ROHINI COLLEGE OF ENGINEERING & TECHNOLOGY
Near Anjugramam Junction, Kanyakumari Main Road, Palkulam, Variyoor P.O - 629401
Kanyakumari Dist, Tamilnadu., E-mail : admin@rcet.org.in, Website : www.rcet.org.in

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

Name Of The Subject : COMMUNICATIONENGINEERING

Subject code : EC8395

Regulation : 2017

UNIT I- ANALOG MODULATION

NOISE:

Noise is an unwanted electrical signal which gets added on a transmitted signal when it is travelling towards the receiver. Electrical noise is defined as any undesired electrical energy. For Example: In audio recording any unwanted electrical signals that fall within the audio frequency band of 0 khz to 15khz will interface with the music and therefore considered as noise.

Noise figure is a figure of merit and used to indicate how much the signal to noise ratio gets degraded as a signal passes through a series of circuits.

Noise can be divided into two general categories:

(i) Correlated Noise : Implies a relationship between the signal and the noise.
(ii) Uncorrelated Noise : It is present all the time whether there is a signal or not.

Uncorrelated Noise:

Uncorrelated can be divided into two general categories: (i) External noise and (ii) Internal noise.

External Noise:

It is a Noise generated outside the device or circuit. There are three primary sources of external noise.

(i) Atmospheric ,
(ii) Extra terrestrial and
(ii) Manmade noise.

Extraterrestrial Noise consists of electrical signals that originate from outside earths atmosphere and is therefore also called as deep space noise. This noise originates from the milky way , other galaxies and the sun.

Extraterrestrial noise is subdivided into two categories.: (i) Solar and (ii) Cosmic.

Internal Noise: It is the noise caused by electrical interference generated within a device or circuit.

There are three primary kinds of internally generated noise are:

(i) Thermal.
(ii) Shot ,
Transits time.

INTRODUCTION TO COMMUNICATION SYSTEM:

Communication is the process of establishing connection (or link) between two points for information exchange.

The Science of Communications involving long distances is called Telecommunication (the world Tele standing for long distance)

The Two basic types of communication systems are

(i) Analog.

(ii) Digital.

In Analog Systems: Both the information and the carrier are analog signals.

In Digital Systems: The digital pulses are transferred between two or more points in a communication system.

Analog communication:

The modulation systems or techniques in which one of the characteristics of the carrier is changed in proportion with the instantaneous value of modulating signal is called analog communication system.

Advantages of Analog communications

- Transmitters and Receivers are simple
- Low bandwidth requirement
- FDM can be used

Disadvantages of analog communication

- Noise affects the signal quality
- It is not possible to separate noise and signal
- Repeaters can‘t be used between transmitter
- Coding is not possible
- It is not suitable for the transmission of secret information

General Communication Systems:

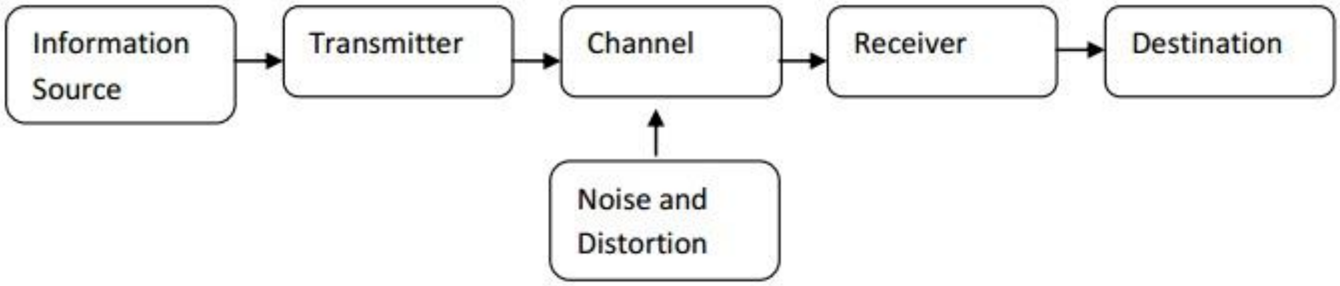

Fig1.1: Block diagram of a general communication system (Source: Brainkart)

Drawbacks of Baseband Transmission (without Modulation)

- Excessively large antenna heights.
- Signals get mixed up.
- Short range of communication.
- Multiplexing is not possible.
- Poor quality of reception.

