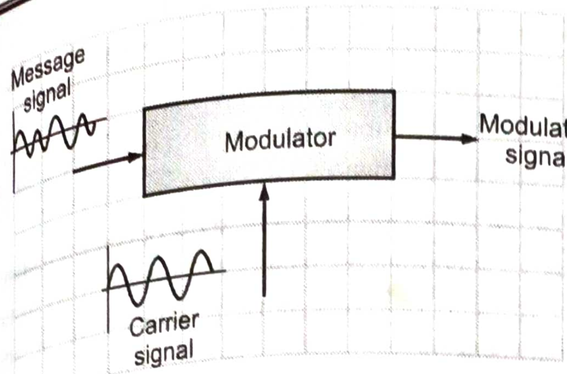


(1b1) **Fig. 1.3.1**

- As the analog signal is of low frequency, it cannot travel longer distance and hence needs to travel with the help of carrier which is high frequency signal.
- As shown in the Fig. 1.3.1, low frequency modulating signal is superimposed on high frequency carrier to obtain modulated output.
- In the process of modulation, one of the parameters (amplitude, frequency or phase) is changed according to message signal. This variation of the parameter then carries the information.
- Modulation is done at the transmitter and reverse process, Demodulation, is done at the receiver.
- Modulation is the process of an "upshifting" of the message frequencies to a frequency range suitable for transmission. E.g., a message containing frequencies of audio band (20 Hz to 20 kHz) can be upshifted to range of few MHz with the help of modulation.
- Today all long distance communication systems are possible because of modulation.

1.4 NEED OF MODULATION/ ADVANTAGES OF MODULATION

GQ. Explain how modulation reduces height of antenna and avoids mixing of signals. **(5 Marks)**

UQ. Explain any two need of modulation. **(MU - Q. 1(b), Dec. 17, 5 Marks)**

UQ. Explain need of modulation. Justify it with example. **(MU - Q. 1(a), Dec. 19, 5 Marks)**

UQ. Write short note on : Need of modulation. **(MU - Q. 6(a), May 19, 5 Marks)**

(A) Reduces height of antenna
(B) Avoids mixing of the signals
(C) Multiplexing is possible
(D) Increases range of communication
(E) Improves quality of reception

(A) Reduces height of antenna

- For efficient transmission and reception of electromagnetic waves, the height of antenna should be multiple of quarter wavelength $\left(\lambda = \frac{c}{f}\right)$ of radiation frequency.
- Antenna size is inversely proportional to the frequency to be radiated.
- For a signal of 10 kHz, the required antenna height is 75 km and for a signal at 1 MHz an antenna height required is 75 meters. 75 km is not practically possible but 75 m, does. This can be proved mathematically as shown :

$$\text{Minimum antenna height} = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10 \times 10^3}$$

$= 7500$ meters, i.e., 7.5 km

75 km is practically not possible.

Now upshifting frequency to f = 1MHz, we get

$$\text{Minimum antenna height} = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10^6}$$

$= 75$ meters

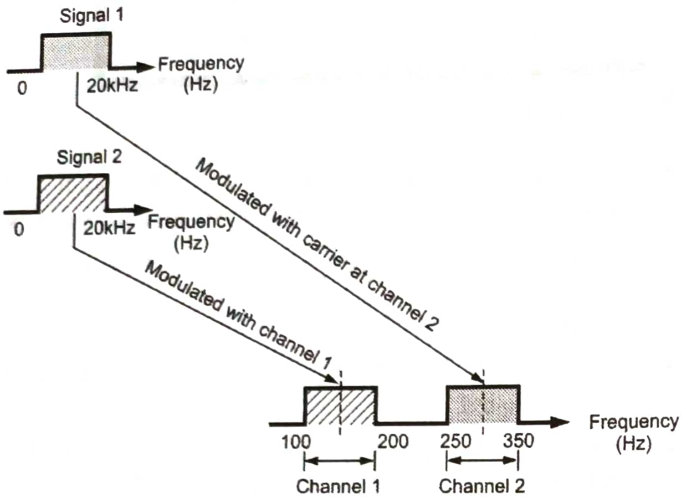
75 meters is practically possible. Thus proved that modulation reduces required height of antenna.

