UNIT I
ANALOG COMMUNICATION

Modulation :

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

What are the 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.

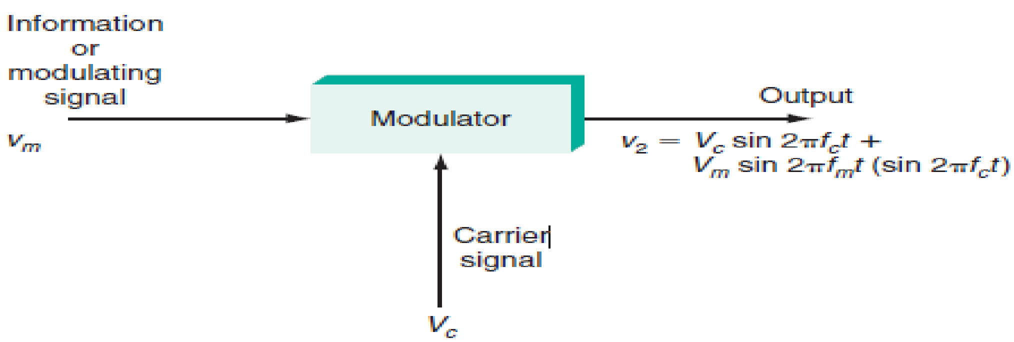
a) Reduction in antenna height b) Long distance communication
c) Ease of radiation d) Multiplexing
e) Improve the quality of reception f) Avoid mixing up of other signals

AMPLITUDE MODULATION

Modulation in which the some characteristics of a carrier wave is varied in accordance with some characteristic of the modulating signal. Amplitude modulation implies the modulation of a coherent carrier wave by mixing it in a nonlinear device with the modulating signal to produce discrete upper and lower sidebands, which are the sum and difference frequencies of the carrier and signal.

The envelope of the resultant modulated wave is an analog of the modulating signal. The instantaneous value of the resultant modulated wave is the vector sum of the corresponding instantaneous values of the carrier wave, upper sideband, and lower sideband. Recovery of the modulating signal may be by direct detection or by heterodyning.

The carrier frequency remains constant during the modulation process, but its amplitude varies in accordance with the modulating signal. An increase in the amplitude of the modulating signal causes the amplitude of the carrier to increase. Both the positive and the negative peaks of the carrier wave vary with the modulating signal. An increase or a decrease in the amplitude of the modulating signal causes a corresponding increase or decrease in both the positive and the negative peaks of the carrier amplitude.



Mathematical Representation of AM:
Time domain analysis:

The variation of the carrier amplitude with respect to time and are said to be in the time domain.
Using trigonometric functions, we can express the sine wave carrier with the simple expression

$$v_c = V_c \sin 2\pi f_c t$$

In this expression, represents the instantaneous value of the carrier sine wave voltage at some specific time in the cycle; represents the peak value of the constant unmodulated carrier sine wave as measured between zero and the maximum amplitude of either the positive-going or the negative-going alternations and fc is the frequency of the carrier sine wave; and *t* is a particular point in time during the carrier cycle.

A sine wave modulating signal can be expressed with a similar formula

$$v_m = V_m \sin 2\pi f_m t$$

Where v_m = instantaneous value of information signal 1

Vm-peak amplitude of information signal

fm _ frequency of modulating signal

The envelope of the modulating signal varies above and below the peak carrier amplitude. That is, the zero reference line of the modulating signal coincides with the peak value of the unmodulated carrier. Because of this, the relative amplitudes of the carrier and modulating signal are important. In general, the amplitude of the modulating signal should be less than the amplitude of the carrier. When the amplitudeof the modulating signal is greater than the amplitude of the carrier, distortion will occur, causing incorrect information to be transmitted.

In amplitude modulation, it is particularly important that the peak value of the modulating signal be less than the peak value of the carrier. Mathematically,

$Vm < Vc$

Values for the carrier signal and the modulating signal can be used in a formula to express the complete modulated wave. First, keep in mind that the peak value of the carrier is the reference point for the modulating signal; the value of the modulating signal is added to or subtracted from the peak value of the carrier.

The instantaneous value of either the top or the bottom voltage envelope can be computed by using the equation

$$v_1 = V_c + v_m = V_c + V_m \sin 2\pi f_m t$$

which expresses the fact that the instantaneous value of the modulating signal algebraically adds to the peak value of the carrier. Thus we can write the instantaneous value of the complete modulated wave by substituting for the peak value of carrier voltage as follows:

$$v_2 = v_1 \sin 2\pi f_c t$$

Now substituting the previously derived expression for and expanding, we get the following:

$$v_2 = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

where v_2 is the instantaneous value of the AM wave (or v_{AM}), $V_c \sin 2\pi f_c t$ is the carrier waveform, and $(V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$ is the carrier waveform multiplied by the modulating signal waveform. It is the second part of the expression that is characteristic of AM. A circuit must be able to produce mathematical multiplication of the carrier and modulating signals in order for AM to occur. The AM wave is the product of the carrier and modulating signals.

