,t - \sin(\omega_c - 3\omega_m)\,t] \\
& + J_4\,(m_f)\,[\sin(\omega_c + 4\omega_m)\,t + \sin(\omega_c - 4\omega_m)\,t] \\
& + \ldots\ldots\} \qquad \ldots (2.33)
\end{aligned}
$$

From this equation it is seen that the FM wave consists of:

(i) Carrier (First term in equation).

(ii) Infinite number of sidebands (All terms except first term are sidebands).

The amplitudes of carrier and sidebands depend on 'J' coefficient.

$\omega_c = 2\pi f_c, \qquad \omega_m = 2\pi f_m$

So in place of ω_c and ω_m, we can use f_c and f_m.

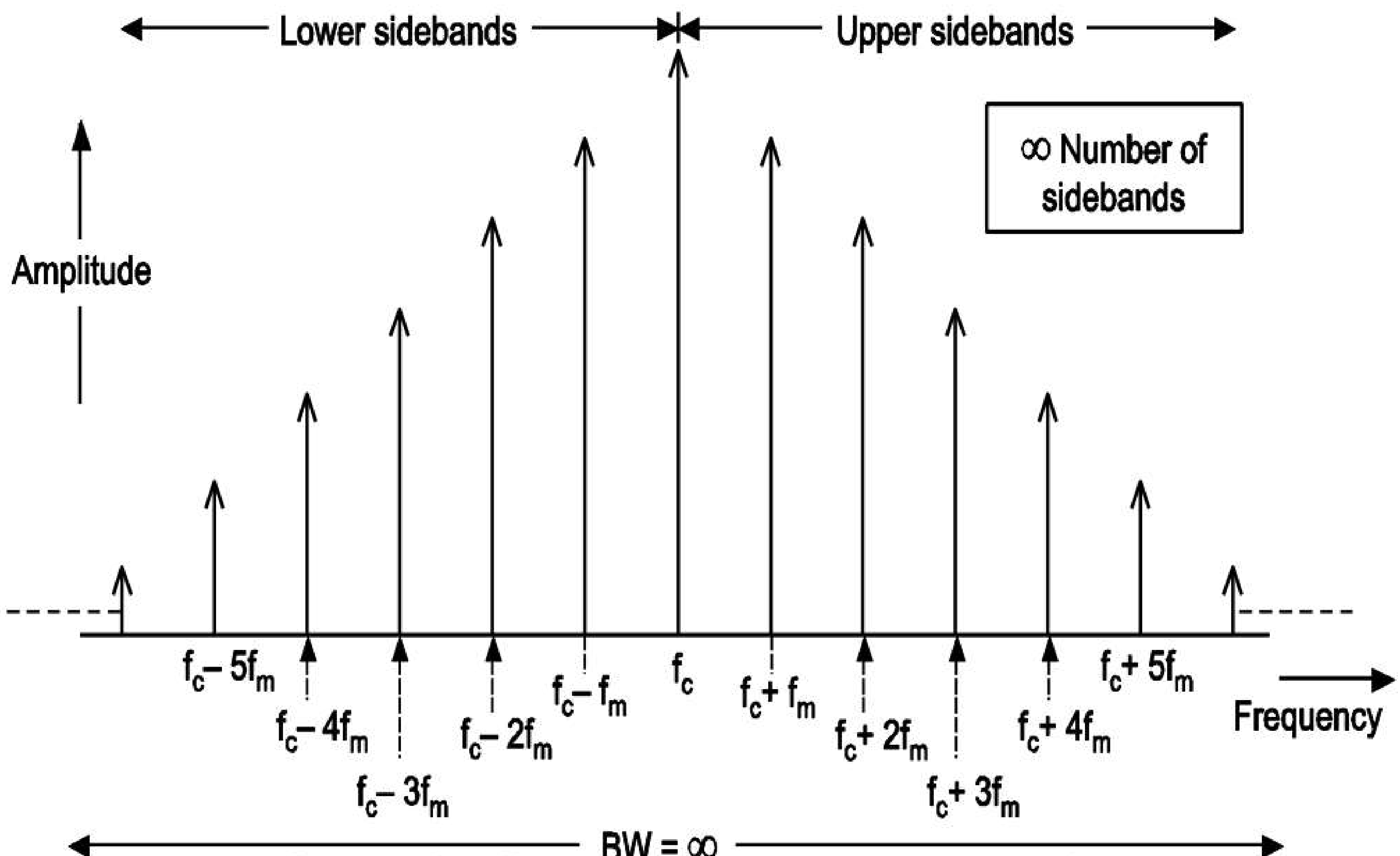


Fig. : Ideal Frequency Spectrum of FM

Bandwidth of FM

From frequency spectrum of FM wave shown in Fig. 2.26, we can say that the bandwidth of FM wave is infinite.

But practically, it is calculated based on how many sidebands have significant amplitudes.

(i)The Simple Method to calculate the bandwidth is –

$$BW = 2f_m \times \text{Number of significant sidebands} \quad \text{--(1)}$$

With increase in modulation index, the number of significant sidebands increases. So that bandwidth also increases.

(ii)The second method to calculate bandwidth is by **Carson's rule.**

Carson's rule states that, the bandwidth of FM wave is twice the sum of deviation and highest modulating frequency.

$$BW=2(\delta+\mathbf{fmmax}) \qquad \ldots(2)$$

Highest order side band = To be found from table 2.1 after the calculation of modulation Index m where, m = **δ/fm**

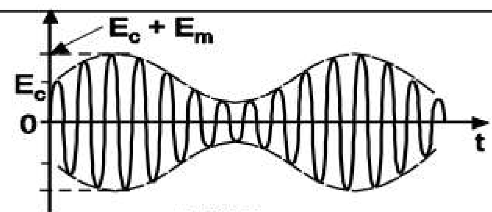
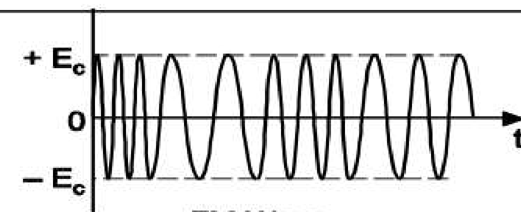