(B) Avoids mixing of the signals

- Imagine that two music programmers are playing at the same time within hearing distance.
- It is difficult for anyone to hear one of them and avoid the other one.
- Thus it becomes strain for human ear to separate these sounds, as almost all musical frequencies are in the range of 50 Hz to 10 kHz.
- However with modulation, if the frequencies are upshifted and two programmers are allotted two different range carriers, it becomes easier to separate them.
- Thus, listeners can choose the program by just selecting the appropriate frequency band. This is

shown in Fig. 1.4.1.

- For avoiding mixing of signals, in modulation each modulating signal is superimposed on some different carrier.



(1b2)**Fig. 1.4.1 : Modulation avoids mixing of signals**

(C) Multiplexing is possible

- Multiplexing is process in which two or more signals can travel along the same transmission channel.
- This is possible only with modulation. As explained above, modulation avoids mixing of signals, and the different modulating signals are allotted with different carriers, there are very less chances of interferences.
- Thus, modulation allows different signals to travel along same channel without interference.
- E.g., different TV channels occupy same frequency range and travel along same channel without getting mixed with the help of modulation.

(D) Increases range of communication

- Modulating signal is of low frequency and low frequency signal cannot travel longer distance. Modulation makes use of high frequency carrier which is able to travel longer distances.
- E.g. RF (radio frequency) wave will travel longer distance as compared to audio frequency wave.
- Modulation also reduces attenuation, as a result, signal travels longer distance.

(E) Improves quality of reception

Modulation reduces effect of noise to a great extent. This improves quality of reception.

1.5 CONCEPT OF NOISE

- Commonly the disturbance we hear is noise, but in telecommunications the word noise refers to the electrical disturbances.
- E.g., in television receivers, snow or confetti (coloured snow) superimposes picture and we get 'noisy picture' or in radio receivers, noise produces 'hiss' in output loudspeakers.
- Noise in communication can be introduced in channels and in communication equipments.
- It cannot be avoided completely. It affects the signal by various ways, i.e., by reducing amplitude, reduction in bandwidth, etc.

Definition : It is the random unwanted energy that interferes with the desired signal.

1.6 CORRELATED AND UNCORRELATED SOURCES OF NOISE IN COMMUNICATION SYSTEM

UQ. State in brief different types of noise. **(MU - Q. 1(c), Dec. 17, 5 Marks)**

UQ. What are different sources of noise ? Classify and explain various noises that affect communications. **(MU - Q. 3(a), May 19, 20 Marks)**

- There are two general categories of noise.

(1) Correlated noise (2) Uncorrelated noise

(1) Correlated noise

It indicates the relationship between signal and noise. It exists only when signal exists.

(2) Uncorrelated noise

- It is present at all time. It is present irrespective of presence of signal.
- Uncorrelated noise sources are categorised in two subclasses namely :

(i) Internal noise (ii) External noise

$$= A \sin \omega_c t \quad ...(2.4.3)$$

- Amplitude 'A' in Equation (2.4.3) is the carrier wave's amplitude which is varying according to amplitude of modulating signal. Hence to derive equation of AM, we need to determine 'A'.

  From Fig. 2.4.1(c) we get,

$$A = E_c + e_m$$

$$\therefore \quad A = E_c + E_m \sin \omega_m t \quad \text{...From Equation (2.4.2)} \quad ...(2.4.4)$$

- Modulation index or depth of modulation 'm' is the ratio of amplitude of modulating signal to the amplitude of carrier signal.

Therefore, $$m = \frac{E_m}{E_c} \quad ...(2.4.5)$$

Putting Equation (2.4.5) in Equation (2.4.4) we get,

$$\therefore \quad A = E_c [1 + m \sin \omega_m t] \quad ...(2.4.6)$$

Substituting Equation (2.4.6) in Equation (2.4.4) we get,

$$e_{AM} = A \sin \omega_c t$$

$$\therefore \quad e_{AM} = E_c [1 + m \sin \omega_m t] \sin \omega_c t$$

$$\therefore \quad e_{AM} = E_c \sin \omega_c t + m E_c \sin \omega_c t \sin \omega_m t \quad ...(2.4.7)$$

Now Equation (2.4.7) can beexpanded by using trigonometrical relation,

$$\sin x \sin y = \frac{1}{2} [\cos (x - y) - \cos (x + y)]$$

$$\therefore \sin \omega_c t \cdot \sin \omega_m t = \frac{1}{2}$$

$$[\cos (\omega_c - \omega_m) t - \cos (\omega_c + \omega_m) t] \quad ...(2.4.8)$$

