Unit-2

Analog communication

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Why modulation ?

I. Long distance communication

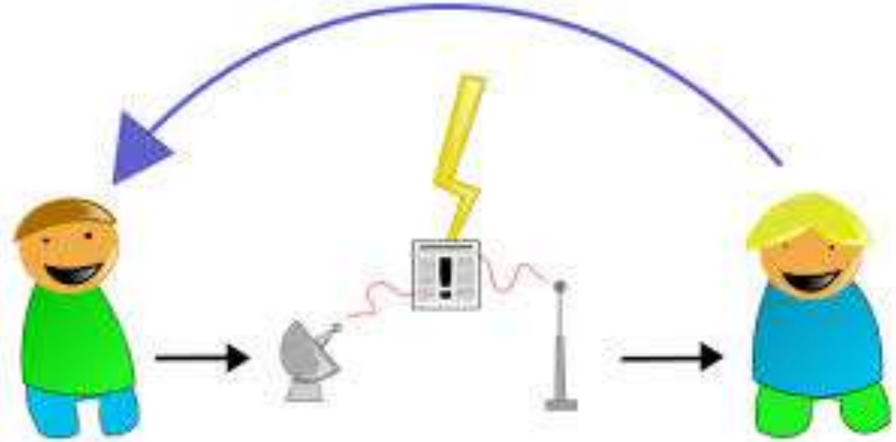
- The message signal is low frequency signal that cannot be transmitted over the transmission channel directly.
- These channels are suited for transmitting high frequency signal for long distance.

II. Interference

- In radio communication, signals from various sources are transmitted through a common media, that is open space.
- This cause interference among various signals, and no use full message is received or recovered by the receiver.
- The problem of interference is solved by translating the message signals to different radio frequency spectra (frequency translation)

BARRIERS TO COMMUNICATION

(Noise/ Interference)



Modulation improves the strength of the signal without disturbing the parameters of the original signal.

What is Modulation?

- A message carrying a signal has to get transmitted over a distance and for it to establish a reliable communication, it needs to take the help of a high frequency signal which should not affect the original characteristics of the message signal.

- A high frequency signal can travel up to a longer distance, without getting affected by external disturbances.
- We take the help of such high frequency signal which is called as a **carrier signal** to transmit our message signal.
- Such a process is simply called as Modulation.

Need for Modulation

- Baseband signals are incompatible for direct transmission.
- For such a signal, to travel longer distances, its strength has to be increased by modulating with a high frequency carrier wave, which doesn’t affect the parameters of the modulating signal.

Advantages of Modulation

- Reduction of antenna size
- No signal mixing
- Increased communication range
- Multiplexing of signals
- Possibility of bandwidth adjustments
- Improved reception quality

Modulation process

Message or Modulating Signal

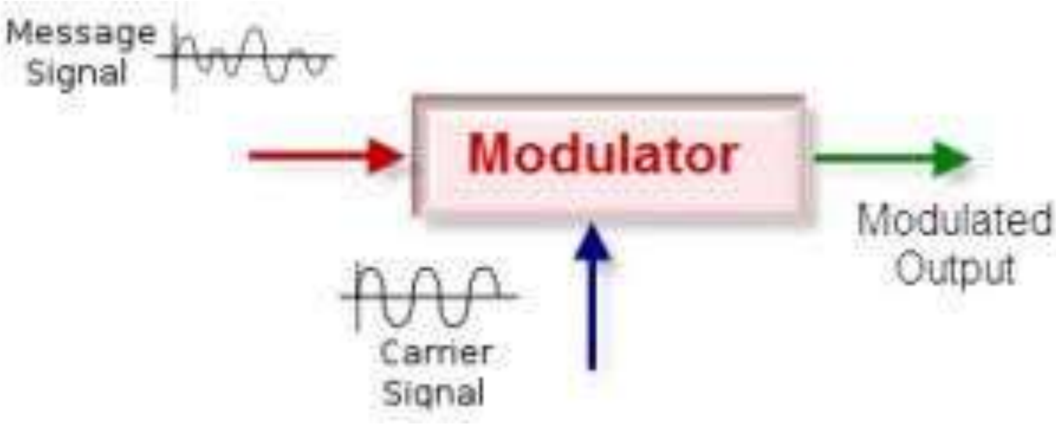
- The signal which contains a message to be transmitted, is called as a **message signal**.
- It is a baseband signal, which has to undergo the process of modulation, to get transmitted.
- Hence, it is also called as the **modulating signal**.

Carrier Signal

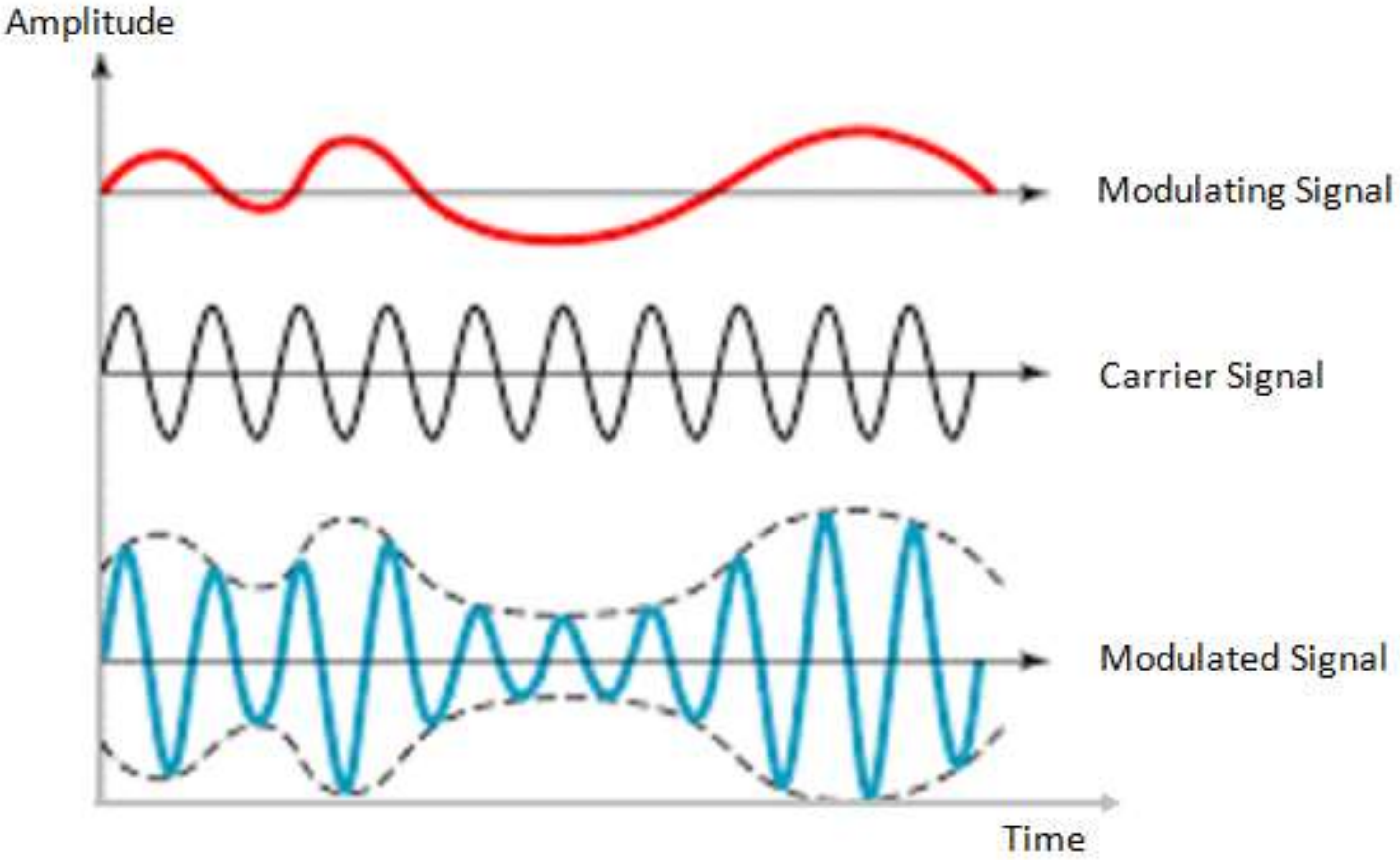
- The high frequency signal which has a certain phase, frequency, and amplitude but contains no information, is called a **carrier signal**.
- It is an empty signal. It is just used to carry the signal to the receiver after modulation.

