Modulation

Modulation is defined as the process by which some characteristics of a signal called carrier is varied in accordance with instantaneous value of another signal called modulating signa. The carrier's characteristics that can be modified include amplitude, frequency, or phase, leading to different types of modulation:

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

The two types of analog modulation are

a) Amplitude modulation

b) Angle modulation

AMPLITUDE MODULATED

Amplitude modulation is the process in which instantaneous amplitude of the carrier signal is varied according to the amplitude of the modulating signal keeping the frequency and phase of the carrier signal constant.

The AM process requires two inputs:

1. Carrier Signal: A high-frequency, constant-amplitude signal, usually a sinusoidal wave, which serves as the primary medium for carrying the information.
2. Information Signal: A lower-frequency signal containing the actual information to be transmitted. This could be a simple sinusoidal wave or a complex waveform with multiple frequencies, depending on the nature of the data. In AM, the carrier's amplitude is adjusted in a linear relationship with the amplitude of the information signal, effectively "embedding" the information within the variations of the carrier's strength. This method makes it possible to transmit the information signal across a communication channel using a high-frequency carrier that can travel greater distances and penetrate obstacles more effectively than low-frequency signals alone.

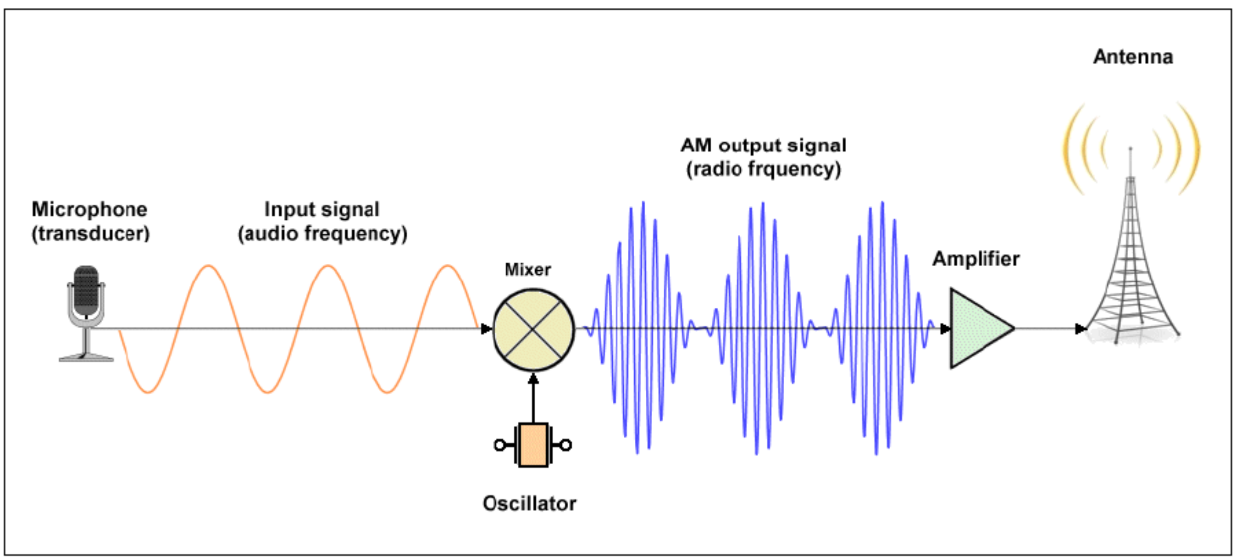


Fig. 1: Block diagram of AM modulation

AMPLITUDE MODULATED

Amplitude modulation is the process in which instantaneous amplitude of the carrier signal is varied according to the amplitude of the modulating signal keeping the frequency and phase of the carrier signal constant.

Let the instantaneous carrier current be $A\sin(2\pi f_c t)$ or $A\cos(2\pi f_c t)$

The modulating signal $g(t)=B\sin(2\pi f_m t)$ or $g(t)=B\cos(2\pi f_m t)$

Types of Amplitude Modulation (AM):

AM can be further classified into various types:

1. Double Sideband with Large Carrier (DSB-LC): This is the most commonly used form of AM, especially for AM radio broadcasting, where both sidebands and the full carrier signal are transmitted.
2. Double Sideband Suppressed Carrier (DSB-SC): Similar to DSB-LC, but without transmitting the carrier signal, reducing power requirements.
3. Single Sideband (SSB): In this type, only one of the two sidebands from the DSB-SC signal is transmitted, significantly saving bandwidth and power.