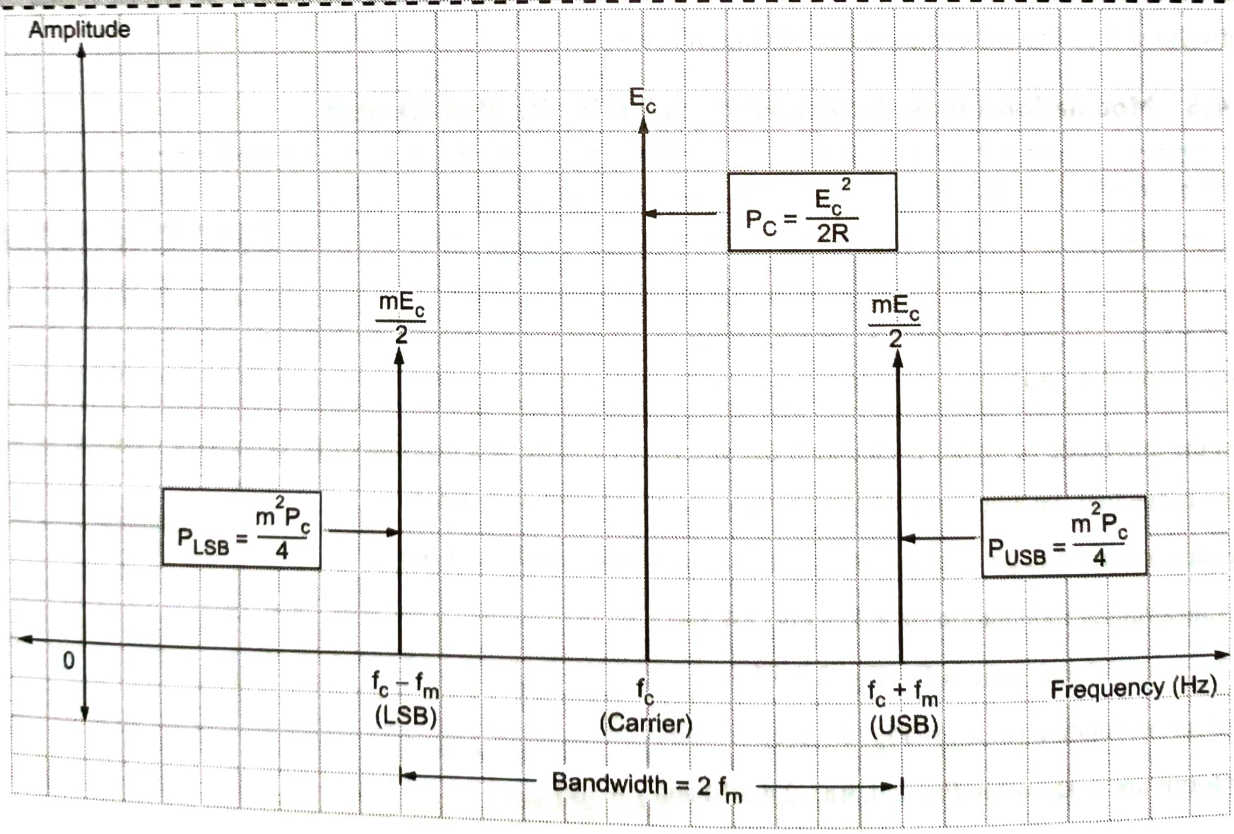
Substituting Equation (2.4.8) in Equation (2.4.7) we get,

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

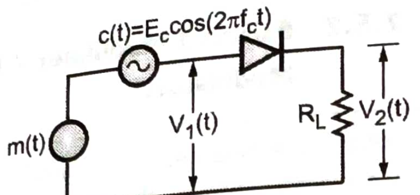
- This is the equation of AM.
- Equation of AM contains three terms :
  (i) Unmodulated carrier
  (ii) Lower sideband (LSB) $(f_c - f_m)$
  (iii) Upper sideband (USB) $(f_c + f_m)$