Modulated Signal

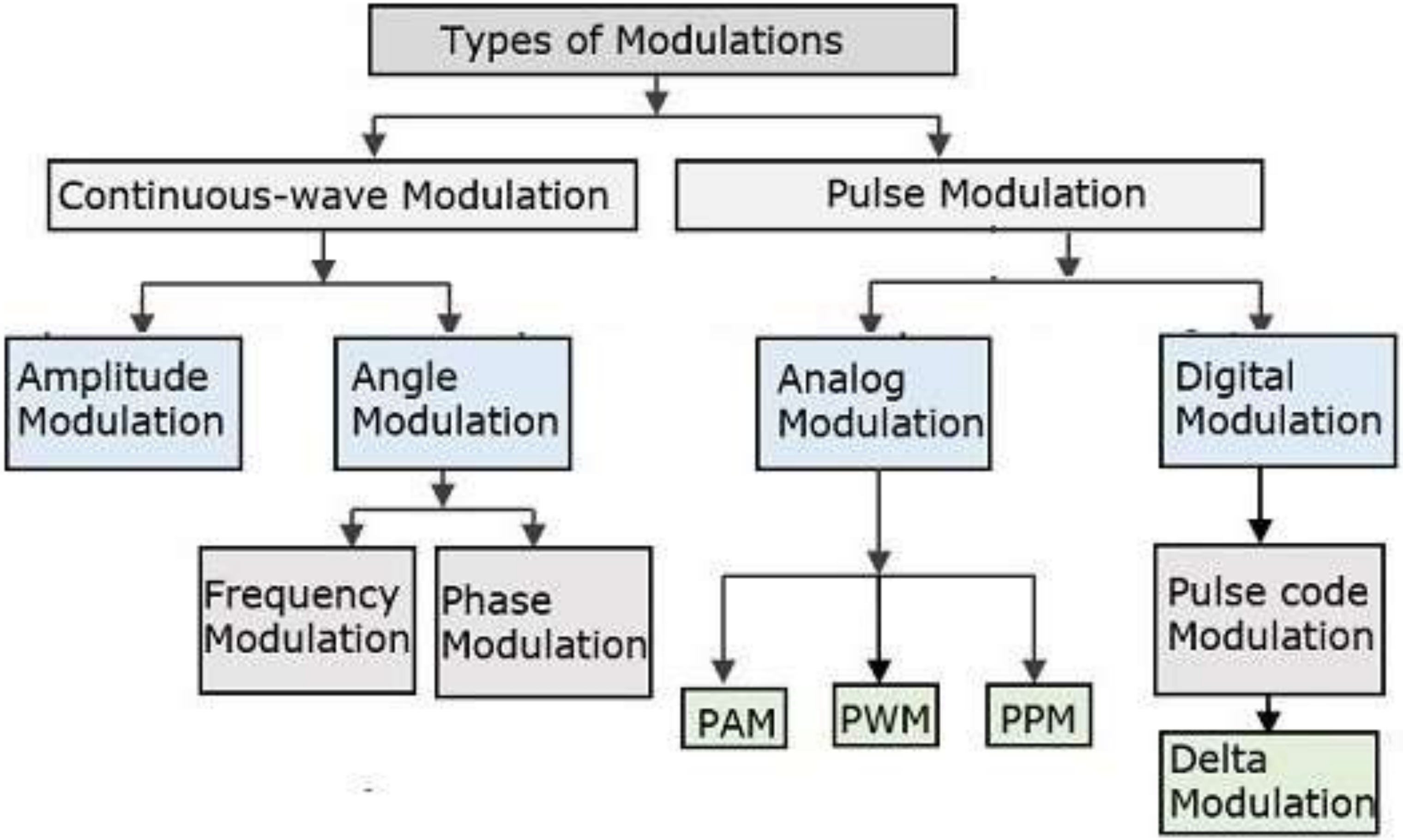
- The resultant signal after the process of modulation, is called as the **modulated signal**.
- This signal is a combination of the modulating signal and the carrier signal.



Example


Amplitude
Modulating Signal
Carrier Signal
Modulated Signal
Time

Types of Modulation



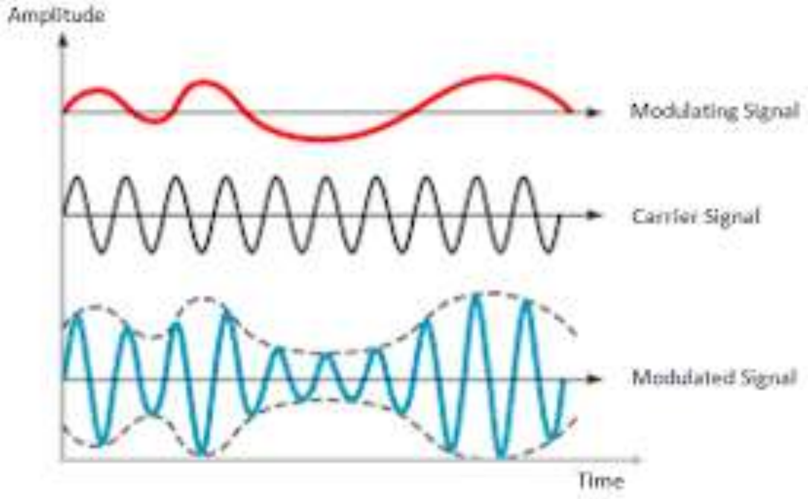
- Types of Modulations
  - Continuous-wave Modulation
    - Amplitude Modulation
    - Angle Modulation
      - Frequency Modulation
      - Phase Modulation
  - Pulse Modulation
    - Analog Modulation
      - PAM
      - PWM
      - PPM
    - Digital Modulation
      - Pulse code Modulation
        - Delta Modulation

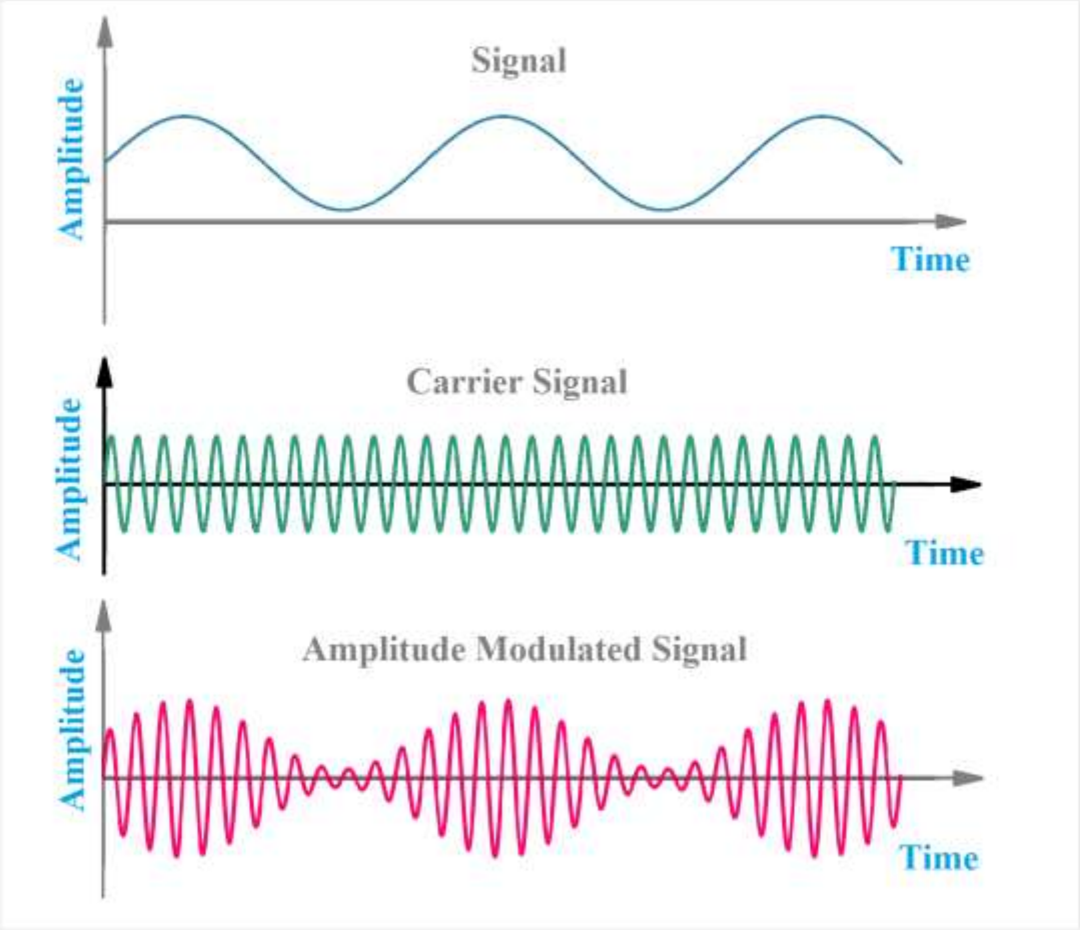
Continuous-wave Modulation

- In continuous-wave modulation, a high frequency sine wave is used as a carrier wave.
- This is further divided into amplitude and angle modulation