4. Vestigial Sideband (VSB): A modified form of SSB that transmits a portion of the second sideband, simplifying the signal generation and reception process, commonly used in TV broadcasting.

I. Double Sideband Large Carrier (DSB-LC)

The expression of AM wave is given by:

AMPLITUDE MODULATED

Amplitude modulation is the process in which instantaneous amplitude of the carrier signal is varied according to the amplitude of the modulating signal keeping the frequency and phase of the carrier signal constant.

Let the instantaneous carrier current be $i = A \sin \omega_c t$

The modulating signal $g(t) = B \sin \omega_s t$

The modulation index is m or k $m = \frac{B}{A}$

The AM (DSB-LC) signal

$$(A + B \sin w_m t)(\sin w_c t)$$

$$A\left(1 + \frac{B}{A}\sin w_m t\right)(\sin w_c t)$$

$$(\sin A)(\sin B) = \frac{1}{2}\cos(A - B) - \frac{1}{2}\cos(A + B)$$

$$i = A \sin w_c t + \frac{mA}{2}[\cos(w_c - w_m)t - \cos(w_c + w_m)t]$$

A سعة الموجة الحاملة

B سعة الإشارة

M معامل التضمين

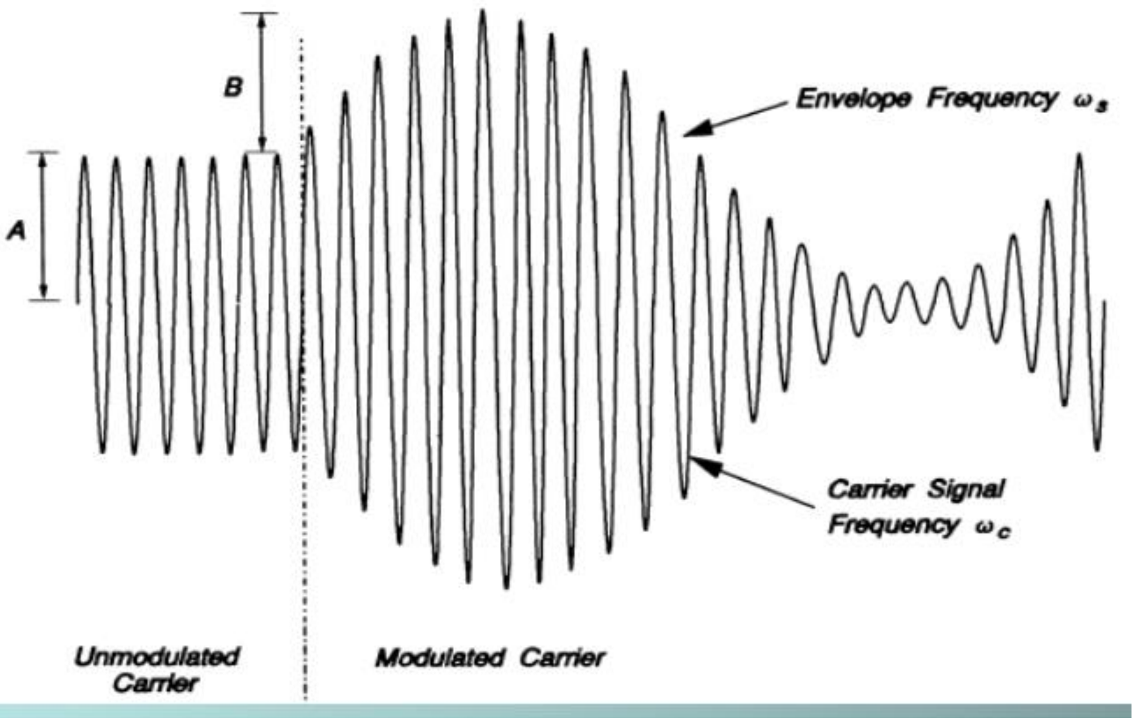


Figure: Amplitude modulated wave: the carrier frequency remains sinusoidal at wc while the envelope varies at frequency ws