2.4.3 AM Spectrum / Frequency Domain Representation of AM

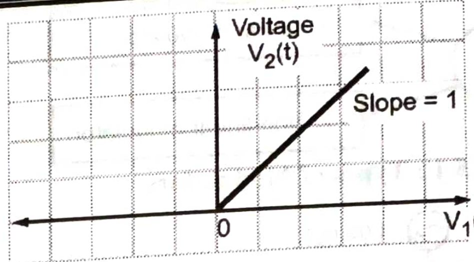
GQ. Draw AM wave diagram in frequency domain. **(2 Marks)**



(1b5) **Fig. 2.4.2 : AM spectrum**



(6A33)(a) Circuit diagram of switching modulator



(6A34)(b) Input-output characteristic curve(ideal)

Fig. 2.4.8 : Switching modulators

- Carrier signal c(t) is applied to the diode.
- This carrier signal is of large amplitude. Therefore it swings across the characteristic curve of the diode.
- This carrier signal is of large amplitude. Therefore it swings across the characteristic curve of the diode.
- The name given as switching modulator as diode here acts as switch.
- This means it shows zero impedance when it is forward biased. This corresponds to c (t) > 0.
- ***Refer Fig. 2.4.8(b).*** It shows the transfer characteristic of the diode- load resistor combination.
- It is piecewise linear characteristic input voltage $V_1(t)$ will be sum of the carrier and message signal.

$$\therefore V_1(t) = E_c \cos(2\pi f_c t) + m(t) \qquad \ldots(2.4.15)$$

- As we know, $|m(t)| << E_c$, therefore resulting load voltage $V_2(t)$ is given by,

$$V_2(t) \simeq \begin{cases} V_1(t), & c(t) > 0 \\ 0 & c(t) < 0 \end{cases} \qquad \ldots(2.4.16)$$

- Thus it can be said that, load voltage $V_2(t)$ varies between $V_1(t)$ and zero periodically.
- This variation happens at the rate of carrier frequency f_c.
- Thus by assuming $|m(t)| << E_c$, we have replaced non-linear behaviour of diode by an approximately equivalent piecewise linear time varying operation.
- Equation (2.4.16) can be mathematically written as,

$$V_2(t) \simeq [E_c \cos(2\pi f_c t) + m(t)]\, g_{T_0}(t) \qquad \ldots(2.4.17)$$

Where $g_{T_0}(t)$ = Periodic pulse train of duty cycle equal to one half

and $T_o = \frac{1}{f_c}$

- As $g_{T_0}(t)$ is periodic pulse train, it can be represented in Fourier series format.

$$\therefore g_{T_0}(t) = \frac{1}{2} + \frac{2}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos[2\pi f_c t(2n-1)] \qquad \ldots(2.4.18)$$

- From Equations (2.4.17) and (2.4.18), we can conclude that $V_2(t)$ is actually sum of two components.

(A) First component

$$\frac{E_c}{2}\left[1 + \frac{4}{\pi E_c} m(t)\right] \cos(2\pi f_c t)$$

It is the AM wave. To maintain the diode as switch, E_c should be kept large enough.

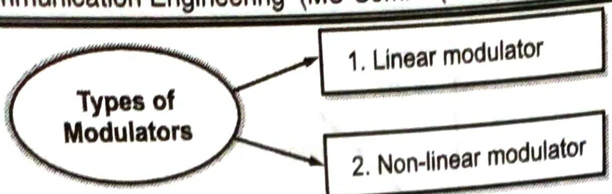
(B) Second component

- Unwanted components whose spectrum comprises of delta functions at 0, $\pm 2f_c$, $\pm 4f_c$, ...are present.
- But these unwanted components are removed from $V_2(t)$ by band pass filters.

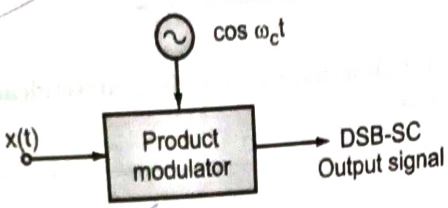
2.5 DSBSC GENERATION METHODS

GQ. Explain DSB-SC Modulator.