Frequency domain analysis:

When only a single-frequency sine wave modulating signal is used, the modulation process generates two sidebands. If the modulating signal is a complex wave, such as voice or video, a whole range of frequencies modulate the carrier, and thus a whole range of sidebands are generated.

The upper sideband f_{USB} and lower sideband f_{LSB} are computed as

$$f_{USB} = f_c + f_m \qquad \text{and} \qquad f_{LSB} = f_c - f_m$$

where f_c is the carrier frequency and f_m is the modulating frequency.

The existence of sidebands can be demonstrated mathematically, starting with the equation for an AM signal described previously:

$$v_{AM} = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

By using the trigonometric identity that says that the product of two sine waves is

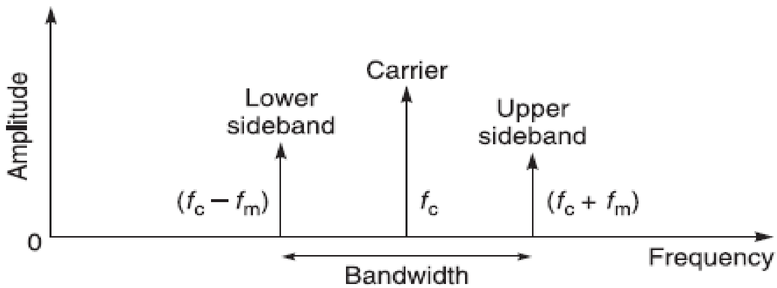
$$\sin A \sin B = \frac{\cos(A - B)}{2} - \frac{\cos(A + B)}{2}$$

and substituting this identity into the expression a modulated wave, the instantaneous amplitude of the signal becomes

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2}\cos 2\pi t(f_c - f_m) - \frac{V_m}{2}\cos 2\pi t(f_c + f_m)$$

where the first term is the carrier; the second term, containing the difference $f_c - f_m$, is the lower sideband; and the third term, containing the sum $f_c + f_m$, is the upper sideband.

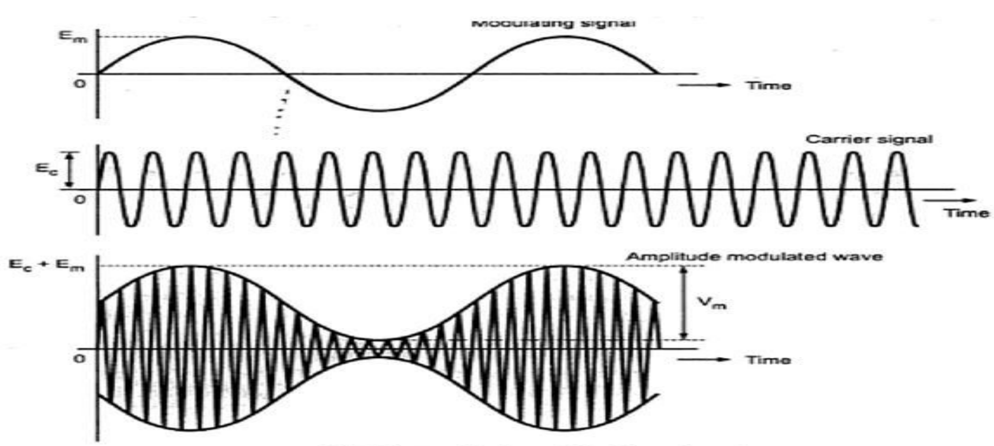
Frequency spectrum



A plot of signal amplitude versus frequency is referred to as a frequency-domain display. Bandwidth is The difference between these two frequencies defines the transmission bandwidth Bw for an AM wave,which is exactly twice the message bandwidth W or f.

B W = 2w (radians) or $2f_m$(hz)

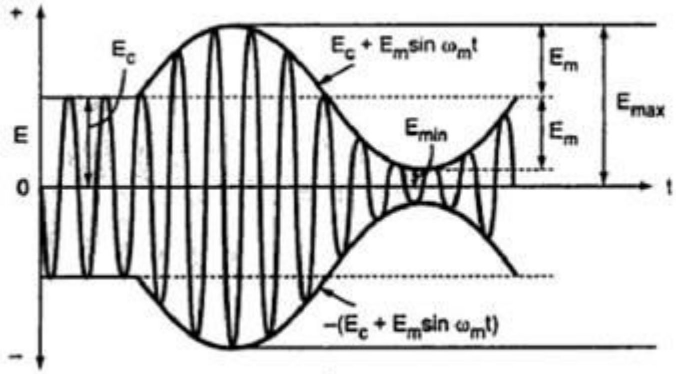
Graphical Representation of AM:



(a) Sinusoidal modulating signal
(b) Sinusoidal high frequency carrier
(c) Amplitude modulated signal

Modulation Index - The ratio between the amplitudes between the amplitudes of the modulating signal and carrier, expressed by the equation:

$$m = \frac{E_m}{E_c}$$



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

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

and

$$E_c = E_{max} - E_m$$

$$= E_{max} - \frac{E_{max} - E_{min}}{2} \text{ by putting for } E_m$$

$$= \frac{E_{max} + E_{min}}{2}$$

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

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

$$\boxed{m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}}$$

Power calculation:

You can see how the power in an AM signal is distributed and calculated by going back to the original AM equation:

$$v_{AM} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t(f_c - f_m) - \frac{V_m}{2} \cos 2\pi t(f_c + f_m)$$

where the first term is the carrier, the second term is the lower sideband, and the third term is the upper sideband.

