MODULE 5
COMMUNICATION SYSTEMS

Quote of the day

"Weakness of attitude becomes weakness of character".

— Albert Einstein

What are the Basic Types of Analogue Modulation Methods ?

Consider the carrier signal below:

$$e_c(t) = E_c(t)\cos(2\pi f_c t + \theta)$$

1. Changing of the carrier amplitude $E_c(t)$ produces

Amplitude Modulated signal **(AM)**

2. Changing of the carrier frequency f_c produces

Frequency Modulated signal **(FM)**

3. Changing of the carrier phase θ produces

Phase Modulated signal **(PM)**

Figure *Amplitude modulation*

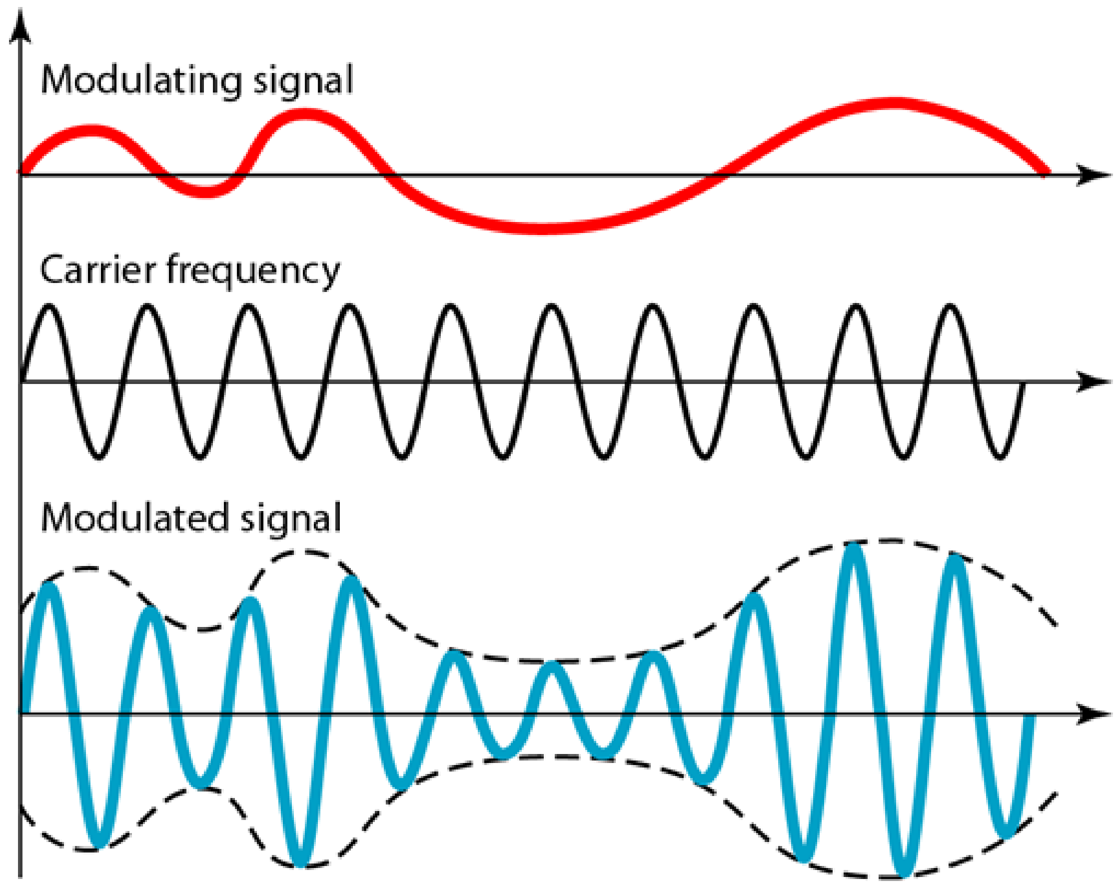


Figure *Frequency modulation*

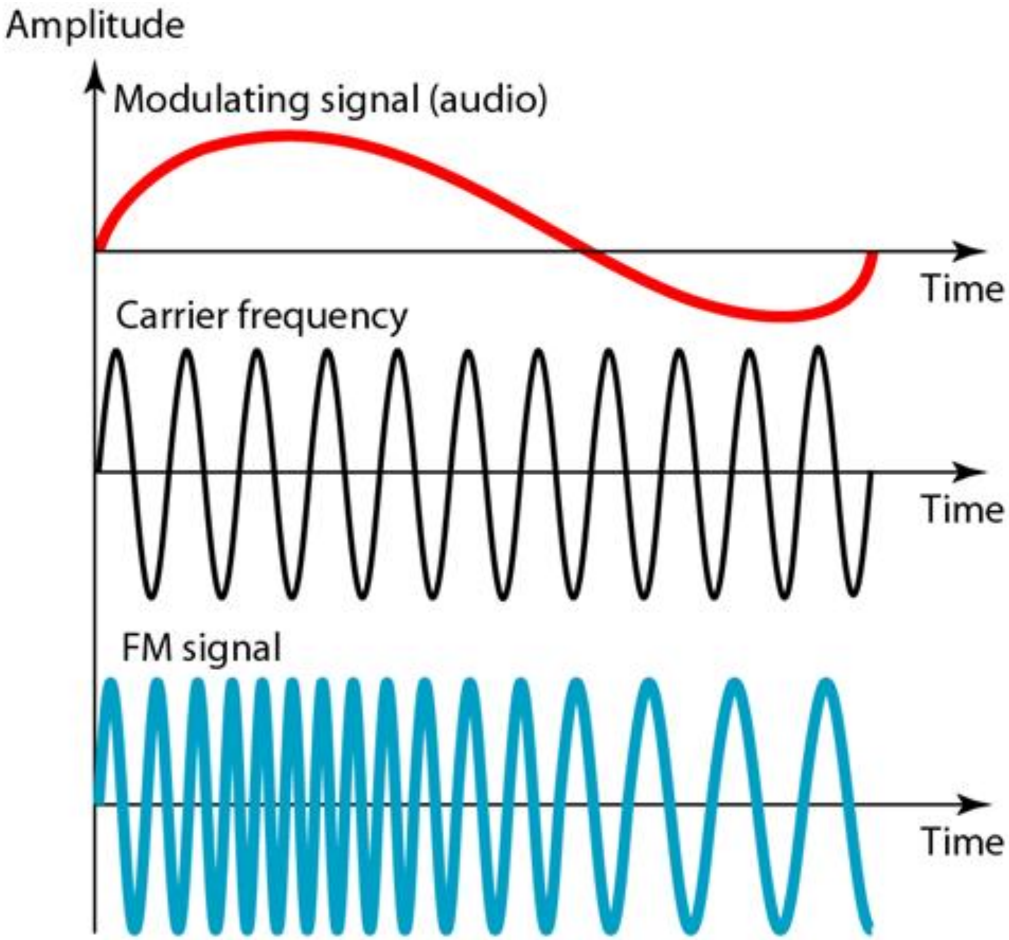
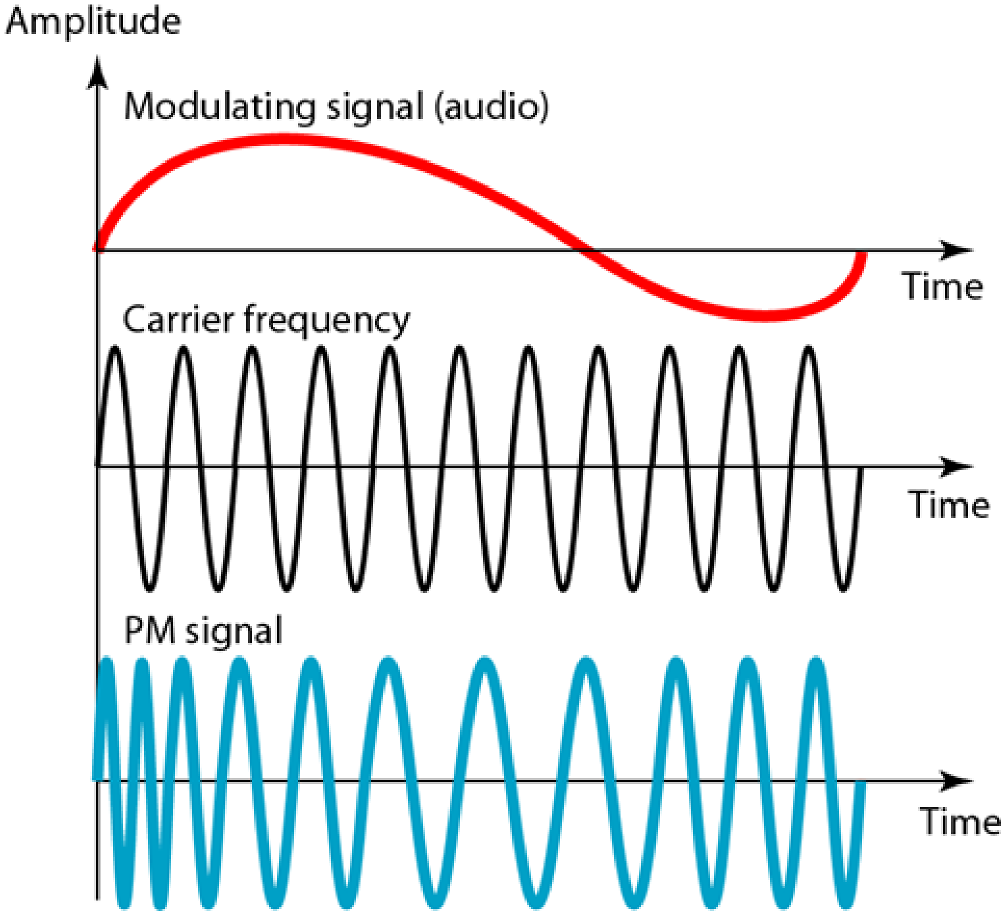
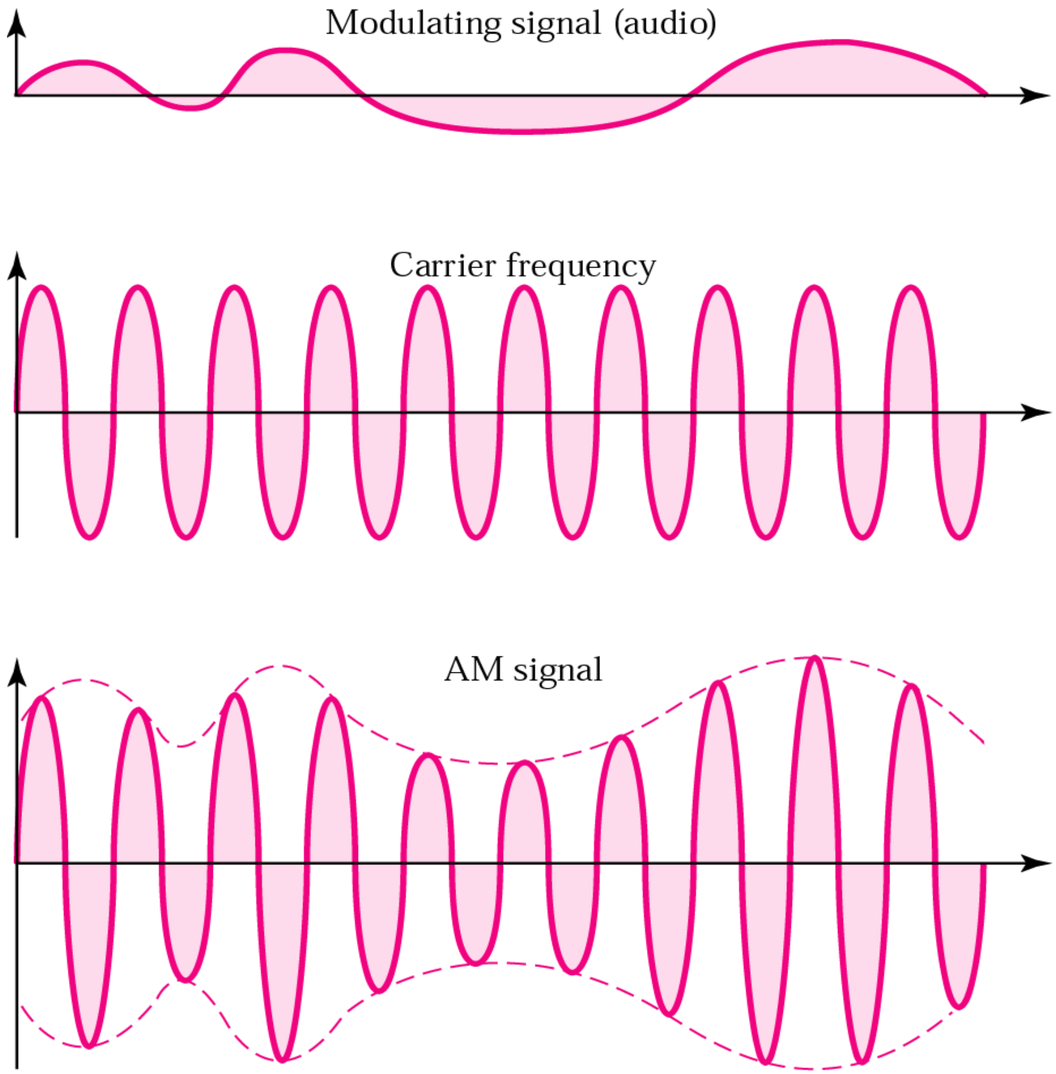