- DSB-SC signal can be simply obtained by multiplying modulating signal x (t) with carries signal (cos $\omega_c t$).
- Hence a device known as product modulator or multiplier modulator is used.
- ***Refer Fig. 2.5.1.*** It shows DSB-SC generation by product modulator.
- There are two types of product modulators :



(6A11)Fig. 2.5.1 : Types of Modulators



(6A28)Fig. 2.5.1(a) : DSB-SC generation

2.5.1 Linear Modulator

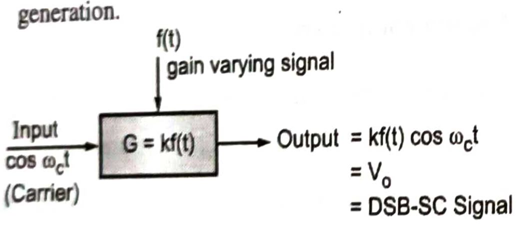
- It is a system whose gain or transfer functions can be varied with time.
- This can be done by varying time at certain points.
- Let the gain is proportional to f (t) (signal)

$\therefore$ G = k f (t)

Where G = gain ; k = constant

f (t) = gain varying signal

- *Refer Fig. 2.5.2.* It shows linear modulator for DSB-SC generation.



(6A29)Fig. 2.5.2 : Linear modulator

- Thus, output is nothing but DSB-SC signal.

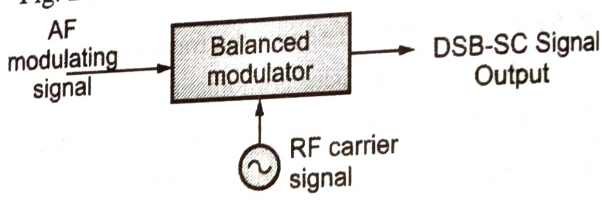
2.5.2 Balanced Modulator / Non-linear Modulators

GQ. What is a balanced modulator? With the help of waveforms, prove that the carrier is getting suppressed.

GQ. Explain non-linear modulator for DSBSC generation.

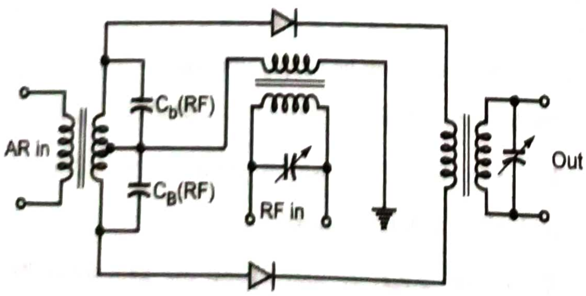
(A) Principle of operation
(B) Working
(C) Mathematical analysis

- **Function :** Balanced modulators are the devices used to suppress the unwanted carrier in AM wave.
- Fig. 2.5.3 shows balanced modulator.

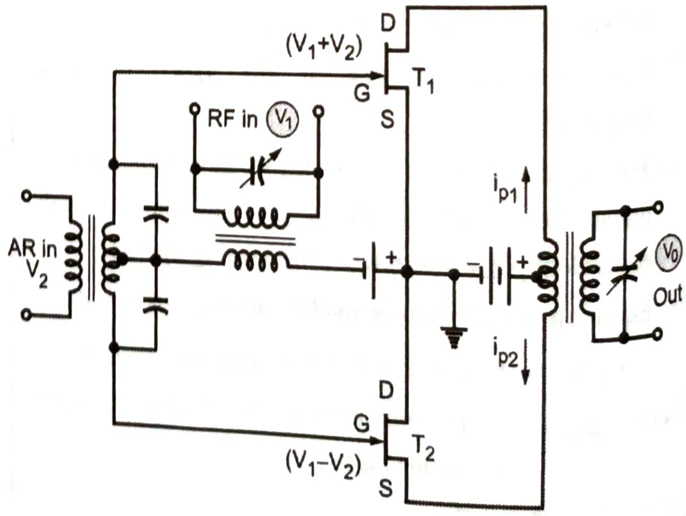


(6A30)Fig. 2.5.3 : Balanced modulator

(A) Principle of operation of Balanced Modulator



(6A31)(a) Balanced modulator using diode



(6A32)(b) FET balanced modulator

Fig. 2.5.4 : Balanced modulators

- If two signals at different frequencies are passed through a non-linear resistance then DSB-SC is obtained at the output.
- The devices showing non-linear resistance are diodes, JFETs etc.
- Hence based on the non-linear device used there are two types of balanced modulators.
  (i) Balanced modulator using diodes.
  (ii) Balanced modulator using FETs.

Refer Figs. 2.5.4(a) and (b). It shows balanced modulators using (a) diodes and (b) FETs.