The power in the carrier and sidebands can be calculated by using the power formula $P = V^2/R$, where P is the output power, V is the rms output voltage, and R is the resistive part of the load impedance, which is usually an antenna. We just need to use the coefficients on the sine and cosine terms above in the power formula:

$$P_T = \frac{(V_c/\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} = \frac{V_c^{\,2}}{2R} + \frac{V_m^{\,2}}{8R} + \frac{V_m^{\,2}}{8R}$$

Remembering that we can express the modulating signal V_m in terms of the carrier V_c by using the expression given earlier for the modulation index $m = V_m/V_c$; we can write

$$V_m = mV_c$$

If we express the sideband powers in terms of the carrier power, the total power becomes

$$P_T = \frac{(V_c)^2}{2R} + \frac{(mV_c)^2}{8R} + \frac{(mV_c)^2}{8R} = \frac{V_c^{\,2}}{2R} + \frac{m^2V_c^{\,2}}{8R} + \frac{m^2V_c^{\,2}}{8R}$$

Since the term $V_c^{\,2}/2R$ is equal to the rms carrier power P_c, it can be factored out, giving

$$P_T = \frac{V_c^{\,2}}{2R}\left(1 + \frac{m^2}{4} + \frac{m^2}{4}\right)$$

Finally, we get a handy formula for computing the total power in an AM signal when the carrier power and the percentage of modulation are known:

$$P_T = P_c\left(1 + \frac{m^2}{2}\right)$$

The output power is easily calculated by using the formula

$$P_T = I_T^{\,2}R \quad \text{where } I_T = I_c\sqrt{(1 + m^2/2)}.$$

Here *Ic* is the unmodulated carrier current in the load, and *m* is the modulation index.
The maximum power in the AM wave is *Pt* = 1.5*Pc*, when *m=1*. This is important, because it is the maximum power that relevant amplifiers must be capable of handling without distortion.

DOUBLE SIDE BAND AND SINGLE SIDE BAND SUPPRESSED CARRIER AM:

DOUBLE SIDE BAND SUPPRESSED CARRIER AM:

- Full-carrier AM is simple but not efficient
- Removing the carrier before power amplification allows full transmitter power to be applied to the sidebands
- Removing the carrier from a fully modulated AM systems results in a double-sideband suppressed-carrier transmission

Suppress the carrier, leaving the upper and lower sidebands which is the type of signal referred to as a *double-sideband suppressedcarrier (DSSC* or *DSB)* signal. The benefit, of course, is that no power is wasted on thecarrier. Double-sideband suppressed carrier modulation is simply a special case of AM with no carrier.

A typical DSB signal is shown in Fig. 1.2

A time-domain display of a DSB AM signal.

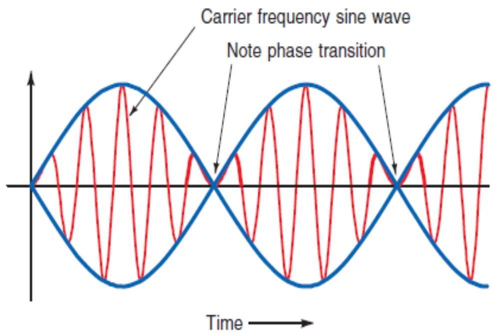


Fig 1.2:DSB SC Signal

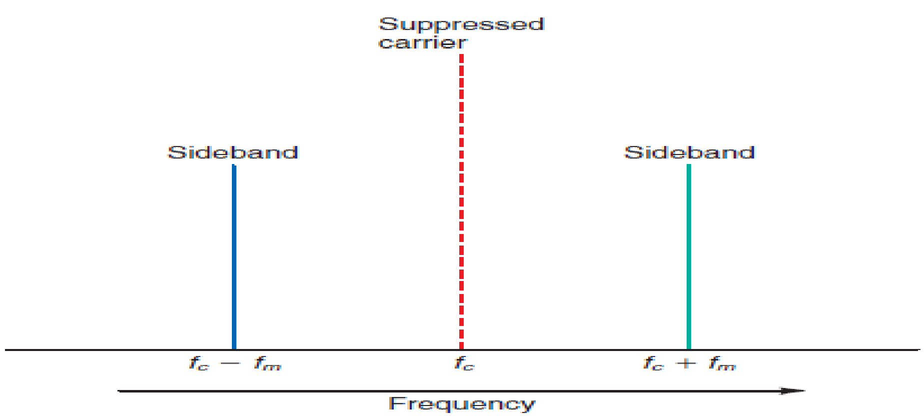
This signal, the algebraic sum of the two sinusoidal sidebands, is the signal produced when a carrier is modulated by a single-tone sine wave information signal. DSB signal is a sine wave at the carrier frequency, varying in amplitude as shown.