The above drawbacks can be overcome by means of modulation techniques

Modulation, Types, Need for Modulation:

Modulation is the changing characteristics of the carrier signal with respect to the instantaneous change in message signal.

Needs for modulation: In order to carry the low frequency message signal to a longer distance, the high frequency carrier signal is combined with it.

a) Reduction in antenna height
b) Long distance communication
c) Ease of radiation
d) Multiplexing
e) Improve the quality of reception
f) Avoid mixing up of other signals

Frequency modulation: Frequency Modulation is the changing frequency of the carrier signal with respect to the instantaneous change in message signal

Phase modulation: Phase Modulation is defined as changing the phase of the carrier signal with respect to the instantaneous change in message signal.

Deviation ratio: Deviation ratio is the worst case modulation index and is equal to the maximum peak frequency deviation divided by the maximum modulating signal frequency. Mathematically the deviation ratio is DR= f (max)/fm(max).

Amplitude modulation: Amplitude Modulation is defined as changing the amplitude of the carrier signal with respect to the instantaneous change in message signal.

Carson's rule : Carson's rule: Carson's rule states that the bandwidth required to transmit an angle modulated wave as twice the sum of the peak frequency deviation and the highest modulating signal frequency. Mathematically carson's rule is B=2(f +fm) Hz.

Modulation index: It is defined as ratio of amplitude of the message signal to the amplitude of the carrier signal. m=Em/Ec.

Percentage modulation: It is the percentage change in the amplitude of the output wave when the carrier is acted on by a modulating signal. M=(Em/Ec)*100

THEORY OF AMPLITUDE MODULATION

Amplitude Modulation

Amplitude Modulation is the changing the amplitude of the carrier signal with respect to the instantaneous change in message signal.

The amplitude modulated wave form, its envelope and its frequency spectrum and bandwidth.

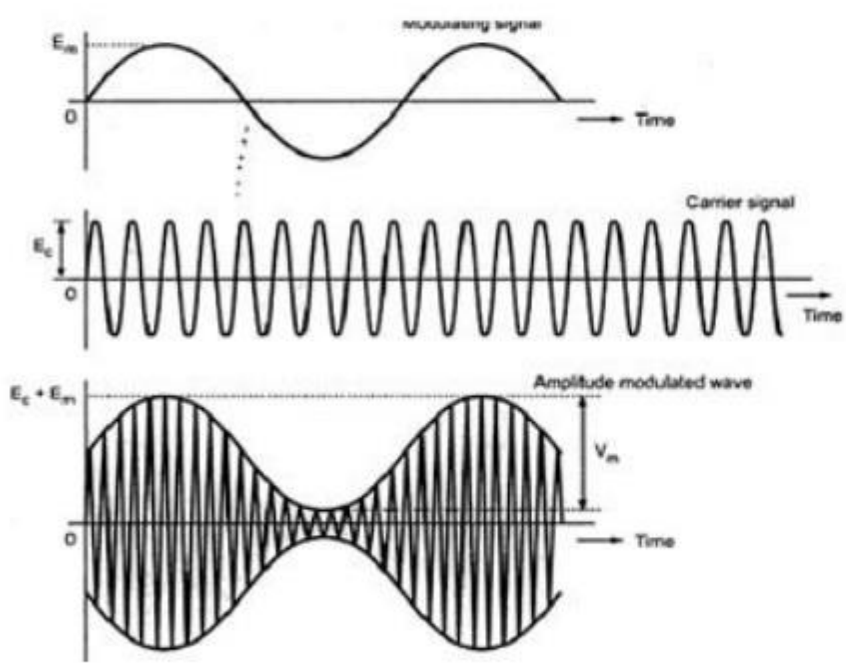

Fig 1.2.1(a) Sinusoidal modulation signal (b)High frequency carrier (c) AM signal.
(Source: Brainkart)

Let us represent the modulating signal by e_m and it is given as,

$$e_m = E_m \sin \omega_m t \qquad \text{... (1.2.1)}$$

and carrier signal can be represented by e_c as,

$$e_c = E_c \sin \omega_c t \qquad \text{... (1.2.2)}$$

Here E_m is maximum amplitude of modulating signal

E_c is maximum amplitude of carrier signal

ω_m is frequency of modulating signal

and ω_c is frequency of carrier signal.