Figure ***Phase modulation***



Conventional Amplitude Modulation (Full AM)



Derive the Frequency Spectrum for Full-AM Modulation (DSB-LC)

1 Consider the carrier signal is

$$e(t) = E_c \cos(\omega_c t) \quad \text{where } \omega_c = 2\pi f_c$$

2 In the same way, a modulating signal (information signal) can also be expressed as

$$e_m(t) = E_m \cos \omega_m t$$

3 The amplitude-modulated wave can be expressed as

$$e(t) = \left[E_c + e_m(t)\right]\cos(\omega_c t)$$

4 By substitution

$$e(t) = \left[E_c + E_m \cos(\omega_m t)\right]\cos(\omega_c t)$$

5 Let us define the modulation index m.

$$m = \frac{E_m}{E_c} \quad \Rightarrow \quad \therefore E_m = mE_c$$

6 Therefore the full AM signal may be written as

$$e(t) = (E_c + mE_c \cos(\omega_m t))\cos(\omega_c t)$$

$$e(t) = E_c \cos(\omega_c t) + mE_c \cos(\omega_m t)\cos(\omega_c t)$$

Applying the trigonometric formula to the 2nd term of this expression

$$\cos A \cos B = 1/2[\cos(A+B) + \cos(A-B)]$$

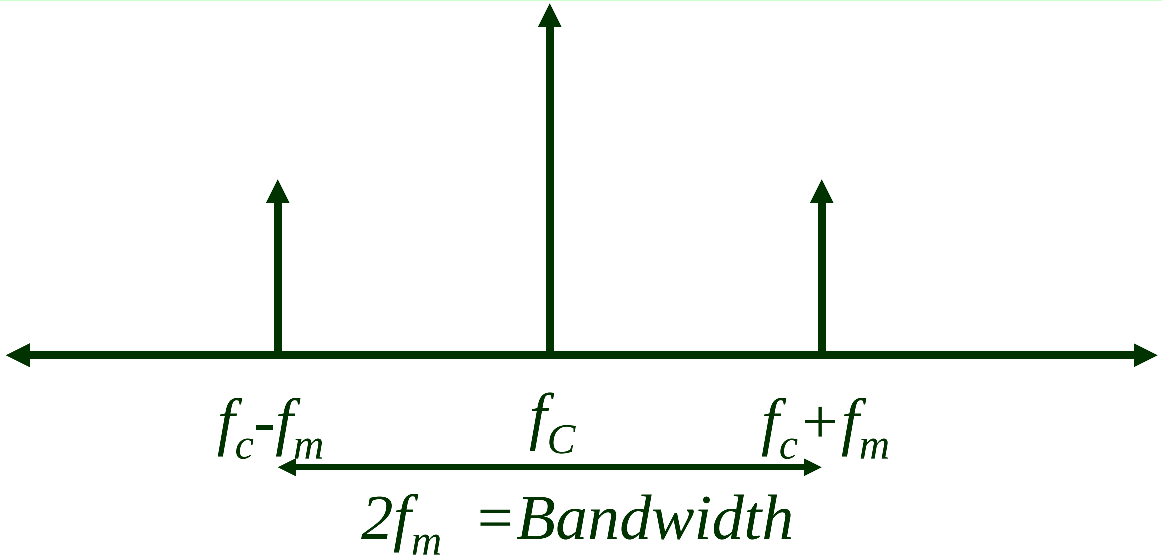
$$e(t) = E_c(\cos\omega_c t) + \frac{mE_c}{2}\cos(\omega_c + \omega_m)t + \frac{mE_c}{2}\cos(\omega_c - \omega_m)t$$

Frequency Spectrum of the above AM signal and its Bandwidth

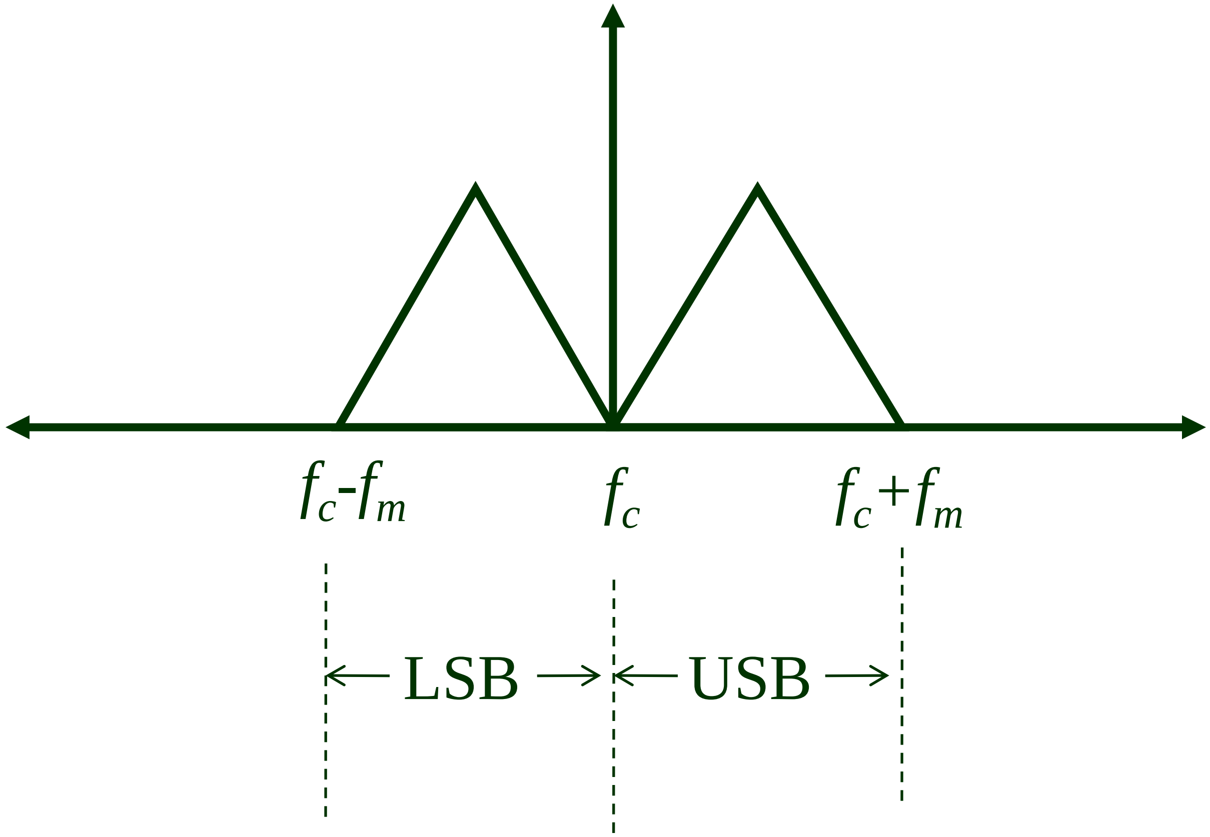
$$e(t) = E_c(\cos\omega_c t) + \frac{mE_c}{2}\cos(\omega_c + \omega_m)t + \frac{mE_c}{2}\cos(\omega_c - \omega_m)t$$