Note that the envelope of this waveform is not the same as that of the modulating signal, as it is in a pure AM signal with carrier. A unique characteristic of the DSB signal is the phase transitions that occur at the lower-amplitude portions of the wave.

In above Fig. 1.2,note that there are two adjacent positive-going half-cycles at the null points in the wave.That is one way to tell from an oscilloscope display whether the signal shown is a true DSB signal.A *frequency-domain display* of a DSB signal is given in Fig. 1.3

Fig1.3 Frequency spectrum

A frequency-domain display of DSB signal.



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Double-sideband suppressed carrier signals are generated by a circuit called *balanced modulator*. The purpose of the balanced modulator is to produce the sum and difference frequencies but to cancel or balance out the carrier. Balanced modulators are kind of product modulator used to multiply two incoming message and carrier signal which will produce DSB SC output.

Despite the fact that elimination of the carrier in DSB AM saves considerable power,DSB is not widely used because the signal is difficult to demodulate (recover) at the receiver. One important application for DSB, however, is the transmission of the color information in a TV signal.

SINGLE SIDE BAND SUPPRESSED CARRIER AM:

In DSB transmission, since the sidebands are the sum and difference of the carrier and modulating signals, the information is contained in both sidebands. As it turns out, there is no reason to transmit both sidebands in order to convey the information. One sideband can be suppressed; the remaining sideband is called a *single-sideband suppressed carrier (SSSC* or *SSB)* signal. SSB signals offer four major benefits.

1. The primary benefit of an SSB signal is that the spectrum space it occupies is only one-half that of AM and DSB signals. This greatly conserves spectrum space and allows more signals to be transmitted in the same frequency range.

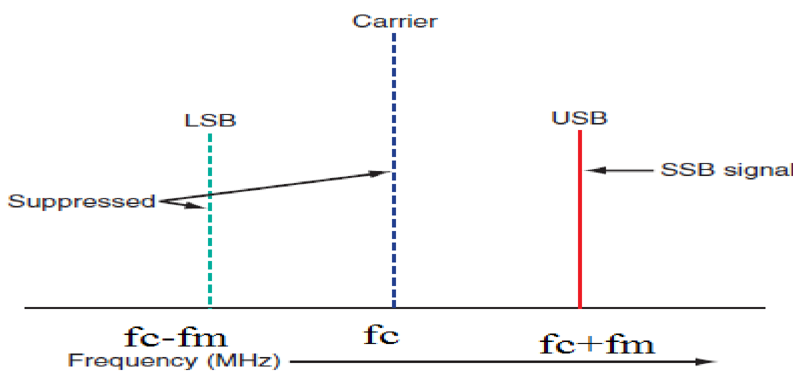
2. All the power previously devoted to the carrier and the other sideband can be channeled into the single sideband, producing a stronger signal that should carry farther and be more reliably received at greater distances. Alternatively, SSB transmitters can be made smaller and lighter than an equivalent AM or DSB transmitter because less circuitry and power are used.

3. Because SSB signals occupy a narrower bandwidth, the amount of noise in the signal is reduced.

4. There is less selective fading of an SSB signal over long distances. An AM signal is really multiple signals, at least a carrier and two sidebands. These are on different requencies, so they are affected in slightly different ways by the ionosphere and upper atmosphere, which have a great influence on radio signals of less than about 50 MHz. The carrier and sidebands may arrive at the receiver at slightly different times, causing a phase shift that can, in turn, cause them to add in such a way as to cancel one another rather than add up to the original AM signal. Such cancellation, or *selective fading,* is not a problem with SSB since only one sideband is being transmitted.

The two sidebands of an AM signal are mirror images of one another

- As a result, one of the sidebands is redundant
- Using *single-sideband suppressed-carrier* transmission results in reduced bandwidth and therefore twice as many signals may be transmitted in the same spectrum allotment
- Typically, a 3dB improvement in signal-to-noise ratio is achieved as a result of SSBSC



Bandwidth is fm(Hz).Transmission bandwidth is cut into half if one side band is suppressed with carrier.

ANGLE MODULATION

Combination of frequency and phase modulation is angle modulation. Angle modulation is a method of analog modulation in which either the phase or frequency of the carrier wave is varied according to the message signal. In this method of modulation the amplitude of the carrier wave is maintained constant.

• Angle Modulation is a method of modulation in which either Frequency or Phase of the carrier wave is varied according to the message signal. In general form, an angle modulated signal can represented as

$$s(t) = A_c \cos[\theta(t)]$$

Where A_c is the amplitude of the carrier wave and _*(t)* is the angle of the modulated carrier and also the function of the message signal.

The instantaneous frequency of the angle modulated signal, s(t) is given by

$$f_i(t) = \frac{1}{2\pi}\frac{d\theta(t)}{dt}$$

The modulated signal, s(t) is normally considered as a rotating phasor of length A_c and angle $\theta(t)$. The angular velocity of such a phasor is $d\theta(t)/dt$, measured in radians per second.