Amplitude Modulation.

- If the amplitude of the high frequency carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal, then such a technique is called as **Amplitude Modulation**.




Signal
Amplitude
Time
Carrier Signal
Amplitude
Time
Amplitude Modulated Signal
Amplitude
Time

Amplitude Modulation

2.1. INTRODUCTION

- ***Amplitude modulation (AM) is the process by which amplitude of the carrier signal is varied in accordance with the instantaneous amplitude value of the modulating signal, but frequency and phase of the carrier remains constant.***
- It is a relatively ***inexpensive*** and a low-quality form of modulation technique that is used for ***commercial broadcasting of both audio*** and ***video signals***.
- AM *is* simply called as ***Double Side Band- Full Carrier (DSB-FC)***, because it contains carrier as well as two side bands.

2.2. MATHEMATICAL OR TIME DOMAIN REPRESENTATION OF AN AM

$$\text{Modulating signal } V_m(t) = V_m \cos \omega_m t \qquad \ldots (1)$$

$$\text{Carrier signal } V_c(t) = V_c \cos \omega_c t \qquad \ldots (2)$$

Where,

V_c – Amplitude of the carrier signal (volts) , and

V_m – Amplitude of the modulating signal (volts).

- The amplitude of the carrier signal is ***changed after amplitude modulation***, which is the amplitude of an AM wave and is expressed as,

$$V_{AM} = V_c + V_m(t) \qquad \ldots (3)$$

By substitute equation (1) in equation (3), we get

$$= V_c + V_m \cos \omega_m t$$

$$= V_c\left[1 + \frac{V_m}{V_c} \cos \omega_m t\right]$$

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$$\boxed{V_{AM} = V_c(1 + m_a \cos \omega_m t)} \qquad \dots (4)$$

Modulation index of AM = $m_a = \frac{V_m}{V_C}$

Hence, ***AM wave*** can be expressed as,

$$V_{AM}(t) = V_{AM} \cos \omega_c t \qquad \dots (5)$$

- By substituting equation (4) for the amplitude of an AM signal in equation (5), we get

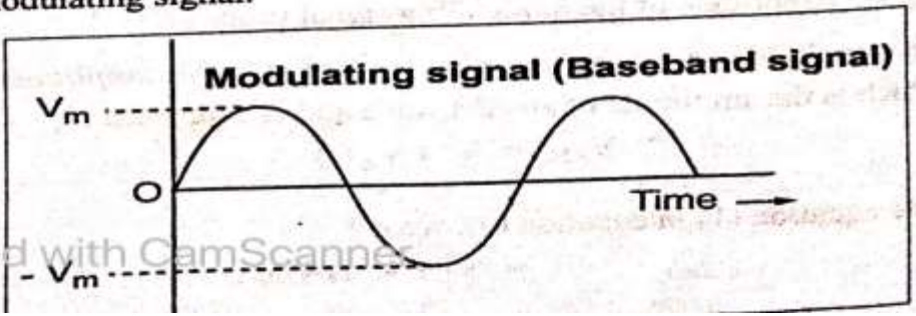
$$\boxed{V_{AM}(t) = V_c(1 + m_a \cos \omega_m t) \cos \omega_c t} \qquad \dots (6)$$

- In terms of frequency, that is, $\omega = 2\pi f$, than the AM wave from equation (6) may be expressed as,

$$\boxed{V_{AM}(t) = V_c(1 + m_a \cos 2\pi f_m t) \cos (2\pi f_c t)} \qquad \dots (7)$$

Equations (6) and (7) are called as ***time domain*** representations of an AM signal.

- This Amplitude Modulation Double Sideband Full Carrier (AM DSB-FC) is sometimes called ***conventional AM*** or ***simply AM.*** The ***shape*** of the AM modulated wave is called as ***AM envelope*** which contains all the frequencies and is used to transfer the information through the system.
- An increase in the modulating signal amplitude causes the amplitude of the carrier to increase. The shape of the AM envelope is identical to the shape of the modulating signal.



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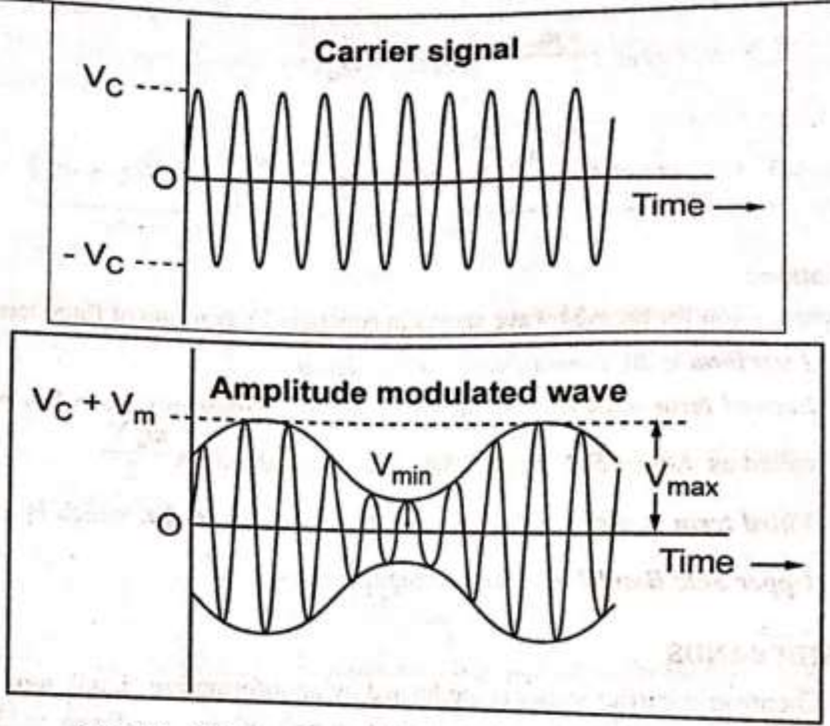

Fig. 2.1. AM waveform for sinusoidal modulating signal

2.3. AM FREQUENCY SPECTRUM AND BANDWIDTH

An AM modulator is a ***nonlinear device***. Therefore, the nonlinear mixing occurs, where the output envelope is a complex wave made up of a carrier voltage, the carrier frequency, the sum $(f_c + f_m)$ and difference $(f_c - f_m)$ frequencies.