(B) Working of Balanced Modulator

- The modulation voltage V_2 is fed in push pull configuration and carrier voltage V_1 is applied in parallel to the pair of identical diodes or FETs.
- In case of FETs, the carries voltage is applied to the two gates in phase.
- The modulating voltage is 180° out of phase at the gates as they are placed at opposite ends of center tapped transformer.
- The modulated output currents of the two FETs are combined in the center tapped transformer's primary of the push pull output transformer. Hence they get subtracted.
- If the system is perfectly symmetrical, the carrier frequency gets cancelled.
- But in practice this is not possible. Hence carrier gets suppressed heavily.

(C) Mathematical analysis of Balanced Modulator

Refer Fig. 2.5.4(b).

At gate of T_1, the input voltage = $V_1 + V_2$.

At gate of T_2, the input voltage = $V_1 - V_2$.

- Let the proportionality constants be same for both the FETs and are 'a', 'b' and 'c'.
- Hence determining two drain currents,

$$i_{d1} = a + b(V_1 + V_2) + c(V_1 + V_2)^2$$

...[$i = a + bv + cV^2$ for non-linear resistance device]

$$= a + bV_1 + bV_2 + c\left(V_1^2 + 2V_1V_2 + V_2^2\right)$$

$$= a + bV_1 + bV_2 + cV_1^2 + 2cV_1V_2 + cV_2^2 \quad ...(2.5.1)$$

Similarly,

$$i_{d2} = a + b(V_1 - V_2) + c(V_1 - V_2)^2$$

$$= a + bV_1 - bV_2 + c\left(V_1^2 - 2V_1V_2 + V_2^2\right)$$

$$= a + bV_1 - bV_2 + cV_1^2 - 2cV_1V_2 + cV_2^2 \quad ...(2.5.2)$$

- But the primary current i_1 is the difference between the individual drain currents.

Therefore, $i_i = i_{d1} - i_{d2}$

Substituting i_{d1} and i_{d2} from Equations (2.5.1) and (2.5.2) we get,

$$i_1 = i_{d1} - i_{d2} = 2bV_2 + 4cV_1V_2$$

Now V_1 = Carrier voltage = $V_c \sin \omega_c t$

and V_2 = Modulating voltage = $V_m \sin \omega_m t$

$$\therefore i_1 = 2bV_m \sin \omega_m t + 4c\, V_m V_c \sin \omega_c t \cdot \sin \omega_m t \quad ...(2.5.3)$$

But $\sin \omega_c t \cdot \sin \omega_m t = \frac{1}{2}[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$

[$\because 2 \sin A \cdot \sin B = \cos(A - B) - \cos(A + B)$]

Hence Equation (2.5.3) becomes

$$i_1 = 2bV_m \sin \omega_m t + 4cV_m V_C \cdot \frac{1}{2}[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t] \quad ...(2.5.4)$$

- As we know,

V_o = output voltage = αi_1

Where i_1 = Primary current

α = Proportionality constant

$$\therefore V_o = \alpha i_1$$

$$= \alpha[2bV_m \sin \omega_m t + 2cV_m V_c [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$$

$$= 2\alpha bV_m \sin \omega_m t + 2\alpha cV_m V_c [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$$

Let $P = 2\alpha bV_m$ and $Q = 2\alpha cV_m V_c$

Then

$$V_o = \underbrace{P \sin \omega_m t}_{\text{Modulating frequency}} + \underbrace{Q \cos(\omega_c - \omega_m)t}_{\text{Lower sideband}} - \underbrace{Q \cos(\omega_c + \omega_m)t}_{\text{Upper sideband}} \quad ...(2.5.5)$$