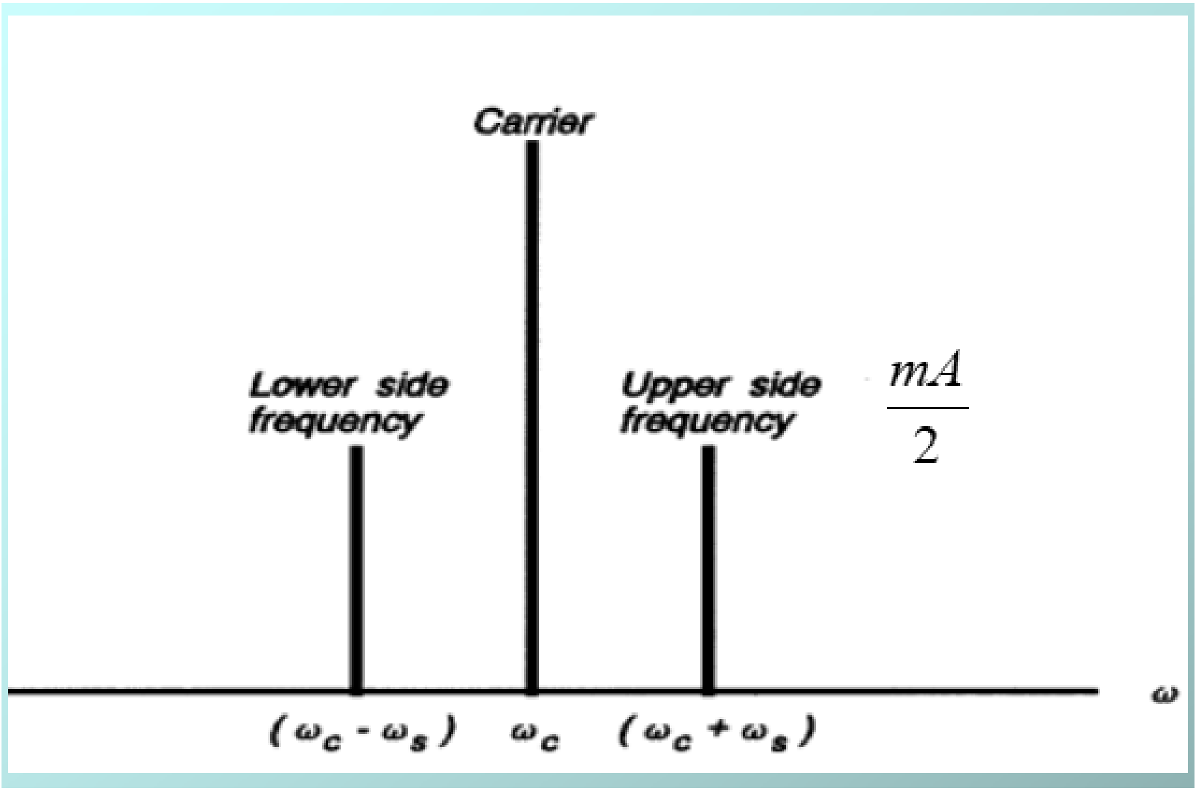


Figure : The AM wave in frequency domain. Note that there are three distinct frequencies present