2.3.1. FREQUENCY SPECTRUM OF AN AM WAVE

The AM wave can be expressed as,

$$\begin{aligned} V_{AM}(t) &= V_c (1 + m_a \cos \omega_m t) \cos \omega_c t \\ &= V_c \cos \omega_c t + m_a V_c \cos \omega_m t \cos \omega_c t \end{aligned}$$

We know that,

$$\cos \omega_m t \cos \omega_c t = \frac{\cos (\omega_c - \omega_m) t + \cos (\omega_c + \omega_m) t}{2}$$

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$$V_{AM}(t) = V_c \cos \omega_c t + \frac{m_a V_c}{2} [\cos (\omega_c - \omega_m) t + \cos (\omega_c + \omega_m) t]$$

$$V_{AM}(t) = \underbrace{V_C \cos \omega_C t}_{Carrier} + \underbrace{\frac{m_a V_C}{2} \cos(\omega_C - \omega_m)t}_{Lower\ sideband} + \underbrace{\frac{m_a V_C}{2} \cos(\omega_C + \omega_m)t}_{Upper\ side\ band} \quad \dots (1)$$

Observations

The expression for the AM wave shows in equation(1), consists of three terms:

(i) ***First term*** is an ***unmodulated carrier signal.***

(ii) ***Second term*** represents a sinusoidal signal at frequency ***$(f_C - f_m)$***, which is called as ***Lower Side Band(LSB)*** and its ***amplitude*** is $\frac{m_a V_c}{2}$.

(iii) ***Third term*** is a sinusoidal signal at frequency ***$(f_C + f_m)$***, which is called as ***Upper Side Band(USB)*** and its amplitude also $\frac{m_a V_c}{2}$.

2.3.2. SIDEBANDS

- Whenever a carrier signal is modulated by an information signal, ***new signals*** at ***different frequencies*** are generated as part of the non-linear modulation process. These new frequencies are called as ***side frequencies*** or ***sidebands.***

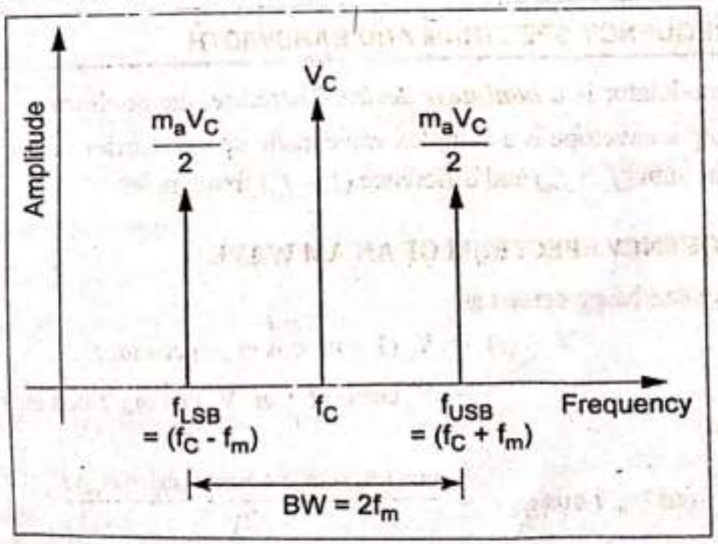

Fig.2.2. Frequency domain representation of AM wave

- The ***sidebands occur*** in the ***frequency spectrum*** directly ***above*** and ***below*** the ***carrier frequency*** f_c.

$$\boxed{\begin{aligned} f_{\text{USB}} &= f_{\text{C}}+f_m \\ f_{\text{LSB}} &= f_{\text{C}}-f_m \end{aligned}}$$

2.3.3. BANDWIDTH OF AM

- The ***bandwidth*** of the ***AM signal*** is given by the ***subtraction*** of the ***highest*** and the ***lowest frequency component*** in the AM frequency spectrum.

$$\begin{aligned} \text{B} &= f_{\text{USB}} - F_{\text{lsb}} \\ &= (f_{\text{C}}+f_m)-(f_{\text{C}}-f_m) \end{aligned}$$

$$\boxed{\text{B} = 2\times f_m}$$

where B – Bandwidth of AM in Hertz, and

f_m – Maximum modulating signal frequency in Hertz.

- Thus, the bandwidth of AM signal is ***twice the maximum frequency of modulating signal.***

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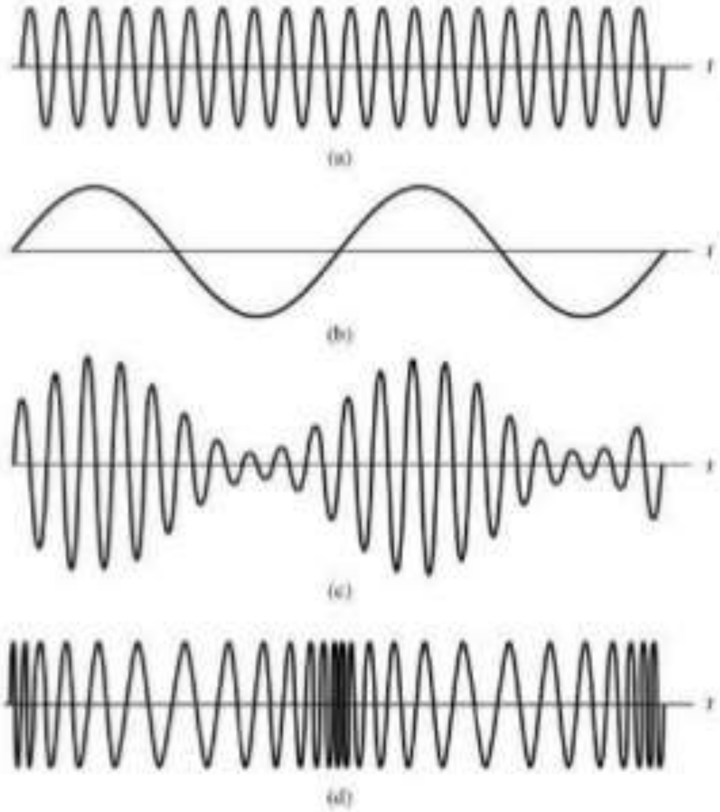
Angle Modulation

- If the angle of the carrier wave is varied, in accordance with the instantaneous value of the modulating signal, then such a technique is called as **Angle Modulation**

CW Modulation



(a) Carrier wave.

(b) Sinusoidal modulating signal.

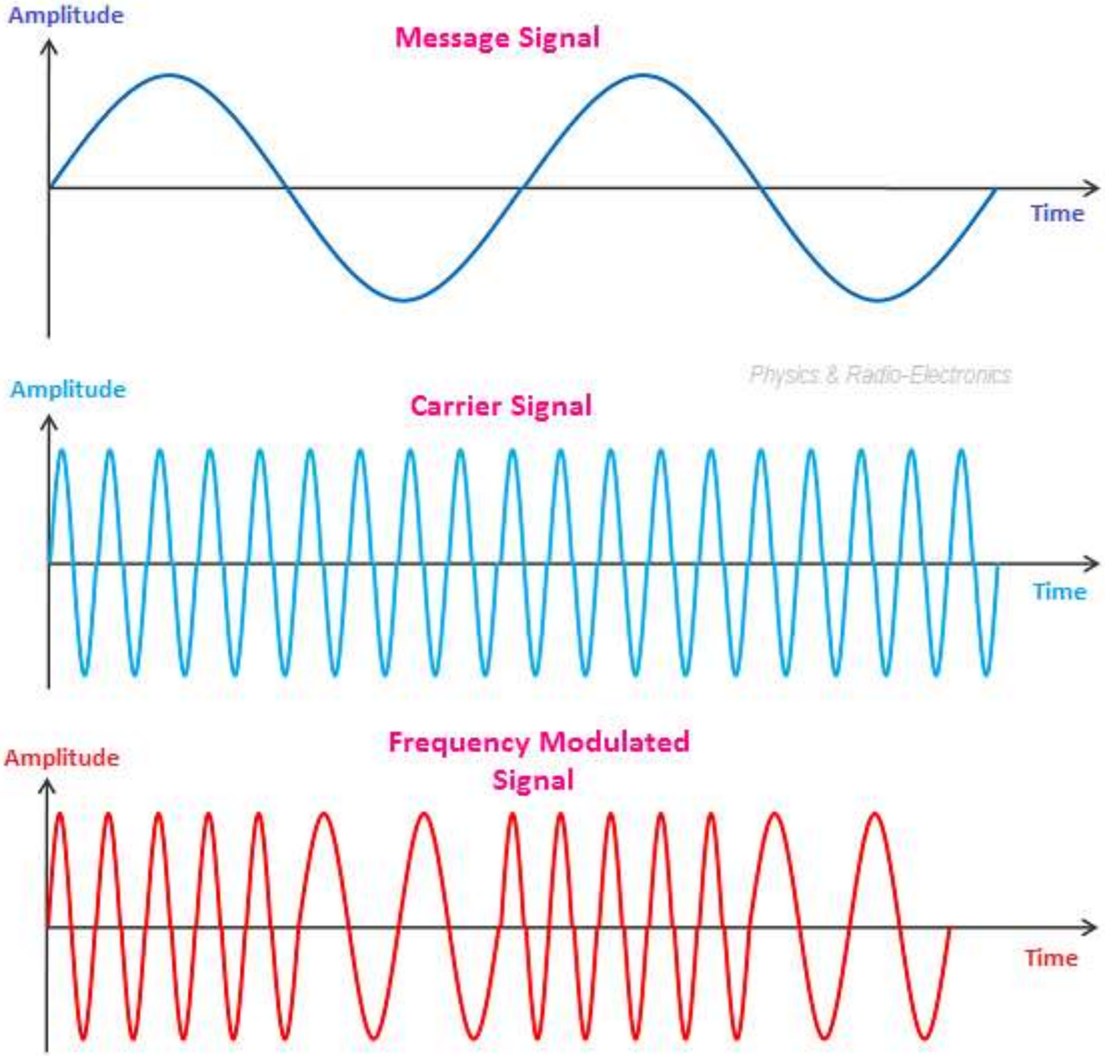
(c) Amplitude-modulated signal.