$$e(t) = E_c(\cos 2\pi f_c t) + \frac{mE_c}{2}\cos(2\pi f_c + 2\pi f_m)t + \frac{mE_c}{2}\cos(2\pi f_c - 2\pi f_m)t$$

$$e(t) = E_c(\cos 2\pi f_c t) + \frac{mE_c}{2}\cos(f_c + f_m)2\pi t + \frac{mE_c}{2}\cos(f_c - f_m)2\pi t$$



Frequency Spectrum for a complex input signal with AM



Frequency Spectrum of an AM signal

The frequency spectrum of AM waveform contains three parts:

1. A component at the carrier frequency f_c
2. An upper side band (USB), whose highest frequency component is at f_c+f_m
3. A lower side band (LSB), whose lowest frequency component is at f_c-f_m

∴ *The bandwidth of the modulated waveform is* twice *the information signal bandwidth.*

- Because of the two side bands in the frequency spectrum its often called Double Sideband with Large Carrier.(DSB-LC)

- The information in the base band (information) signal is duplicated in the **LSB** and **USB** and the **carrier** conveys **no** information.

What is the significance of modulation index ?

Modulation Index (m)

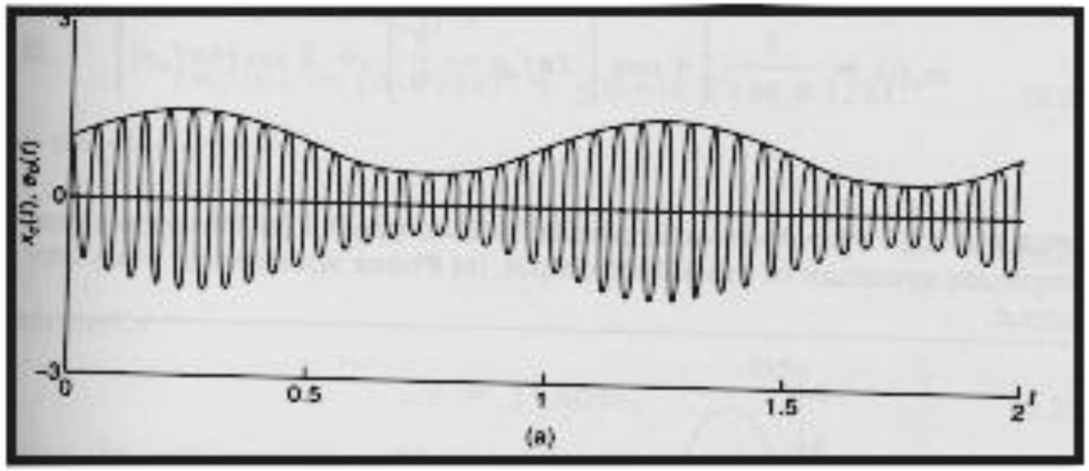
- **m** is merely defined as a parameter, which determines the amount of modulation.

- What is the degree of modulation required to establish a desirable AM communication link?

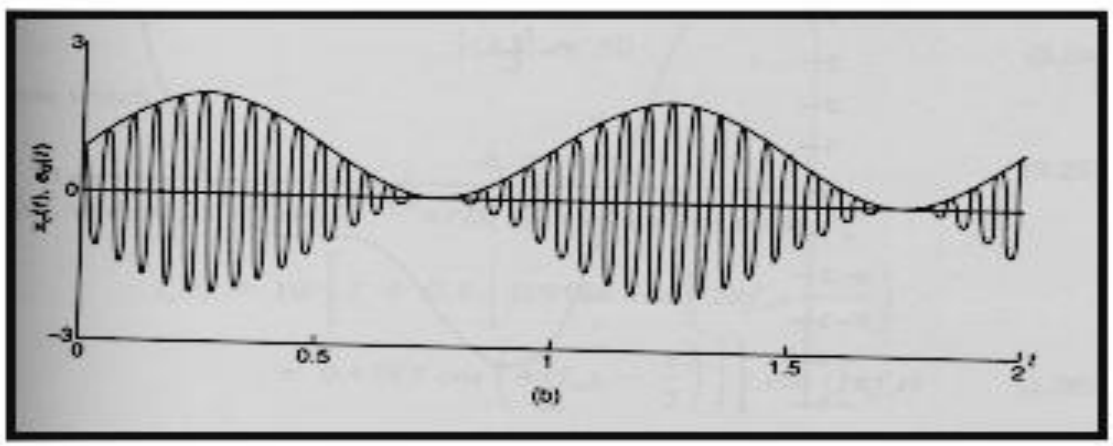
Answer is to maintain m<1.0 (m<100%).