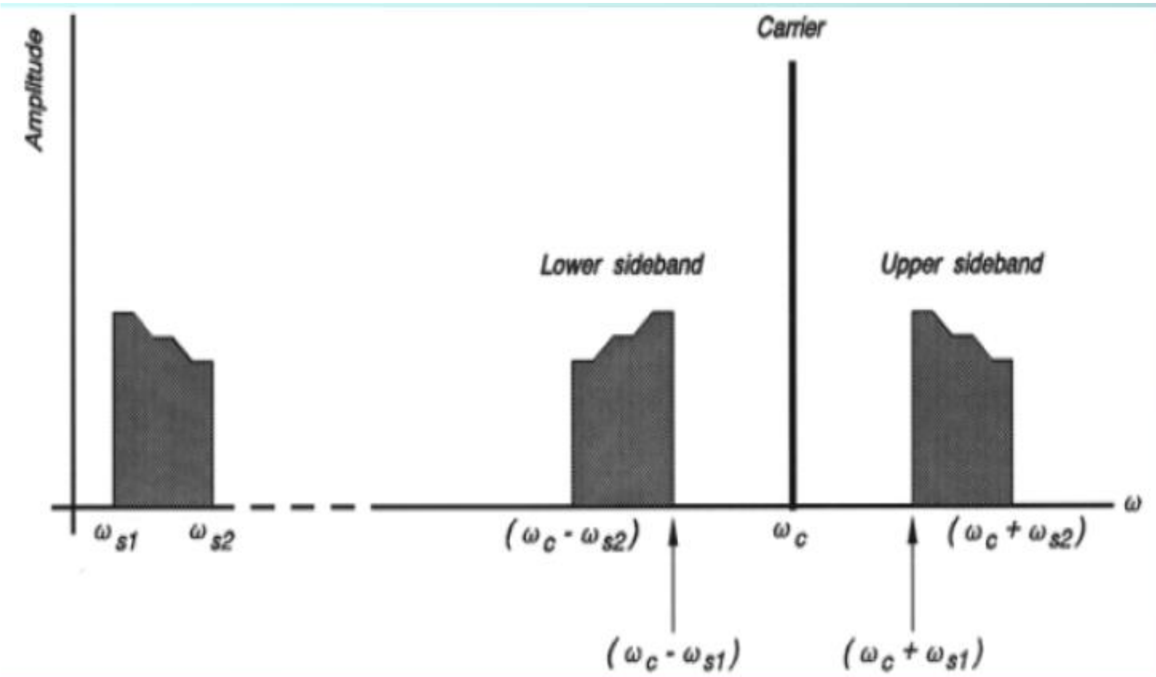


Figure : The AM wave in frequency domain when the single frequency modulating signal is replaced by a band of audio frequencies. Note that the information in the signal resides only in the sidebands.

Spectrum of DSB-LC:

Amplitude modulation (AM), specifically Double Sideband Large Carrier (DSB-LC), effectively shifts the spectrum of the modulating signal $\boldsymbol{m}(\boldsymbol{t})$ to align with the carrier frequency $\boldsymbol{fc}$. This process results in a modulated signal that contains three distinct frequency components:

i. Carrier Frequency $\boldsymbol{fc}$: This is the central frequency of the transmitted signal, which remains unchanged during modulation.

ii. Upper Sideband Frequency $\boldsymbol{fc}+\boldsymbol{fm}$: This component represents the carrier frequency increased by the frequency of the modulating signal fm.

It carries the higher frequency information from the modulating signal.

iii. Lower Sideband Frequency $fc-fm$: This component represents the carrier frequency decreased by the frequency of the modulating signal fm. It carries the lower frequency information from the modulating signal.

these three frequency components create the spectrum of the AM modulated wave when the modulating signal consists of a single frequency. The presence of both upper and lower sidebands ensures that the information contained in the modulating signal is fully transmitted.

The bandwidth of the modulated signal is significant in determining how the signal can be transmitted and received effectively. The bandwidth of the DSB-LC signal is calculated as twice the frequency of the modulating signal:

$$BW = Maximum\ Freq. - Minimum\ Freq.$$

$$BW = (fc + fm) - (fc - fm)$$

$$BW = 2fm$$

Modulation index:

The modulation index (or modulation depth) in Amplitude Modulation (AM) quantifies the extent to which the carrier signal varies in response to the modulating (message) signal. It's an essential factor for ensuring signal fidelity and efficient transmission. The modulation index is typically denoted as m and defined as follows:

$$m = \frac{B}{A}$$

Ranges for the Modulation Index

The modulation index m in amplitude modulation (AM) describes the degree to which the carrier wave is modulated by the message signal, with ideal values typically in the range from (0 to1):

- $\boldsymbol{m}$=$\mathbf{0}$: No modulation occurs. The carrier wave maintains a constant amplitude Ec without carrying any information from the message signal.

- $\mathbf{0}$<$\boldsymbol{m}$<$\mathbf{1}$: This is the optimal range for modulation, where the carrier is modulated without distortion. As m increases toward 1, the modulation depth increases, enhancing the clarity of the transmitted signal.