(d) Angle-modulated signal.

Frequency Modulation

- If the frequency of the carrier wave is varied, in accordance with the instantaneous value of the modulating signal, then such a technique is called as **Frequency Modulation**

Frequency Modulation


Message Signal

Carrier Signal

Frequency Modulated Signal

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Phase Modulation

- If the phase of the high frequency carrier wave is varied in accordance with the instantaneous value of the modulating signal, then such a technique is called as **Phase Modulation**.

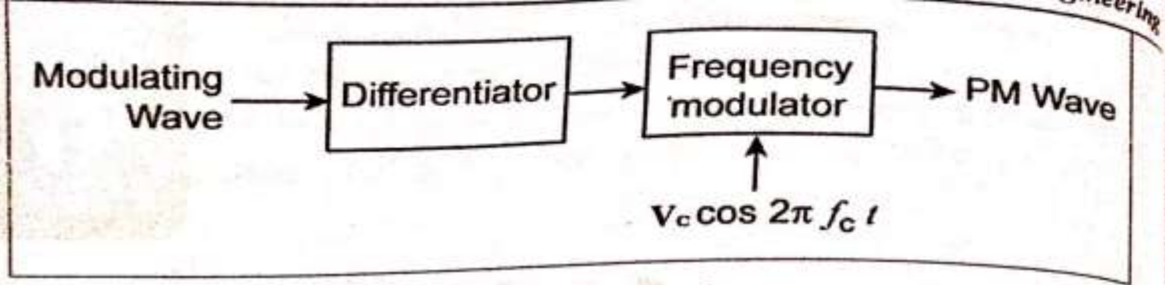

Fig.6.2. PM wave generation using a frequency modulator

- The modulating wave is first differentiated and then applied to the frequency modulator to produce PM wave.

6.2.1. REPRESENTATION OF PM

- The PM wave is obtained by varying the phase angle ϕ of a carrier signal in proportion with the amplitude of the modulating signal
- The PM wave can be expressed as,

$$V_{PM}(t) = V_c \cos(\omega_c t + \phi_P \cos \omega_m t) \quad \dots (1)$$

Here, ϕ_P – Maximum phase change corresponding to the maximum amplitude of the modulating signal.

$$V_{PM}(t) = V_c \cos(\omega_c t + m_p \cos \omega_m t) \quad \dots (2)$$

where, $m_p = \phi_P$ = Modulation index of PM.

m_p represents the ***peak phase deviation*** in radians for a phase-modulated carrier.

MODULATION INDEX (M_P) OF PM

- *In PM, the modulation index is proportional to the amplitude of the modulating signal, independent of its frequency* and is expressed as

$$\boxed{m_p = K_p V_m} \quad \dots (3)$$

where,

K_p – Deviation sensitivity (radians per volt), and

V_m – Peak modulating signal amplitude (volts)

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DEVIATION SENSITIVITY (K_p)

- *A deviation sensitivity represents the input-output transfer function of the modulators, which gives the relationship between what output parameter changes with respect to specified changes in the input signal.*
- Therefore, according to equation (3), the equation(2) can be rewritten in terms of modulation index as

$$V_{PM}(t) = V_c \cos(\omega_c t + K_p V_m \cos \omega_m t) \qquad \dots (4)$$

6.3. FREQUENCY MODULATION (FM)

6.3.1. INTRODUCTION

- ***Frequency modulation can be defined as the process by which the frequency of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal.***
- Here, the ***amplitude and phase of the carrier signal remains constant*** after modulation process.
- In PM, phase angle varies linearly with modulating signal whereas in FM phase angle varies linearly with the integral of modulating signal.
- First the modulating signal is integrated and then applied to the phase modulator to produce FM wave.

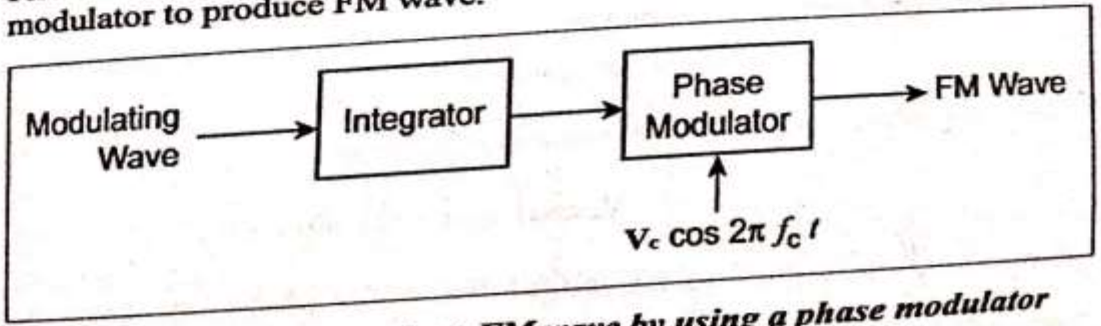

Fig. 6.3. Generation of an FM wave by using a phase modulator

6.3.2. REPRESENTATION OF FM

- For the single tone FM, the modulating signal $V_m(t)$ be a sinusoidal signal

$$V_m(t) = V_m \cos \omega_m t \qquad \dots (1)$$

- Frequency modulation takes place, when the angular velocity of the carrier wave varies in proportion to the instantaneous amplitude of the modulating signal. The instantaneous angular velocity ω_i is given by,

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$$\omega_i = \omega_c + K_f V_m (t) \quad \dots (2)$$

Here, K_f is the ***deviation sensitivity*** of FM, substituting equation(1) in equation(2) we get

$$= \omega_c + K_f V_m \cos \omega_m t \quad \dots (3)$$

- Maximum frequency deviation Δf is given by,

$$\boxed{\Delta f = \frac{K_f V_m}{2\pi} \text{ (or) } \Delta\omega = K_f V_m}$$

Maximum frequency deviation Δf can be written in a ***more practical form*** as,

$$\Delta f = K_f V_m \text{ (Hz)}$$

Integration of equation (3) gives the ***instantaneous phase angle of the frequency*** modulated wave.

$$\phi_i = \int \omega_i \, dt = \int (\omega_c + K_f V_m \cos \omega_m t) \, dt$$

$$= \int (\omega_c + \Delta\omega \cos \omega_m t) \, dt$$

$$= \omega_c t + \frac{\Delta\omega}{\omega_m} \sin \omega_m t \qquad \because \Delta\omega = 2\pi \Delta f \quad \because \omega_m = 2\pi f_m$$

$$\boxed{\phi_i = \omega_c t + \frac{\Delta f}{f_m} \sin \omega_m t} \quad \dots (4)$$

- The FM wave can be expressed as ,

$$V_{FM}(t) = V_c \cos \phi_i \quad \dots (5)$$

Then, substitute equation (4) in equation (5), we get

$$= V_c \cos\left(\omega_c t + \frac{\Delta f}{f_m} \sin \omega_m t\right) \quad \dots (6)$$