- This is important for successful retrieval of the original transmitted information at the receiver end.

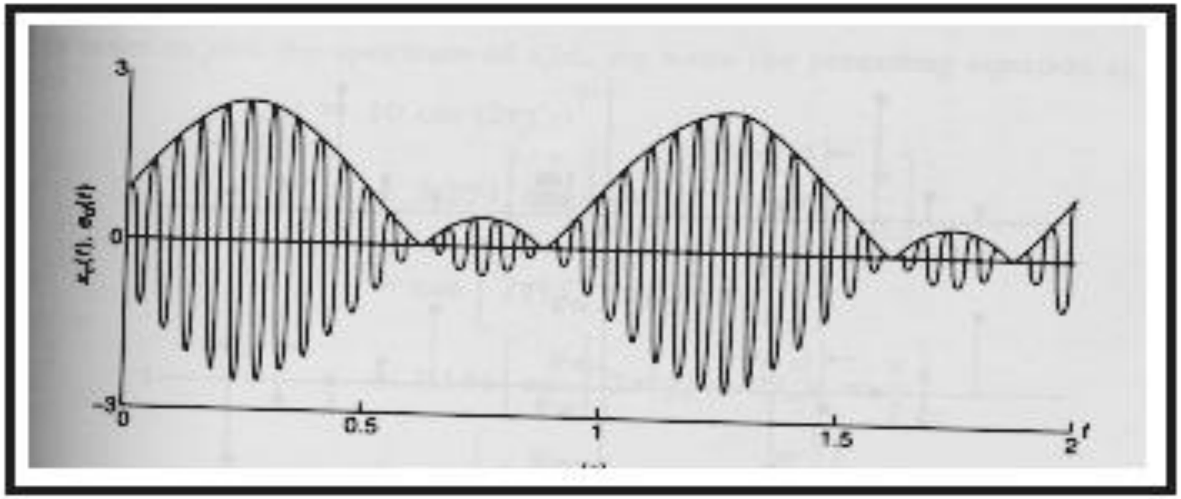
Modulation carrier and envelope detector outputs for various values of the modulation index



m = 0.5

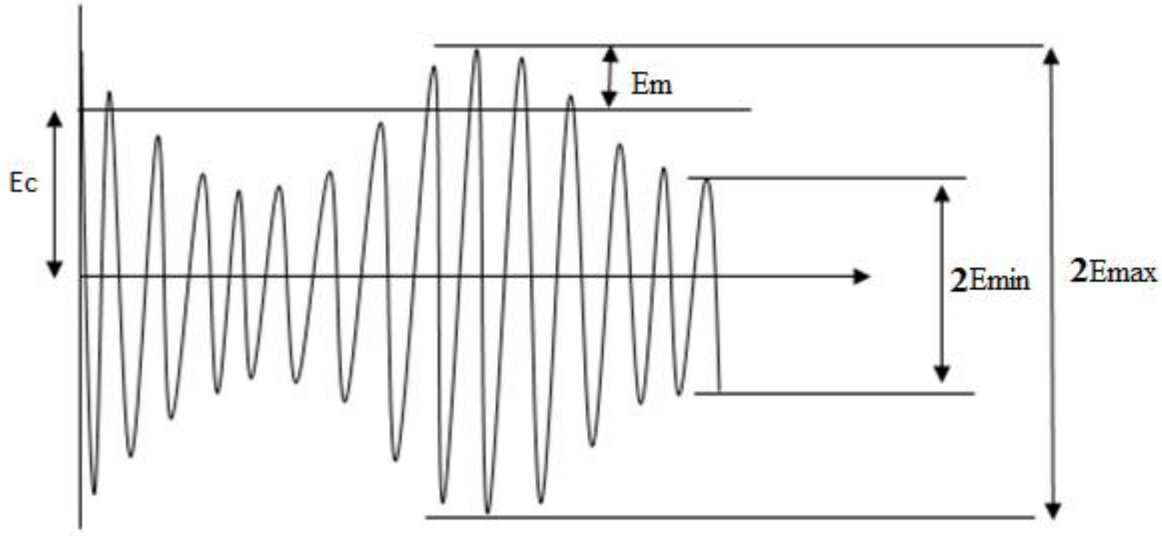


m = 1.0



$m = 1.5$

- If the amplitude of the modulating signal is higher than the carrier amplitude, which in turn implies the modulation index $m \geq 1.0 (100\%)$. This will cause severe distortion to the modulated signal and retrieval of information will be difficult.