Using the above mathematical expressions for modulating and carrier signals, we can create a new mathematical expression for the complete modulated wave. It is given as,

$$E_{AM} = E_c + e_m$$

$$= E_c + E_m \sin \omega_m t \quad \text{by putting } e_m \text{ from equation (1.2.1)}$$

$\therefore$ The instantaneous value of the amplitude modulated wave can be given as,

$$e_{AM} = E_{AM} \sin \theta$$

$$= E_{AM} \sin \omega_c t$$

$$\therefore \quad \boxed{e_{AM} = (E_c + E_m \sin \omega_m t) \sin \omega_c t} \qquad \text{... (1.2.3)}$$

This is an equation of AM wave.

Modulation Index and Percent Modulation

The ratio of maximum amplitude of modulating signal to maximum amplitude carrier signal is called modulation index. i.e.,

$$\boxed{\text{Modulation index, } m = \frac{E_m}{E_c}} \qquad \text{... (1.2.4)}$$

Value of E_m must be less than value of E_c to avoid any distortion in the modulated signal. Hence maximum value of modulation index will be equal to 1 when $E_m=E_c$. Minimum value will be

zero. If modulation index is higher than 1, then it is called *over modulation*. Data is lost in such case. When modulation index is expressed in percentage , it is also called percentage modulation.
Calculation of modulation index from AM waveform:
Fig 1.2.2 shows the AM waveform. This is also called time domain representation of AM signal.

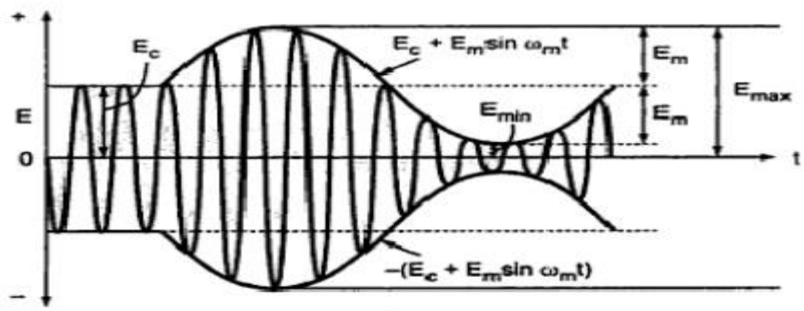

Fig. 1.2.2 AM wave

(Source:Brainkart)

It is clear from the above signal that the modulating signal rides upon the carrier signal. From above figure we can write,

$$E_m = \frac{E_{max} - E_{min}}{2} \quad \text{... (1.2.5)}$$

and

$$E_c = E_{max} - E_m \quad \text{... (1.2.6)}$$

$$= E_{max} - \frac{E_{max} - E_{min}}{2} \text{ by putting for } E_m \text{ from equation (1.2.5)}$$

$$= \frac{E_{max} + E_{min}}{2} \quad \text{... (1.2.7)}$$

Taking the ratio of equation (1.2.5) and above equation,

$$m = \frac{E_m}{E_c} = \frac{\frac{E_{max} - E_{min}}{2}}{\frac{E_{max} + E_{min}}{2}}$$

$$\therefore \quad \boxed{m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}} \quad \text{... (1.2.8)}$$

This equation gives the technique of calculating modulation index from AM wave.

Frequency Spectrum and Bandwidth

The modulated carrier has new signals at different frequencies, called side frequencies or sidebands. They occur above and below the carrier frequency.

i.e. $f_{USB} = f_c + f_m$

$f_{LSB} = f_c - f_m$

Here f_c is carrier frequency and

f_m is modulating signal frequency

f_{LSB} is lower sideband frequency

Consider the expression of AM wave given by equation (1.2.3),I.e.,

$$e_{AM} = (E_c + E_m \sin \omega_m t) \sin \omega_c t \quad \text{... (1.2.9)}$$

We know that $m = \frac{E_m}{E_c}$ from equation (1.2.4). Hence we have $E_m = m E_c$. Putting this value of E_m in above equation we get,

$$\begin{aligned} e_{AM} &= (E_c + m E_c \sin \omega_m t) \sin \omega_c t \\ &= E_c (1 + m \sin \omega_m t) \sin \omega_c t \\ &= E_c \sin \omega_c t + m E_c \sin \omega_m t \sin \omega_c t \quad \text{... (1.2.10)} \end{aligned}$$

We know that $\sin(A)\sin(B) = \frac{1}{2}\cos(A-B) - \frac{1}{2}\cos(A+B)$. Applying this result to last term in above equation we get,