- The ratio $\frac{\Delta f}{f_m}$ is termed as the ***modulation index*** of the frequency modulated wave and is denoted by m_f.

$$m_f = \frac{\Delta f \text{(Hz)}}{f_m \text{(Hz)}} \quad \dots (7)$$

- After substituting this modulation index in equation (6), then the equation for ***FM wave*** is expressed as,

$$\boxed{V_{FM}(t) = V_c \cos(\omega_c t + m_f \sin \omega_m t)}$$

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6.3.3. FM WAVEFORMS

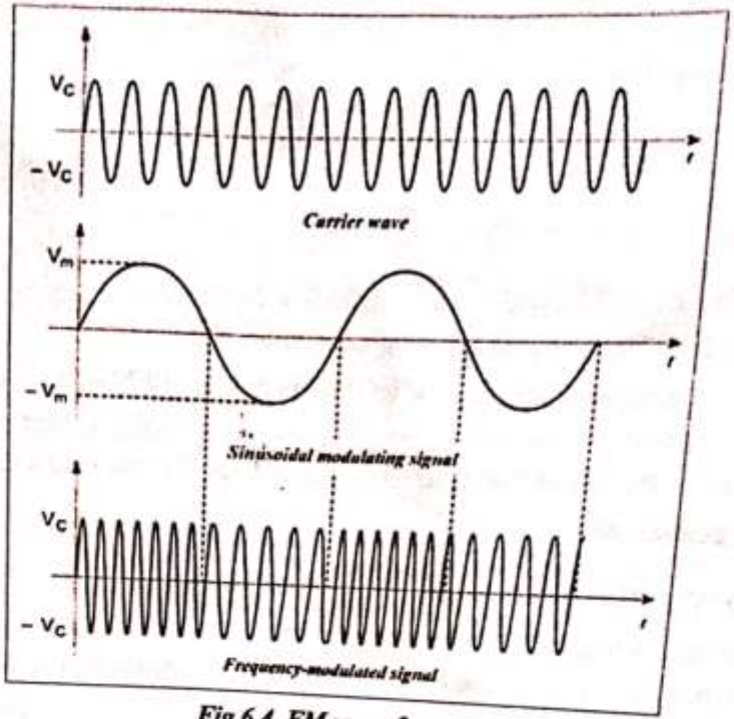

Fig.6.4. FM wave forms

6.3.4. FREQUENCY DEVIATION (ΔF)

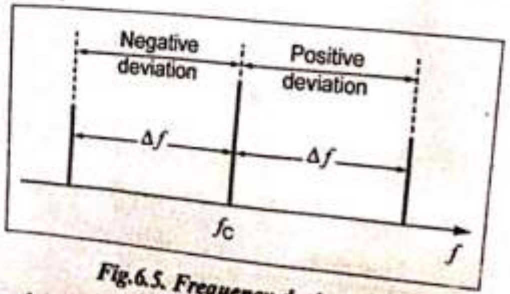

Fig.6.5. Frequency deviation

- *The frequency deviation (Δf) is defined as "the amount by which the carrier frequency(f_c) is varied from its unmodulated value after frequency modulation."*.
- The magnitude of the frequency deviation is proportional to the amplitude of the modulating signal (V_m).

6.3.5. MODULATION INDEX OF FM

- *Modulation index of FM is defined as "the ratio of frequency deviation to modulating frequency".*

$$m_f = \frac{\text{Frequency Deviation}}{\text{Modulating Frequency}}$$

$$m_f = \frac{\Delta f}{f_m} = \frac{K_f V_m}{f_m}$$

It is directly proportional to the amplitude of the modulating signal and inversely proportional to the frequency of the modulating signal.

- The modulation index (m_f) decides the ***bandwidth of FM wave*** and also decides the number of sidebands having significant amplitudes. In ***AM*** the maximum value of the modulation index (m_a) is ***1***. But for ***FM*** the modulation index can be ***greater than 1.***

6.3.6. DEVIATION RATIO (DR)

- Deviation Ratio (DR) is the worst-case (widest – bandwidth) modulation index. *It is a ratio of maximum Peak frequency deviation to the maximum modulating-signal frequency.*

$$\text{Deviation ration (DR)} = \frac{\text{Maximum peak frequency deviation (Hertz)}}{\text{Maximum modulating signal frequency (Hertz)}}$$

$$\boxed{\text{DR} = \frac{\Delta f_{(\text{max})}}{f_{m\,(\text{max})}}}$$

where,

$\Delta f_{(\text{max})}$ – Maximum peak frequency deviation (Hertz), and
$f_{m(\text{max})}$ – Maximum modulating signal frequency (Hertz)

Modulation index	*Sidebands*
1	3
2	4
3	6
4	7
5	8 (maximum)

- In FM broadcasting the maximum value of deviation is limited to 75 kHz. The maximum modulation frequency is also limited to 15 kHz.

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$$\text{Deviation ration} = \frac{75\text{ kHz}}{15\text{ kHz}} = 5$$

- Modulation index or deviation ratio is 5 it will produce eight side bands. A deviation ratio of 5 is the maximum allowed in commercially broadcast FM.

6.3.7. PERCENTAGE MODULATION OF FM

- *The percentage modulation of FM is defined as "the ratio of the* ***actual frequency deviation*** *produced by the modulating signal to the* ***maximum allowable frequency deviation*** *in percentage form".*

$$\text{Percentage modulation} = \frac{\text{Actual frequency deviation}}{\text{Maximum allowable frequency deviation}} \times 100$$

$$\boxed{\%\text{ modulation} = \frac{\Delta f_{(\text{actual})}}{\Delta f_{(\text{max})}} \times 100}$$

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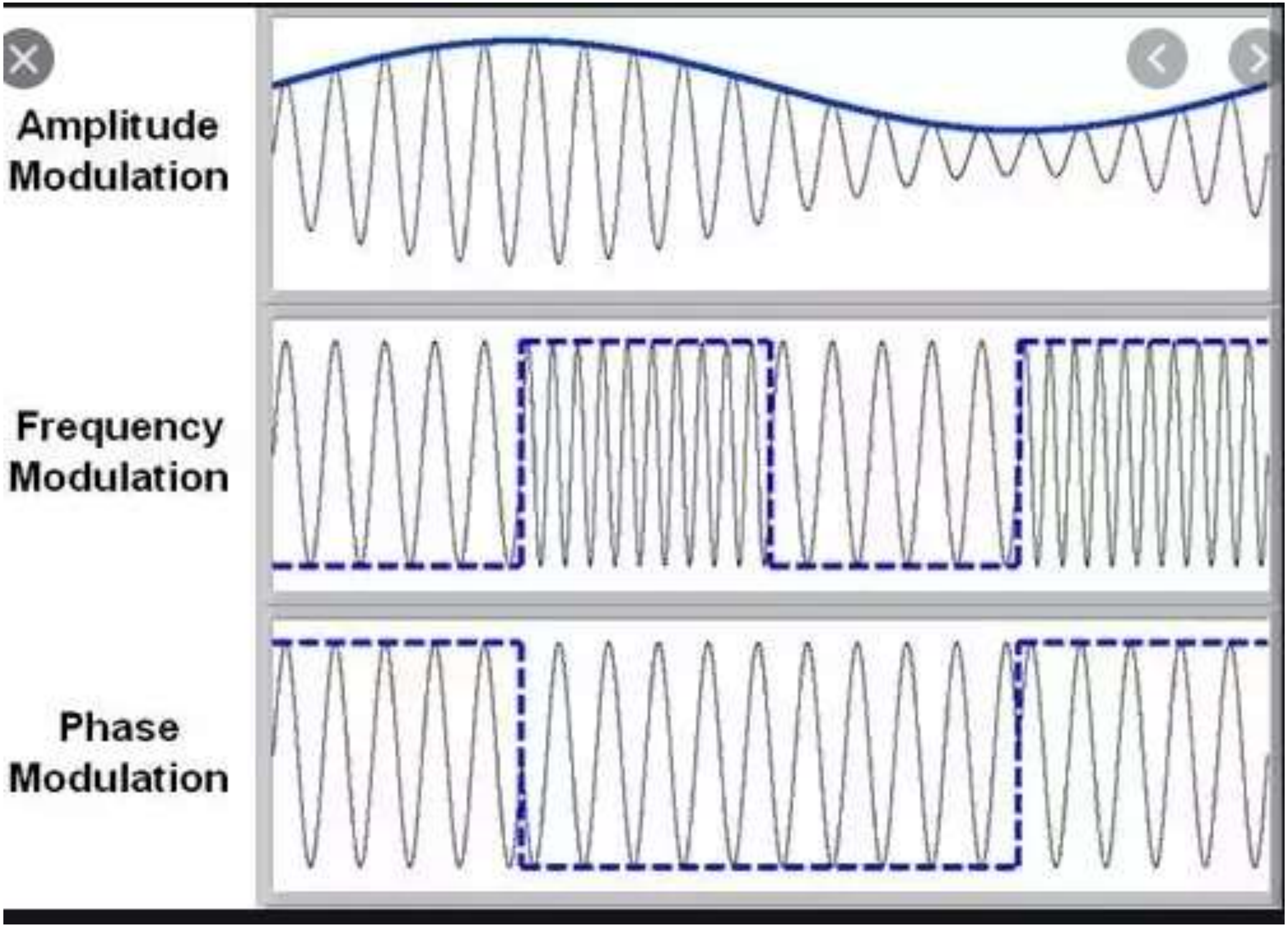
Amplitude Modulation
Frequency Modulation
Phase Modulation