$2E_{max}$ = maximum peak-to-peak of waveform

$2E_{min}$ = minimum peak-to-peak of waveform

$$E_{\max} = E_c + E_m \qquad E_{\min} = E_c - E_m$$

This may be solved to obtain $E_c = \dfrac{E_{\max} + E_{\min}}{2}$ & $E_m = \dfrac{E_{\max} - E_{\min}}{2}$

We know that $m = \dfrac{E_m}{E_c}$ Substituting $E_{m,}$ E_c for m $\therefore m = \dfrac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}$

Calculate the power of AM signals

$$Power, P = \frac{V^2}{R} \qquad if\ R = 1\Omega, then\ P = V^2$$

The amplitude modulated signal is

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

The total power of amplitude modulated signal is

$$P_{t(total)} = P_{c(carrier)} + P_{LSB(Lower\,sideband)} + P_{USB(Upper\,sideband)}$$

$$P_c = \left(\frac{E_c}{\sqrt{2}}\right)^2 = \frac{E_c^2}{2}$$

$$\because E_{c,R.M.S} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} E_c^2 \cos^2(\omega_c t)dt} = \frac{E_c}{\sqrt{2}}$$

Calculation the power of AM signals contd..

Similarly the sideband power P_{LSB} and P_{USB} are

$$P_{LSB} = P_{USB} = \left(\frac{\frac{1}{2} mE_c}{\sqrt{2}} \right)^2 = \frac{m^2 E_c^2}{8} = \frac{m^2}{4} P_c$$

$$P_{LSB} + P_{LSB} = \frac{m^2 E_c^2}{8} + \frac{m^2 E_c^2}{8} = \frac{m^2 E_c^2}{4} = \frac{m^2}{2} P_c$$

The total power of amplitude modulated signal is

$$P_{t(total)} = P_{c(carrier)} + P_{LSB(Lower\,sideband)} + P_{USB(Upper\,sideband)}$$

$$\therefore P_{t(total)} = \frac{E_c^2}{2} + \frac{m^2 E_c^2}{4}$$

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

$$P_{t(total)} = 1.5 P_c \quad \text{for } m = 1$$

Calculate the power efficiency of AM signals

- The ratio of useful power, **power efficiency (transmission efficiency):**

$$\frac{sidebands\,power}{total\ power} = \frac{\left(m^2/2\right)P_c}{\left(1+m^2/2\right)P_c} = \frac{m^2}{2+m^2}$$

- In terms of **power efficiency**, for *m=1* modulation Index, only 33% power efficiency is achieved which tells us that only one-third of the transmitted power carries the useful information.

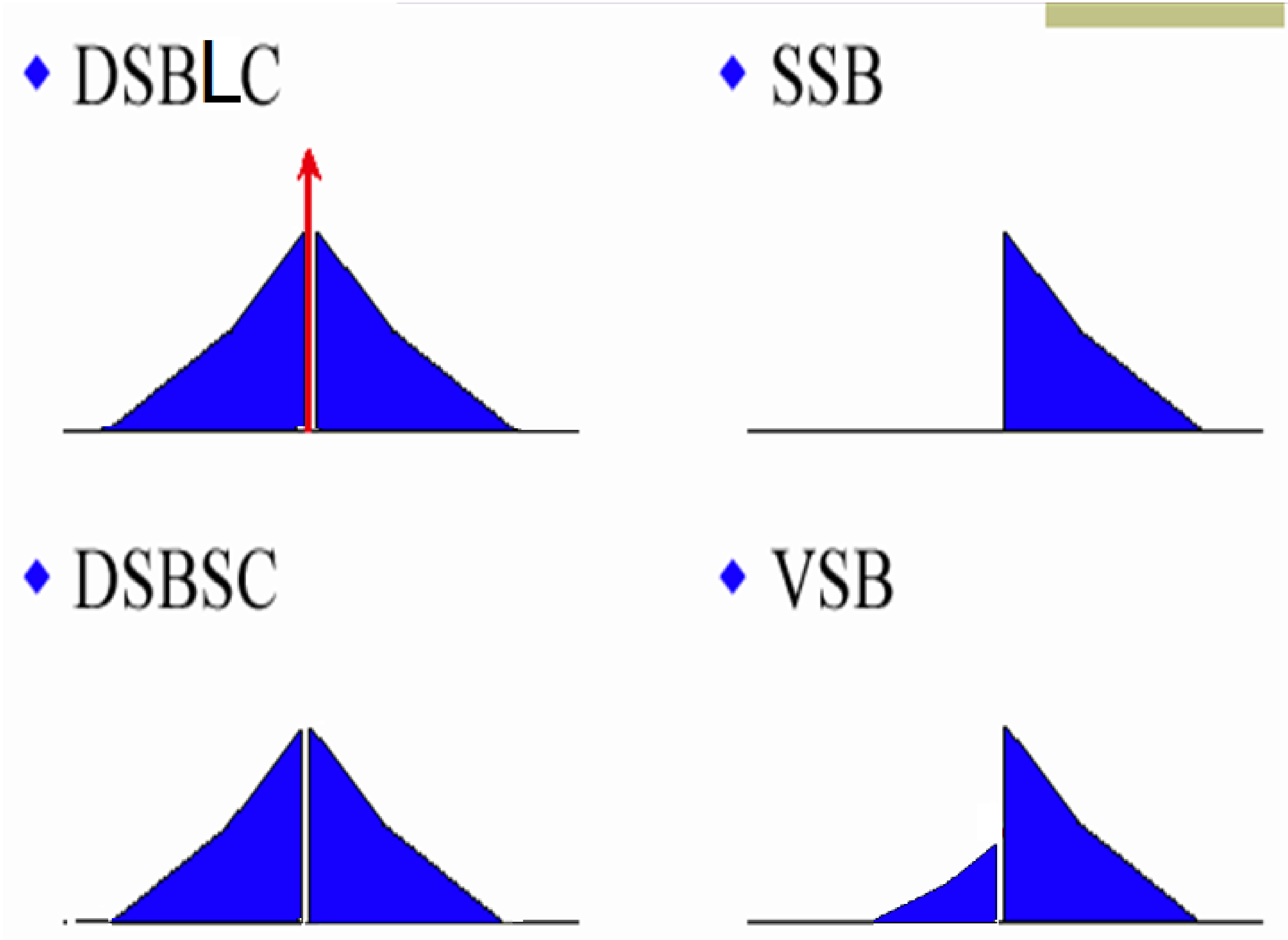
Different Forms of Amplitude Modulation ?