---

$$\begin{aligned} e_{AM} &= E_c \sin \omega_c t + \frac{m E_c}{2} \cos(\omega_c - \omega_m) t \\ &- \frac{m E_c}{2} \cos(\omega_c + \omega_m) t \quad \text{... (1.2.11)} \end{aligned}$$

In the above equation, the first term represents unmodulated carrier, the second term represents lower sideband and last term represents upper sideband. Note that $\omega_c = 2\pi f_c$ and $\omega_m = 2\pi f_m$. Hence above equation can also be written as,

$$e_{AM} = E_c \sin 2\pi f_c\, t + \frac{m E_c}{2} \cos 2\pi (f_c - f_m) t$$

$$- \frac{m E_c}{2} \cos 2\pi (f_c + f_m) t \qquad \text{... (1.2.12)}$$

$$= E_c \sin 2\pi f_c\, t + \frac{m E_c}{2} \cos 2\pi f_{LSB}\, t + \frac{m E_c}{2} \cos 2\pi f_{USB}\, t \qquad \text{... (1.2.13)}$$

From this equation we can prepare the frequency spectrum of AM wave as shown below in fig. 1.2.3.

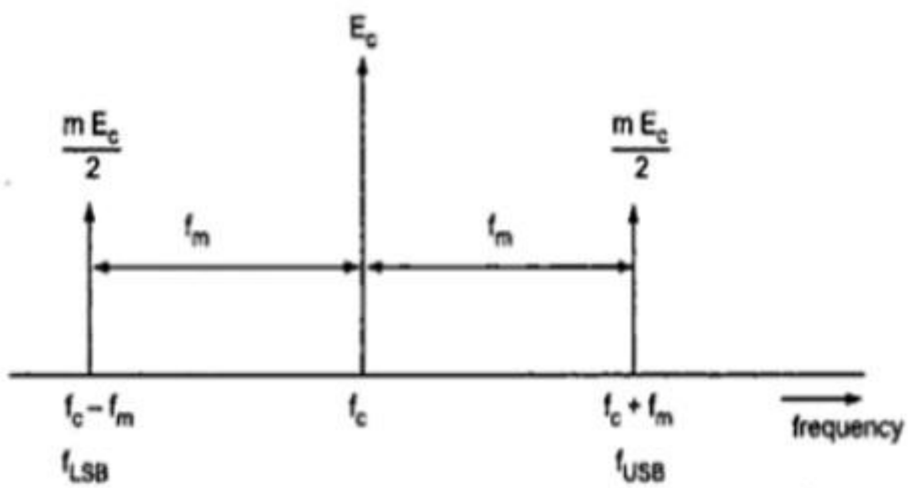

Fig:1.2.3 : Frequency domain Representation of AM Wave

(Source:Brainkart)

This contains full carrier and both the sidebands, hence it is also called Double Sideband Full Carrier (DSBFC) system. We will be discussing this system, its modulation circuits and transmitters next, in this section.

We know that bandwidth of the signal can be obtained by taking the difference between highest and lowest frequencies. From above figure we can obtain bandwidth of AM wave as,

$$BW = f_{USB} - f_{LSB}$$
$$= (f_c + f_m) - (f_c - f_m)$$
$$\therefore \quad \boxed{BW = 2 f_m} \quad \dots (1.2.14)$$

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

Amplitude Modulation of Power distribution:

AM Power Distribution:

AM signal has three components : Un modulated carrier, lower sideband and upper sideband. Hence total power of AM wave is the sum off carrier power Pe and powers in the two sidebands P_{LSB}. i.e.,

$$P_{Total} = P_c + P_{USB} + P_{LSB}$$
$$= \frac{E_{carr}^2}{R} + \frac{E_{LSB}^2}{R} + \frac{E_{USB}^2}{R} \quad \dots (1.2.15)$$

Here all the three voltages are rms values and R is characteristic impedance of antenna in which the power is dissipated. The Carrier Power is,

$$P_c = \frac{E_{carr}^2}{R} = \frac{\left(E_c / \sqrt{2}\right)^2}{R}$$

$$= \frac{E_c^2}{2R} \quad \text{... (1.2.16)}$$

The power of upper and lower sidebands is same. i.e.,

$$P_{LSB} = P_{USB} = \frac{E_{SB}^2}{R}$$ Here E_{SB} is rms voltage of sidebands.