- https://www.youtube.com/watch?v=mHvV_Tv8HDQ

Radio frequency spectrum

- The radio spectrum is the part of the electromagnetic spectrum with frequencies from 30 Hz to 300 GHz.
- Electromagnetic waves in this frequency range, called radio waves, are widely used in modern technology, particularly in telecommunication.

Table 1: Radio-frequency spectrum

Frequency designation	Frequency range
Extremely High Frequency (EHF)	30 – 300GHz
Super High Frequency (SHF)	3 – 30GHz
Ultra High Frequency (UHF)	300MHz – 3GHz
Very High Frequency (VHF)	30 – 300MHz
High Frequency (HF)	3 – 30MHz
Medium Frequency (MF)	300kHz – 3MHz
Low Frequency (LF)	30– 300kHz
Very Low Frequency (VLF)	3 – 30 kHz
Voice Frequency(VF)	300 – 3000Hz
Extremely Low Frequency(ELF)	30 – 300 Hz

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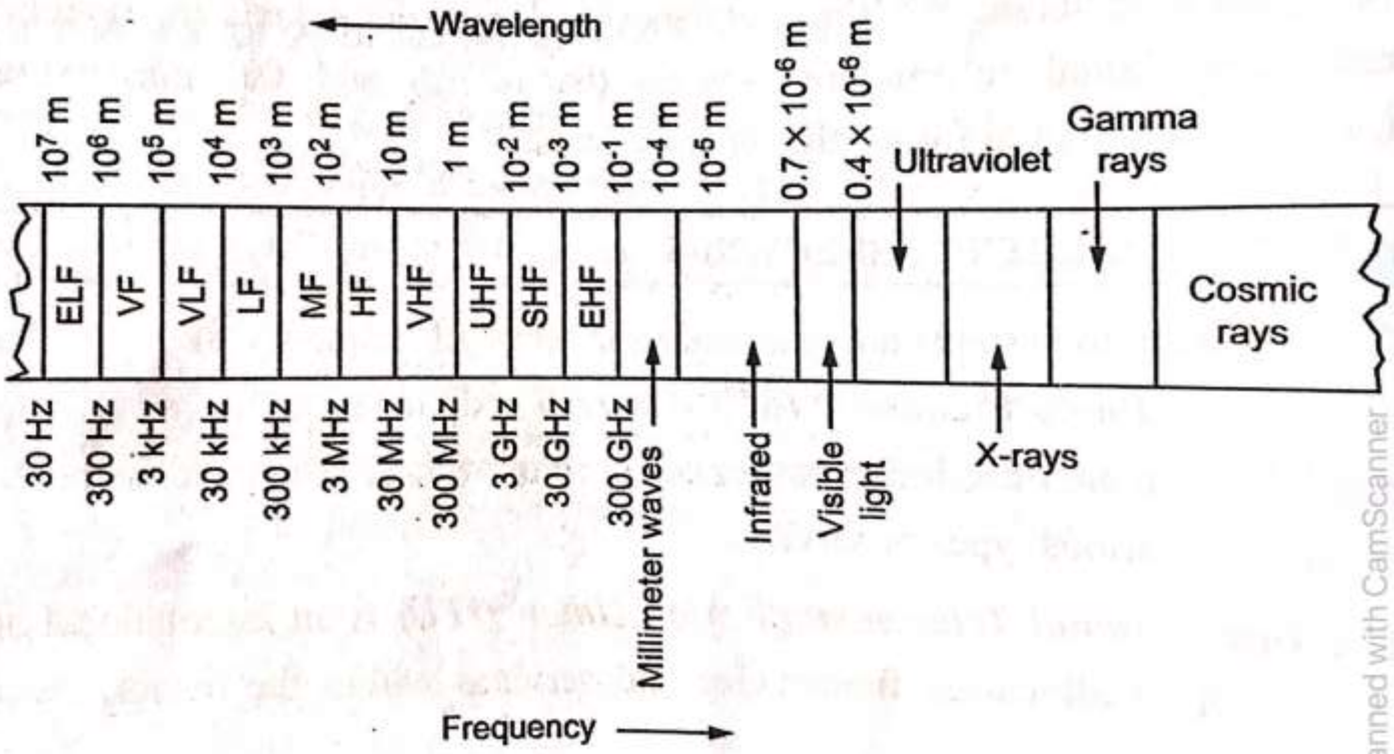

Figure.1.18. Electromagnetic (EM) spectrum used in communications

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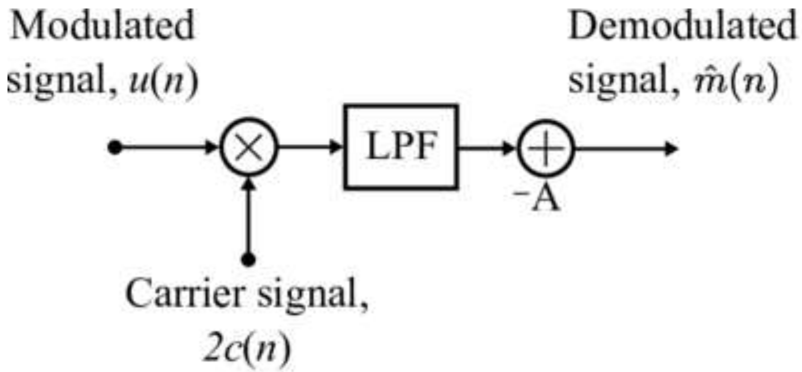
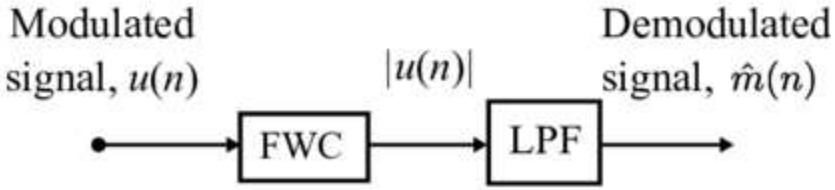
Demodulation

- **Demodulation** is extracting the original information-bearing signal from a carrier wave.
- A **demodulator** is an electronic circuit (or computer program in a software-defined radio) that is used to recover the information content from the modulated carrier wave.



(a) Synchronous demodulator



(b) Asynchronous demodulator

super heterodyne receiver

- A superheterodyne receiver uses signal mixing to **convert the input radio signal into a steady intermediate frequency (IF)** that can be worked with more easily than the original radio signal that has a different frequency, depending on the broadcasting station.

Heterodyning

- The process of mixing two signals having different frequencies to produce a signal with new frequency is called as heterodyning.

5.5.2. GENERAL BLOCKS

5.5.2.1. Rf section

The incoming AM wave is picked up by the receiving antenna and amplified in the RF section which is tuned to the carrier frequency of the incoming wave. The RF section generally consists of a ***preselector*** and an ***amplifier*** stage.