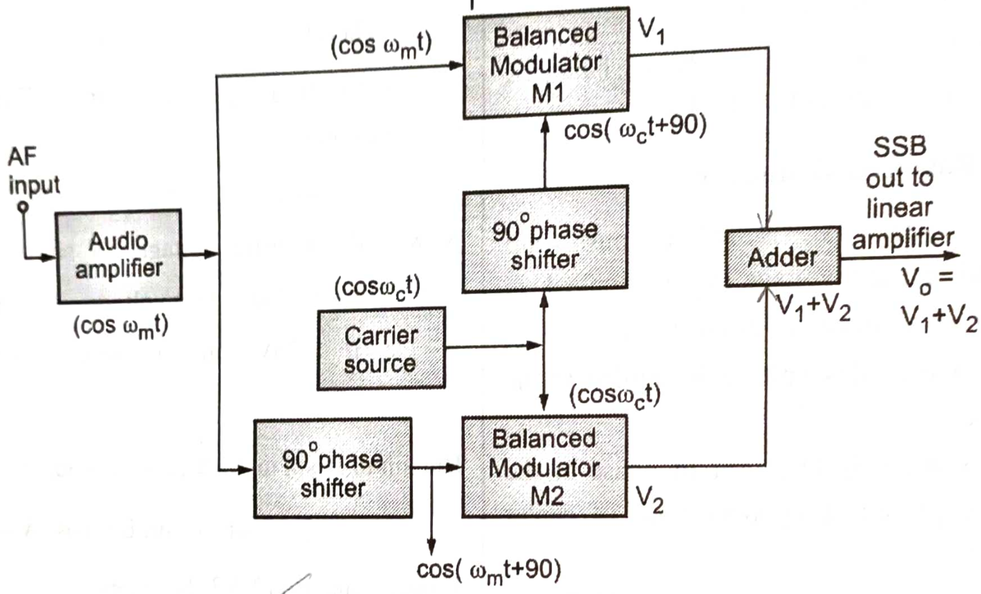
Hence from Equation (2.5.5) it is seen that, **the carrier is cancelled.**

2.5.3 The Phase Shift Method

GQ. Explain phase shift method of SSB generation. State its advantages and disadvantages.

GQ. Draw and explain phase shift method of SSB-SC modulator.

- ***Refer Fig. 2.5.5.*** It shows block diagram of the phase shift method.
- There are no filters used in the phase shift method. Instead it makes use of two balanced modulators and two phase shifting networks.
- Let M_1 and M_2 be the balanced modulator 1 and balanced modulator 2 respectively.
- M_1 receives modulating voltage and 90° phase shifted carrier voltage.



(6A6)**Fig. 2.5.5 : The phase shift method (for LSB suppression)**

- Similarly M_2 receives 90° phase shifted modulating voltage and carrier voltage.
- Both the balanced modulators suppresses the carrier and produces only the sidebands.
- Mathematically,

Let V_1 is the output voltage of M_1 and V_2 is the output voltage of M_2.

$$\therefore \quad V_1 = \cos[(\omega_c t + 90°) - \omega_m t] - \cos[\omega_c t + 90° + \omega_m t]$$

$$\therefore \quad V_1 = \underbrace{\cos[\omega_c t - \omega_m t + 90°]}_{\text{LSB1}} - \underbrace{\cos[\omega_c t + \omega_m t + 90°]}_{\text{USB1}} \quad ...(2.5.6)$$

Similarly,

$$\therefore \quad V_2 = \cos[\omega_c t - (\omega_m t + 90°)] - \cos[\omega_c t + (\omega_m t + 90°)]$$

$$= \underbrace{\cos[\omega_c t - \omega_m t - 90°]}_{\text{LSB2}} - \underbrace{\cos[\omega_c t + \omega_m t + 90°]}_{\text{USB2}} \quad ...(2.5.7)$$