From equation (1.2.13) we know that the peak amplitude of both the sidebands is $\frac{m E_c}{2}$. Hence,

$$E_{SB} = \frac{m E_c / 2}{\sqrt{2}}$$

$$\therefore \quad P_{LSB} = P_{USB} = \left(\frac{m E_c / 2}{\sqrt{2}}\right)^2 \times \frac{1}{R}$$

$$= \frac{m^2 E_c^2}{8R} \quad \text{... (1.2.17)}$$

Hence the total power (equation 1.2.15) becomes,

$$P_{Total} = \frac{E_c^2}{2R} + \frac{m^2 E_c^2}{8R} + \frac{m^2 E_c^2}{8R}$$

$$= \frac{E_c^2}{2R}\left[1 + \frac{m^2}{4} + \frac{m^2}{4}\right]$$

$$\boxed{P_{Total} = P_c\left(1 + \frac{m^2}{2}\right)} \quad \text{... (1.2.19)}$$

$$\frac{P_{Total}}{P_c} = 1 + \frac{m^2}{2} \quad \text{... (1.2.20)}$$

This equation relates total power of AM wave to carrier power, Maximum Value of modulation index, m=1 to avoid distortion. At this value of modulation index, Ptotal = 1.5 Pc. From the above equation we have

Example Problems:

An audio frequency signal $10 \sin 2\pi \times 500\, t$ is used to amplitude modulate a carrier of $50 \sin 2\pi \times 10^5\, t$. Calculate

(i) Modulation index

(ii) Sideband frequencies

(iii) Amplitude of each sideband frequencies

(iv) Bandwidth required

(v) Total power delivered to the load of $600\,\Omega$.

Solution : (i) The given modulating signal is $e_m = 10 \sin 2\pi \times 500 t$. Hence, $E_m = 10$. The given carrier signal is $e_c = 50 \sin 2\pi \times 10^5\, t$, hence, $E_c = 50$. Therefore modulation index will be,

$$m = \frac{E_m}{E_c} = \frac{10}{50} = 0.2 \quad \text{or} \quad 20\%$$

(ii) From the given equations,

$\omega_m = 2\pi \times 500,$ Hence $f_m = 500\, Hz$

And $\omega_c = 2\pi \times 10^5,$ Hence $f_c = 10^5\, Hz$ or 100 kHz

We know that $f_{USB} = f_c + f_m = 100\, kHz + 500\, Hz = 100.5\, kHz$

and $P_{LSB} = f_c - f_m = 100\, kHz - 500\, Hz = 99.5\, kHz.$

(iii) From equation (1.2.13) we know that the amplitudes of upper and lower sidebands is given as,

Amplitude of upper and lower sidebands $= \frac{m E_c}{2} = \frac{0.2 \times 50}{2} = 5V$

(iv) Bandwidth of AM wave is given by equation(1.2.10) as,

$$BW \text{ of } AM = 2f_m = 2\times 500\,Hz = 1\,kHz$$

(v) Total power delivered to the load is given by equation (1.2.18) as

$$P_{total} = \frac{E_c^2}{2R}\left(1+\frac{m^2}{2}\right) = \frac{50^2}{2\times 600}\left(1+\frac{(0.2)^2}{2}\right)$$

$$\therefore \quad = 2.125 \text{ watts}$$

Example : *A 400 W carrier is modulated to a depth of 80% calculate the totall power in the modulated wave.*

Solution : Here carrier power $P_c = 400\,W$ and $m = 0.8$

From equation (1.2.19) total power is,

$$P_{total} = P_c\left(1+\frac{m^2}{2}\right) = 400\left(1+\frac{(0.8)^2}{2}\right)$$

$$= 528\,W$$

Example : *A broadcast transmitter radiates 20 kW when the modulation percentage is 75. Calculate carrier power and power of each sideband.*

Solution : Here total power $P_{total} = 20{,}000\,W$ and $m = 0.75$

From equation (1.2.19) we have $P_{total} = P_c\left(1+\frac{m^2}{2}\right)$

$$\therefore \quad 20{,}000 = P_c\left(1+\frac{(0.75)^2}{2}\right)$$

$$\therefore \quad P_c = 15.6\,kW$$

We know that $P_{total} = P_c\left(1+\frac{m^2}{2}\right) = P_c + P_c\,\frac{m^2}{2}$