An un-modulated carrier has the angle $\theta(t)$ defined as

$$\theta(t) = 2\pi f_c t + \phi_c$$

Where f_c is the carrier signal frequency and ϕ_c is the value of $\theta(t)$ at t = 0.

The angle modulated signal has the angle, $\theta(t)$ defined by

$$\theta(t) = 2\pi f_c t + \phi(t)$$

There are two commonly used methods of angle modulation:

1. Frequency Modulation, and2. Phase Modulation.

FREQUENCY MODULATION

- Frequency Modulation is defined as changing the frequency of the carrier signal with respect to the instantaneous change in message signal. In frequency modulation the instantaneous frequency *fi(t)* is varied linearly with messagesignal, m(t) as:

$$f_i(t) = f_c + k_f m(t)$$

where *kf* is the frequency sensitivity of the modulator in hertz per volt.The instantaneous angle can now be defined as

$$\theta(t) = 2\pi f_c t + 2\pi k_f \int_0^t m(t)dt$$

and thus the frequency modulated signal is given by

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(t)dt\right]$$

Single-Tone Frequency Modulation:

Consider a sinusoidal modulating signal defined as:

$$m(t) = A_m\, Cos(\, 2\pi\, f_m\, t)$$

Substituting for m(t) ,then the instantaneous frequency of the FM signal is

$$f_i(t) = f_c + k_f A_m \cos(2\pi f_m t) \;= f_c + \Delta f \cos(2\pi f_m t)$$

where Δf is called the frequency deviation given by $\Delta \mathrm{f} = k_f A_m$

and the instantaneous angle is

$$\begin{aligned} \theta(t) &= 2\pi \int_0^t f_i(t)dt \\ &= 2\pi f_c t + \frac{\Delta f}{f_m}\sin(\,2\pi f_m t) \\ &= 2\pi f_c t + \beta \sin(\,2\pi f_m t) \end{aligned}$$

$$\text{where } \beta = \frac{\Delta f}{f_m}; \text{ modulation index}$$

The resultant FM signal is

$$s(t) = A_c \cos\left[2\pi f_c t + \beta \sin(2\pi f_m t)\right]$$

The frequency deviation factor indicates the amount of frequency change in the FM signal from the carrier frequency *fc* on either side of it. Thus FM signal will have the frequency components between (*fc* - fm) to (*fc* +fm). The modulation index, mf represents the phase deviation of the FM signal and is measured in radians. Depending on the value of modulation index, FM signal can be classified into two types:

1. Narrow band FM (mf << 1) and
2. Wide band FM (mf >> 1).

Frequency Domain Representation of Wide-Band FM signals:

The FM wave for sinusoidal modulation is given by

$$\begin{aligned} s(t) &= A_c \cos\left[2\pi f_c t + \beta \sin(2\pi f_m t)\right] \\ &= A_c \cos(2\pi f_c t)\cos\left[\beta \sin(2\pi f_m t)\right] - A_c \sin(2\pi f_c t)\sin\left[\beta \sin(2\pi f_m t)\right] \end{aligned}$$

The FM wave can be expressed in terms of complex envelope as:

$$\begin{aligned} s(t) &= \mathrm{Re}\left[A_c \exp\left(j2\pi f_c t + j\beta \sin(2\pi f_m t)\right)\right] \\ &= \mathrm{Re}\left[\tilde{s}(t)\exp\left(j2\pi f_c t\right)\right] \end{aligned}$$

The complex envelope of the FM wave

$$\tilde{s}(t) = A_c \exp\left[j\beta \sin(2\pi f_m t)\right] \;\; and \;\; \tilde{s}(t): \text{periodic function with } f_m$$

The complex envelope is a periodic function of time, with a fundamental frequency equal to the modulation frequency f_m. The complex envelope can be expanded in the form of complex series:

$$\tilde{s}(t) = \sum_{n=-\infty}^{\infty} c_n \exp\left[j2\pi\, n f_m t\right]$$

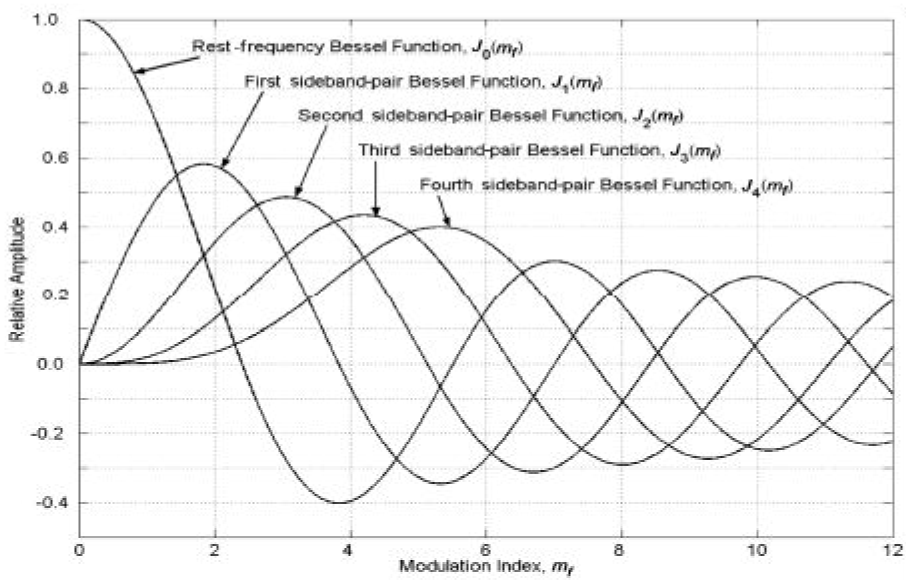
Frequency Spectrum of Angle Modulated Waves