e.g. If m= 20KHZ/5KHZ

From table, for modulation index 4, highest order side band is 7^{th}.

Therefore, the bandwidth is

$$B.W. = 2\ f_m \times \text{Highest order side band}$$
$$=2 \times 5\ \text{kHz} \times 7$$
$$=70\ \text{kHz}$$

Comparison between AM and FM

Parameter	AM	FM
1. Definition	Amplitude of carrier is varied in accordance with amplitude of modulating signal keeping frequency and phase constant.	Frequency of carrier is varied in accordance with the amplitude of modulating signal keeping amplitude and phase constant.
2. Constant parameters	Frequency and phase.	Amplitude and phase.
3. Modulated signal	 AM Wave	 FM Wave
4. Modulation Index	m=Em/Ec	m = δ/ fm
5. Number of sidebands	Only two	Infinite and depends on m_f.
6. Bandwidth	BW = $2f_m$	BW = 2 ($\delta + f_{m\,(max)}$)
7. Application	MW, SW band broadcasting, video transmission in TV.	Broadcasting FM, audio transmission in TV.

Advantages/ Disadvantages/Applications of FM

Advantages of FM

1. Transmitted power remains constant.
2. FM receivers are immune to noise.
3. Good capture effect.
4. No mixing of signals.

Disadvantages of FM

The greatest disadvantages of FM are:

1. It uses too much spectrum space.
2. The bandwidth is wider.
3. The modulation index can be kept low to minimize the bandwidth used.
4. But reduction in M.I. reduces the noise immunity.
5. Used only at very high frequencies.

Applications of FM

1. FM radio broadcasting.
2. Sound transmission in TV.
3. Police wireless.