The second term in above equation represents total sideband power. Hence power of one sideband will be,

$$P_{SB} = \left(P_c\,\frac{m^2}{2}\right)\times\frac{1}{2}$$

$$= 15.6\times\frac{(0.75)^2}{2}\times\frac{1}{2}$$

$$= 2.2\,kW$$

Thus $P_{USB} = P_{LSB} = 2.2\,kW$

Frequency Spectrum of Angle Modulated Waves

We know that AM contains only two sidebands per modulating frequency. But angle modulated signal contains large number of sidebands depending upon the modulation index. Since FM and PM have identical modulated waveforms, their frequency content is same. Consider the PM equation or spectrum analysis,

$$e(t) = E_c \sin[\omega_c t + m \cos\omega_m t]$$

Using Bessel functions, this equation can be expanded as,

$$\begin{aligned} e(t) = E_c \{ & J_0 \sin\omega_c t \\ & + J_1[\sin(\omega_c + \omega_m)t - \sin(\omega_c - \omega_m)t] \\ & + J_2[\sin(\omega_c + 2\omega_m)t + \sin(\omega_c - 2\omega_m)t] \\ & + J_3[\sin(\omega_c + 3\omega_m)t + \sin(\omega_c - 3\omega_m)t] \\ & + J_4[\sin(\omega_c + 4\omega_m)t - \sin(\omega_c - 4\omega_m)t] + \ldots \} \end{aligned}$$

Here $J_0, J_1, J_2 \ldots$ are the Bessel functions.

It is clear from the above discussion that, angle modulated signal has infinite number of sidebands as well as carrier in the output. The sidebands are separated from the carrier by f_m, $2f_m$, $3f_m$ … etc. The frequency separation between successive sidebands is f_m. All the sidebands are symmetric around carrier frequency. The amplitude of the sidebands are $E_c f_0$, $E_c f_1$, $E_c f_2$, $E_c f_3$, $E_c f_4$, … and so on.

Bandwidth Requirement

The bandwidth requirement of angle modulated waveforms can be obtained depending upon modulation index. The modulation index can be classified as low (less than 1), medium (1 to 10) and high (greater than 10). The low index systems are called narrowband FM. For such system the frequency spectrum resembles AM. Hence minimum bandwidth is given as,

$$BW = 2f_m \text{ Hz} \qquad \ldots (2.1.19)$$

For high index modulation, the minimum bandwidth is given as,

$$BW = 2\delta \qquad \ldots (2.1.20)$$

The bandwidth can also be obtained using bessel table. i.e.,

$$BW = 2n f_m \qquad \ldots (2.1.21)$$

Here 'n' is the number of significant sidebands obtained from Bessel table.

Carson's Rule:

Carson's Rule gives approximate minimum bandwidth of angle modulated signal as

$$BW = 2\left[\delta + f_{m(\max)}\right] Hz \qquad \text{... (2.1.22)}$$

Here $f_{m(max)}$ is the maximum modulating frequency. As per Carson's rule, the bandwidth accommodates almost 98% of the total transmitted power.

Angle Modulation

Definition

We know that amplitude, frequency or phase of the carrier can be varied by the modulating signal. Amplitude is varied in AM. When frequency or phase of the carrier is varied by the modulating signal, then it is called angle modulation. There are two types of angle modulation.

1. Frequency Modulation: When frequency of the carrier varies as per amplitude variations of modulating signal, then it is called Frequency Modulation(FM). Amplitude carrier remains constant.

2. Phase Modulation: When phase of the carrier varies as per amplitude variations of modulating signal, then it is called Phase Modulation (PM). Amplitude of the modulated carrier remains constant.

The angle modulated wave is mathematically expressed as,

FM and PM Waveforms

(i) For FM signal, the maximum frequency deviation takes place when modulating signl is at positive and negative peaks.

(ii) For PM signal the maximum frequency deviation takes place near zero crossings o the modulating signal.

(iii) Both FM and PM waveforms are identical except the phase shit.

(iv) From modulated waveform it is difficult to know, whether the modulation is FM or PM.