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 for spectrum analysis,

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

Using Bessel functions, this equation can be expanded as,

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



Plots of Bessel functions

(i) FM signal has infinite number of side bands at frequencies (fc + nfm).
(ii) Relative amplitudes of all the spectral lines depends on the value of Jn(β).
(iii) The number of significant side bands depends on the modulation index (β). With (β<<1), only J0(β) and J1(β) are significant. But for (β>>1), many sidebands exists.
(iv) The average power of an FM wave is P = 0.5Ac (based on Bessel function property).

Transmission bandwidth of FM:

An FM wave consists of infinite number of side bands so that the bandwidth is theoretically infinite. But, in practice, the FM wave is effectively limited to a finite number of side band frequencies compatible with a small amount of distortion. There are many ways to find the bandwidth of the FM wave.

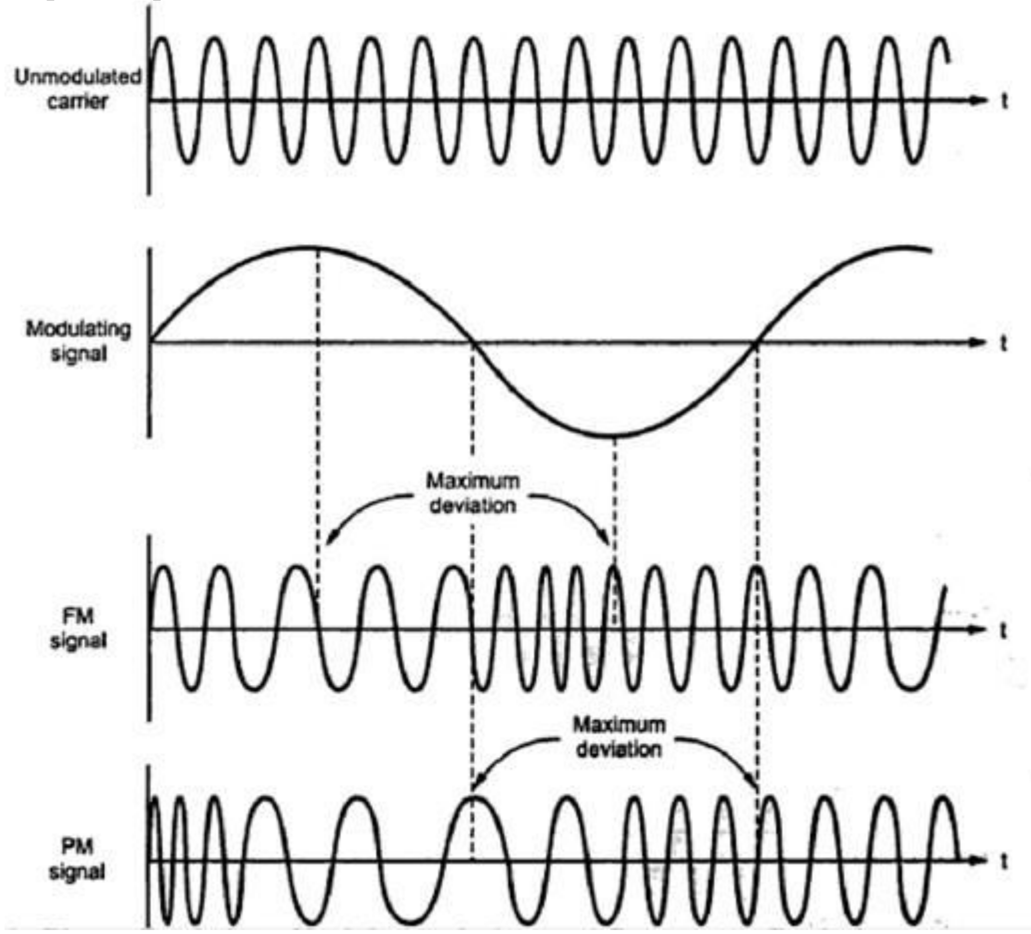
Carson's rule.

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(Δf +fm) Hz.