(i) Preselector

The preselect or is a ***broad-tuned Band Pass Filter (BPF)*** with an adjustable centre frequency that is tuned to the desired carrier frequency of the incoming signal and rejects the unwanted radio frequency called ***"image frequency"*** and it also reduces the noise bandwidth for noise and allows the useful signal.

(ii) RF amplifier

A receiver can have one or more RF amplifiers depending on the desired sensitivity and its output is a desired signal at frequency "f_s"

5.5.2.2. Mixer / Converter SECTION

- The combination of mixer and local oscillator provides a heterodyning function, whereby the incoming signals (RF) is converted to a predetermined fixed ***Intermediate Frequency (IF)*** signal, usually lower than the incoming carrier frequency.
- The carrier and sideband frequencies are translated from RF to IF, the shape of the envelope remains the same and therefore, the original information contained in the envelope remains unchanged.
- The mixer-local oscillator combination is sometimes referred to as the ***first detector*** and in this case the demodulator is called the ***second detector.*** The most common intermediate frequency used in AM broad – case receivers ***is 455 kHz.***

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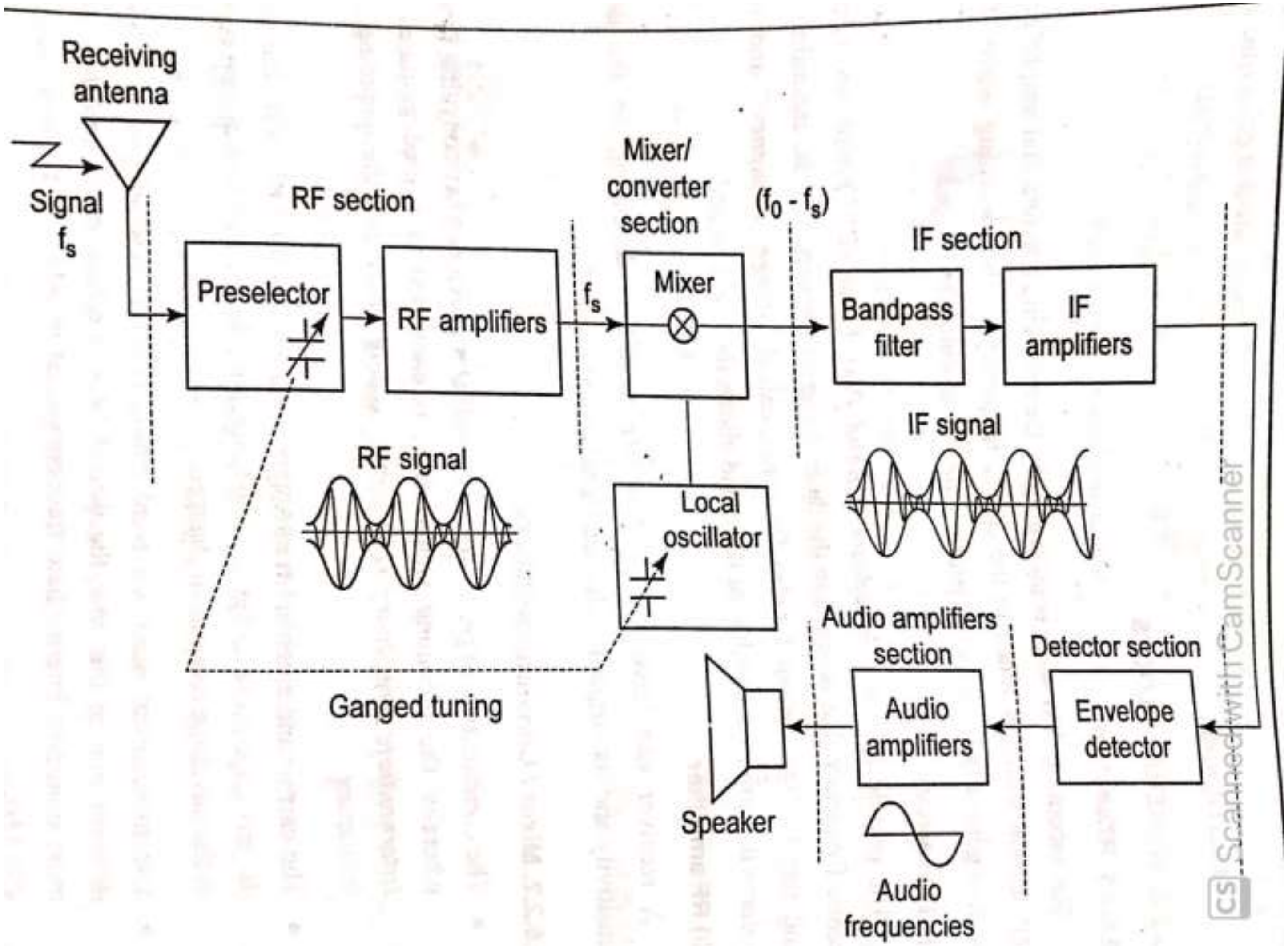

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(i) Local oscillator frequency (f_o)

The mixer receives signals from the RF amplifier at frequency (f_s) and from the local oscillator at frequency (f_0) such that $f_0 > f_s$. The local oscillator frequency f_0 is expressed as,

$$f_0 = f_s + f_i \qquad \dots (1)$$

Where , f_s – Signal frequency, and

f_i – Intermediate frequency.

(ii) Signal frequency (f_s)

The signal frequency f_s is below local oscillator frequency f_0 by an f_i, the intermediate frequency.

$$f_s = f_0 - f_i \qquad \dots (2)$$

(iii) Image signal frequency (f_{si})

Image signal frequency f_{si} is given by

$$f_{si} = f_0 + f_i \qquad \dots (3)$$

By substituting equation (1) in equation (3),

$$f_{si} = f_s + f_i + f_i$$

$$f_{si} = f_s + 2\,f_i \qquad \dots (4)$$

This unwanted signal at frequency f_{si} is known as the ***"image frequency"*** and it is said to be the ***"image"*** of the signal frequency f_s. It must be rejected by the receiver and the image rejection is depends on the ***front end selectivity*** of the receiver, i.e. the selectivity of the RF circuit.

(IV) Image Frequency Rejection Ratio (IFRR)

Image frequency rejection ratio is defined as "the radio of the gain at the signal frequency to the gain at the image frequency". The IFRR of a single tuned circuit is expressed as,

$$\frac{\text{Gain at the signal frequency}}{\text{Gain at the image frequency}} = \alpha = \sqrt{1+Q^2\rho^2} \qquad \dots (5)$$

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Where, $\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} \qquad \dots (6)$

(i) Local oscillator frequency (f_o)

The mixer receives signals from the RF amplifier at frequency (f_s) and from the local oscillator at frequency (f_0) such that $f_0 > f_s$. The local oscillator frequency f_0 is expressed as,

$$f_0 = f_s + f_i \quad \dots (1)$$

Where, f_s – Signal frequency, and

f_i – Intermediate frequency.

(ii) Signal frequency (f_s)

The signal frequency f_s is below local oscillator frequency f_0 by an f_i, the intermediate frequency.

$$f_s = f_0 - f_i \quad \dots (2)$$

(iii) Image signal frequency (f_{si})

Image signal frequency f_{si} is given by

$$f_{si} = f_0 + f_i \quad \dots (3)$$

By substituting equation (1) in equation (3),

$$f_{si} = f_s + f_i + f_i$$

$$f_{si} = f_s + 2\,f_i \quad \dots (4)$$

This unwanted signal at frequency f_{si} is known as the ***"image frequency"*** and it is said to be the ***"image"*** of the signal frequency f_s. It must be rejected by the receiver and the image rejection is depends on the ***front end selectivity*** of the receiver, i.e. the selectivity of the RF circuit.

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of the FM wave is	Amplitude of the PM wave is constant.
Noise Ratio(SNR) is better of PM.	Signal to Noise Ratio(SNR) is inferior than FM.
lely used.	PM is used in some mobile system.
e frequency deviation is nal to the modulating nly and independent of . $f \infty V_m$	In PM, the frequency deviation proportional to both the modulating voltage and modulating frequency. $\Delta f \infty V_m f_m$

RISON OF FM AND AM

FM	AM