1. Conventional Amplitude Modulation **(DSB-LC)**

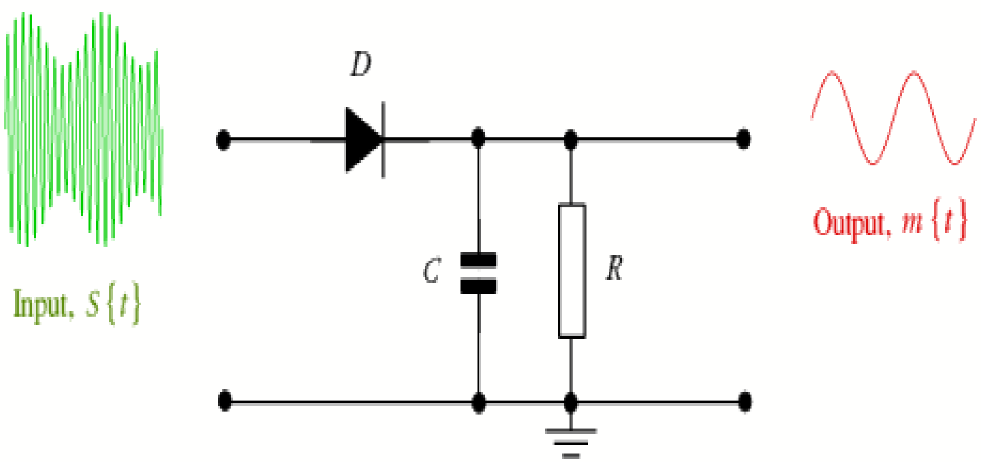
   (Alternatively known as Full AM or Double Sideband with Large carrier (DSB-LC) modulation

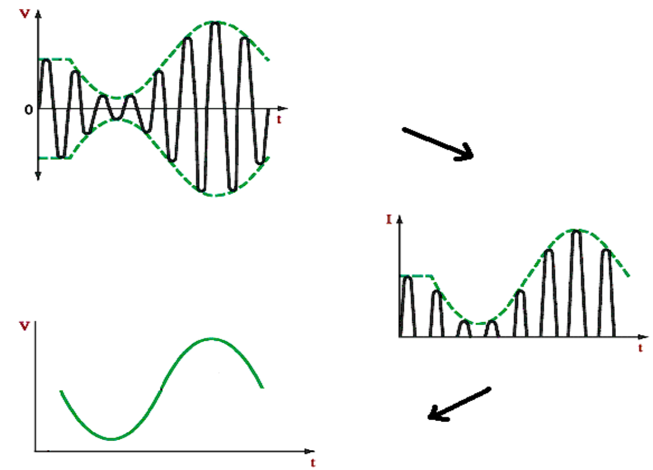
2. Double Side Band Suppressed Carrier **(DSB-SC)** modulation
3. Single Sideband **(SSB)** modulation
4. Vestigial Sideband **(VSB)** modulation

Comparison of Amplitude Modulation methods



Envelope/Diode AM Detector





$$RC \gg T_c = \frac{1}{f_c} \quad also \quad RC \ll T_m = \frac{1}{f_m} \quad \therefore \frac{1}{f_c} \ll RC \ll \frac{1}{f_m}$$

If the modulation depth is > 1, the distortion below occurs