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)

Graphical representation of FM and PM:



PHASE MODULATION

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

In phase modulation the angle is varied linearly with the message signal m(t) as :

$$\theta(t) = 2\pi f_c t + k_p m(t)$$

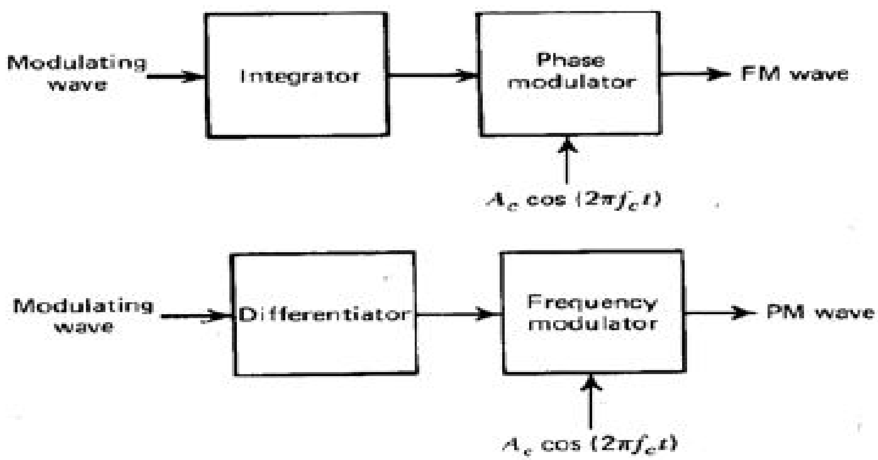
where k_p is the phase sensitivity of the modulator in radians per volt.

Thus the phase modulated signal is defined as

$$s(t) = A_c \cos\left[2\pi f_c t + k_p m(t)\right]$$

Frequency modulation VS Phase modulation

A frequency modulated signal can be generated using a phase modulator by first integrating m(t) and using it as an input to a phase modulator. This is possible by considering FM signal as phase modulated signal in which the modulating wave is integral of m(t) in place of m(t). This is shown in the below fig..

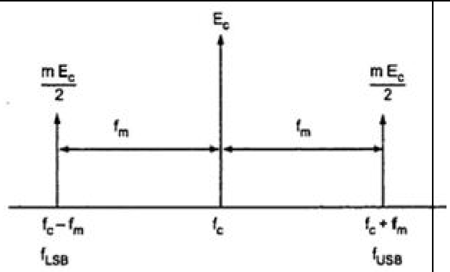
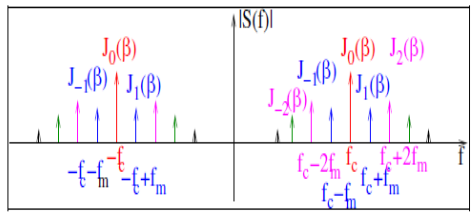
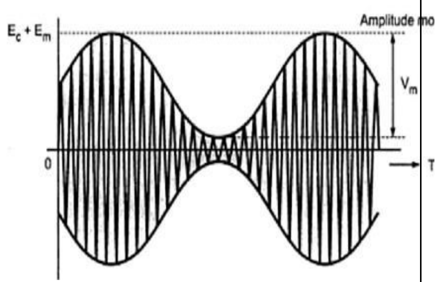
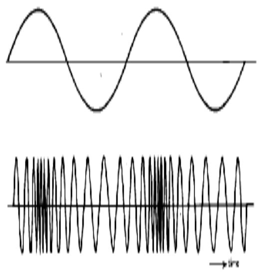
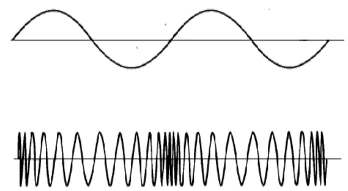


Similarly, a PM signal can be generated by first differentiating m(t) and then using the resultant signal as the input to a FM modulator, as shown in above fig.

Comparison of AM, DSB, SSB and FM

	AM	DSB	SSB	FM
Bandwidth	2 fm	2 fm	fm	2 (β+1)fm
Signal to Noise Ratio	LINEAR	LINEAR	LINEAR	NONLINEAR
EFFICIENCY	33%	50%	100%	<100%
COMPLEXITY	Low	Moderate	Moderate	High

Comparison of Amplitude modulation , Frequency Modulation and Phase modulation

	Amplitude modulation	Frequency Modulation	Phase modulation
Definition	Amplitude Modulation is the process in which the amplitude of a carrier wave is varied in accordance with amplitude of the modulating signal.	Frequency Modulation is the process in which the frequency of a carrier wave is varied in accordance with amplitude of the modulating signal.	Phase Modulation is the process in which the phase of a carrier wave is varied in accordance with amplitude of the modulating signal.
Modulation Index	Ma=Vm/Vc Vm—Maximum amplitude of message signal Vc-maximum amplitude of carrier	Mf=(kVm)/fm or Δf/fm Δf-frequency deviation Fm-modulating frequency	Mp=kVm k-deviation sensitivity Vm-maximum amplitude of message
Frequency spectrum			------
Modulated Waveform			

Noise and different types of noise

Noise is a general term which is used to describe an unwanted signal which affects a wanted signal

Noise may be put into following two categories.