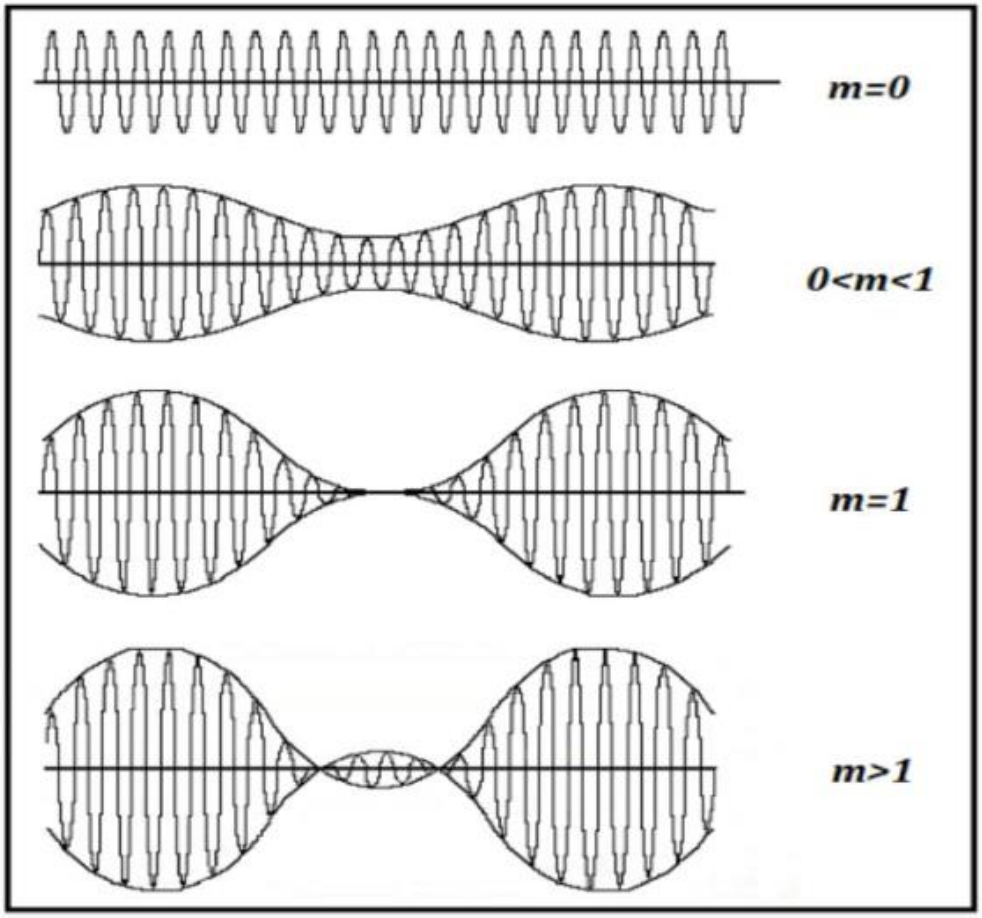
- $\boldsymbol{m}$=$\mathbf{1}$: This represents the maximum modulation without distortion, where the carrier is fully modulated to the maximum amplitude without overlapping sidebands.

$m>1$: Known as overmodulation, this range results in distortion due to the excessive amplitude of the message signal, causing overlapping of sidebands and making it difficult to recover the original signal without distortion.

Alternate Expression Using Maximum and Minimum Amplitudes

The modulation index can also be derived using the maximum ($Vmax$) and minimum ($Vmin$) envelope amplitudes of the modulated signal:

$$m = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$



Power of DSB-LC

There are three components for any DSB-LC waveform, the upper sideband, the lower sideband, and the carrier frequency. If the powers in the three of these are added up, the total power in the modulated signal will be:

$$Pt=Pc+PUSB+PLSB$$

Power Content

$$P_T = Pc + P_{LSB} + P_{USB}$$

$$P = \frac{V^2}{R}$$

$$Amplitude \quad of \quad LSB \quad or \quad USB = \frac{mA}{2}$$

$$P_{LSB} = P_{USB} = \frac{m^2 Pc}{4}$$

$$P_T = Pc + \frac{m^2 Pc}{4} + \frac{m^2 Pc}{4}$$

$$P_T = Pc + \frac{m^2 Pc}{2}$$

$$P_T = Pc\,(1 + \frac{m^2}{2})$$

($\boldsymbol{Pc}$): The carrier power

(P_{USB} , P_{LSB}): Sideband Power: The power in each sideband

($\boldsymbol{Pt}$): Total transmitted power