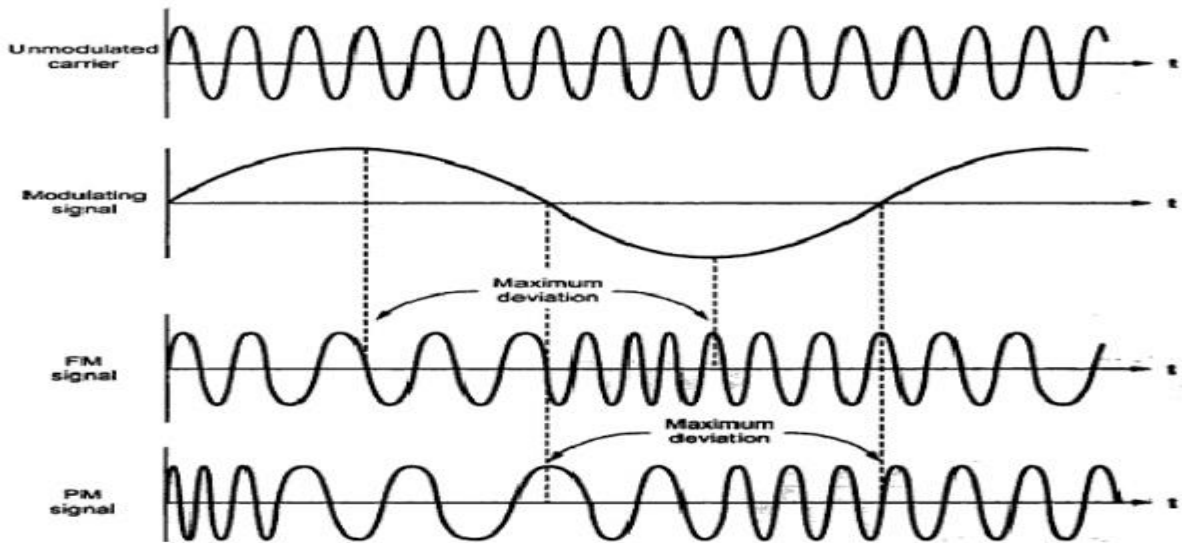

Fig 1.3 a)Unmodulated carrier b)Modulating signal c)FM Signal d)PM Signal (Source:Brainkart)

The expression for frequency deviation, phase deviation and modulation index in angle modulation.

Phase Deviation, Modulation Index and Frequency Deviation

The FM signal, in general is expressed as,

$$e_{FM}(t) = E_c \sin[\omega_c t + m \sin \omega_m t] \quad \text{... (2.1.12)}$$

And the PM signal, in general is expressed as,

$$e_{PM}(t) = E_c \sin[\omega_c t + m \cos \omega_m (t)] \quad \text{... (2.1.13)}$$

In both the above equations, the term 'm' is called *modulation index*. Note that the term $m \sin \omega_m t$ in equation 2.1.12 and $m \cos \omega_m t$ in equation 2.1.13 indicates instantaneous phase deviation $\theta(t)$. Hence 'm' also indicates *maximum phase deviation*. In other words, modulation index can also be defined as maximum phase deviation.

Modulation index for PM :

Comparing equation 2.1.13 and equation 2.1.11, we find that,

$$\boxed{\textbf{Modulation index in PM : } m = kE_m \ \text{ rad}} \quad \text{... (2.1.14)}$$

Thus modulation index of PM signal is directly proportional to peak modulating voltage. And it's unit is radians.

Modulation index for FM:

Comparing equation 2.1.12 and equation 2.1.10 we find that,

$$m = \frac{k_1 E_m}{\omega_m} \quad \text{... (2.1.15)}$$

Thus modulation index of FM is directly proportional to peak modulating voltage, but inversely proportional to modulating signal frequency.

Since $\omega_m = 2\pi f_m$ above equation becomes,

$$m = \frac{k_1 E_m}{2\pi f_m}$$

Here $\frac{k_1 E_m}{2\pi}$ is called *frequency deviation*. It is denoted by δ and its unit is Hz, i.e.,

$$\textbf{Modulation index in FM :} \quad m = \frac{\delta}{f_m} = \frac{\text{Maximum frequency deviation}}{\text{Modulating frequency}} \quad \text{... (2.1.16)}$$

Thus modulation index of M is unities ratio. From above equation and equation 2.1.14, note that the modulation index is differently defined for M and PM signals.

Percentage modulation:

For angle modulation, the percentage modulation is given as the ratio of actual frequency derivation to maximum allowable frequency deviation. i.e.,

$$\%\ \text{modulation} = \frac{\text{Actual frequency deviation}}{\text{Maximum allowable frequency deviation}} \quad \text{... (2.1.17)}$$