1. **External noises**, i.e. noise whose sources are external.

   External noise may be classified into the following three types:

   1. ***Atmospheric noises***
   2. ***Extraterrestrial noises***
   3. ***Man-made noises or industrial noises.***
2. **Internal noise in communication**, i.e. noises which get, generated within the receiver or communication system.

   Internal noise may be put into the following four categories.

   1. ***Thermal noise or white noise or Johnson noise***
   2. ***Shot noise.***
   3. ***Transit time noise***
   4. ***Miscellaneous internal noise.***

(i)Internal noise

• Thermal noise

Conductors contain a large number of *'free"* electrons and *"ions"* strongly bound by molecular forces. The ions vibrate randomly about their normal (average) positions, however, this vibration being a function of the temperature. Continuous collisions between the electrons and the vibrating ions take place. Thus there is a continuous transfer of energy between the ions and electrons. This is the source of resistance in a conductor. The movement of free electrons constitutes a current which is purely random in nature and over a long time averages zero. There is a random motion of the electrons which give rise to noise voltage called thermal noise.

The analysis of thermal noise is based on the Kinetic theory. It shows that the temperature of particles is a way of expressing its internal kinetic energy. Thus *"Temperature"* of a body can be said to be equivalent to the statistical rms value of the velocity of motion of the particles in the body. At -273°C (or zero degree Kelvin) the kinetic energy of the particles of a body becomes zero .Thus we can relate the noise power generated by a resistor to be proportional to its absolute temperature. Noise power is also proportional to the bandwidth over which it is measured. From the above discussion we can write down.

$P_n \propto TB$
$P_n = KTB$ ------ (1)

Where

Pn **=** Maximum noise power output of a resistor.
K = Boltzmann's constant = 1.38 x10-23 joules I Kelvin.
T **=** Absolute temperature.
B = Bandwidth over which noise is measured.

• Shot noise

The most common type of noise is referred to as shot noise which is produced by the random arrival of 'electrons or holes at the output element, at the plate in a tube, or at the collector or drain in a transistor. Shot noise is also produced by the random movement of electrons or holes across a PN junction. Even through current flow is established by external bias voltages, there will still be some random movement of electrons or holes due to discontinuities in the device. An example of such a discontinuity is the contact between the copper lead and the semiconductor materials. The interface between the two creates a discontinuity that causes random movement of the current carriers.

- Transit time noise

Another kind of noise that occurs in transistors is called transit time noise.

Transit time is (he duration of time that it takes for a current carrier such as a hole or current to move from the input to the output.

The devices themselves are very tiny, so the distances involved are minimal. Yet the time it takes for the current carriers to move even a short distance is finite. At low frequencies this time is negligible. But when the frequency of operation is high and the signal being processed is the magnitude as the transit time, then problem can occur. The transit time shows up as a kind of random noise within the device, and this is directly proportional to the frequency of operation.

ii) External noise

• Atmospheric noise

Atmospheric noise or static is caused by lighting discharges in thunderstorms and other natural electrical disturbances occurring in the atmosphere. These electrical impulses are random in nature. Hence the energy is spread over the complete frequency spectrum used for radio communication.

Atmospheric noise accordingly consists of spurious radio signals with components spread over a wide frequency range. These spurious radio waves constituting the noise get propagated over the earth in the same fashion as the desired radio waves of the same frequency. Accordingly at a given receiving point, the receiving antenna picks up not only the signal but also the static from all the thunderstorms, local or remote.

• Industrial noise

By man-made noise or industrial- noise is meant the electrical noise produced by such sources as automobiles and aircraft ignition, electrical motors and switch gears, leakage from high voltage lines, fluorescent lights, and numerous other heavy electrical machines. Such noises are produced by the arc discharge taking place during operation of these machines. Such man-made noise is most intensive in industrial and densely populated areas.

• Extra-terrestrial noise

There are numerous types of extraterrestrial noise or space noises depending on their sources. However, these may be put into following two subgroups.

1. ***Solar noise***
2. ***Cosmic noise***

Solar Noise

This is the electrical noise emanating from the sun. Under quite conditions, there is a steady radiation of noise from the sun. This results because sun is a large body at **a** very high temperature (exceeding 6000°C on the surface), and radiates electrical energy in the form of noise over a very wide frequency spectrum including the spectrum used for radio communication. The intensity produced by the sun varies with time. In fact, the sun has a repeating 11-Year noise cycle. During the peak of the cycle, the sun produces some amount of noise that causes tremendous radio signal interference, making many frequencies unusable for communications. During other years. the noise is at a minimum level.

Cosmic noise

Distant stars are also suns and have high temperatures. These stars, therefore, radiate noise in the same way as our sun. The noise received from these distant stars is thermal noise (or black body noise) and is distributing almost uniformly over the entire sky. We also receive noise from the center of our own galaxy (The Milky Way) from other distant galaxies and from other virtual point sources such as quasars and pulsars.