Now, output of the adder be V_o

Therefore $\quad V_o = V_1 + V_2$

Substituting V_1 and V_2 from Equations (2.5.6) and (2.5.7) we get,

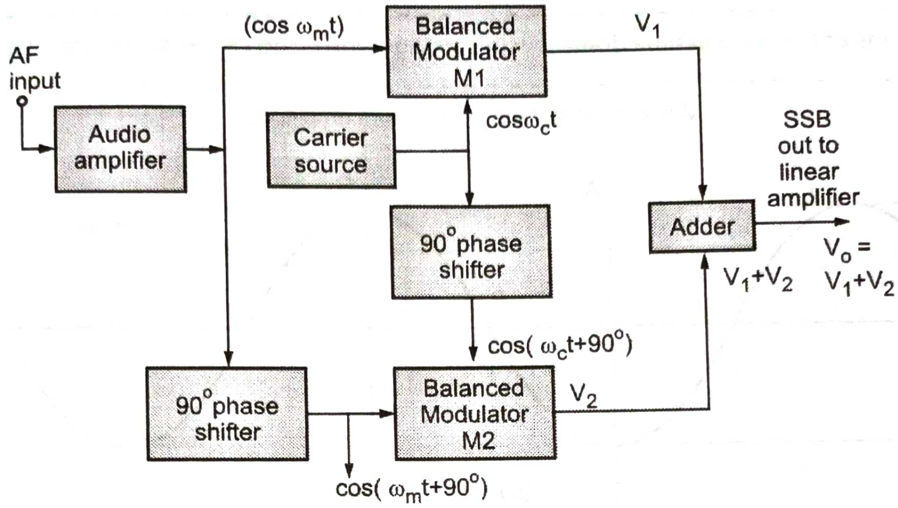
$$V_o = V_1 + V_2$$

$$= \cos[\omega_c t - \omega_m t + 90°] - \cos[\omega_c t + \omega_m t + 90°] + \cos[\omega_c t - \omega_m t - 90°] - \cos[\omega_c t + \omega_m t + 90°]$$

- Now, LSB1 [$\cos(\omega_c t - \omega_m t + 90°)$] leads the reference voltage by 90° whereas LSB2 [$\cos(\omega_c t - \omega_m t + 90°)$] lags the reference voltage by 90°.
- Hence they both get cancelled.

Therefore $\quad V_o = 2\cos[\omega_c t + \omega_m t + 90°] = \text{USB}$

- Hence only upper sideband is present at the output and LSB is suppressed. Thus SSB is generated.
- The main requirement of the phase shift method is two balanced modulators should be balanced with respect to each other.
- The phase shift method for USB suppression. It can be achieved if both phase shifted versions of carrier and the modulating voltages are fed to one of the balanced modulators as shown in Fig. 2.5.6.



(6A7)**Fig. 2.5.6 : The phase shift method (for USB suppression)**

(A) Mathematical Analysis

$$V_1 = \cos[\omega_c t - \omega_m t] - \cos[\omega_c t + \omega_m t] \quad \ldots(2.5.8)$$

$$\therefore \; V_2 = \cos[(\omega_c t + 90° - \omega_m t - 90°)]$$

$$- \cos[\omega_c t + 90° + \omega_m t + 90°]$$

$$= \cos[\omega_c t - \omega_m t] - \cos[\omega_c t + \omega_m t + 180°] \quad \ldots(2.5.9)$$

Comparing Equations (2.5.8) and (2.5.9),

USB1 and USB2 are 180° out of phase with each other and hence get cancelled at adder

Therefore,

$$V_o = V_1 + V_2$$

$$= 2\cos[\omega_c t - \omega_m t] = \text{LSB}$$

Thus USB is suppressed

(B) Advantages of Phase Shift Method

1. No need of frequency up conversion.
2. Filters are not needed.
3. Generation of SSB at any frequency is possible.

(C) Disadvantages of Phase shift Method

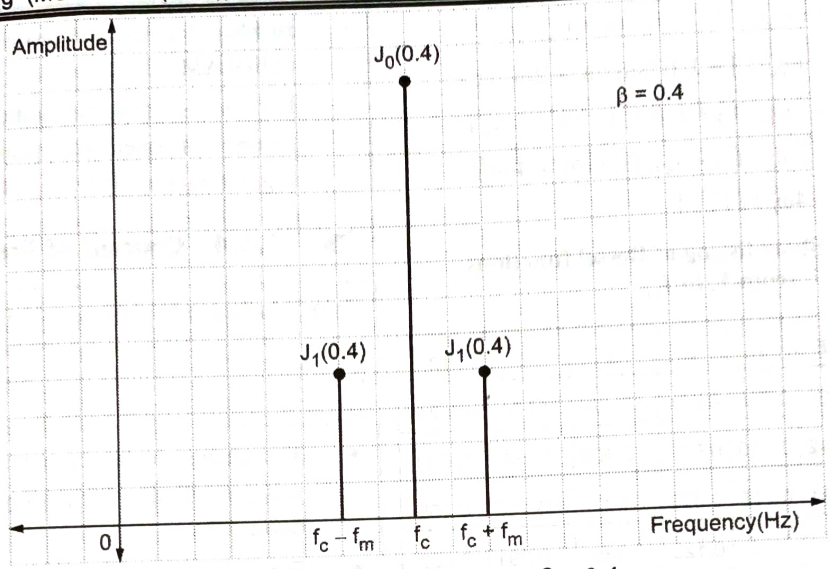
1. Design of 90° phase shifter network is critical.
2. Both balanced modulators should be matched. Practically it is difficult to achieve.

2.6 FREQUENCY MODULATION

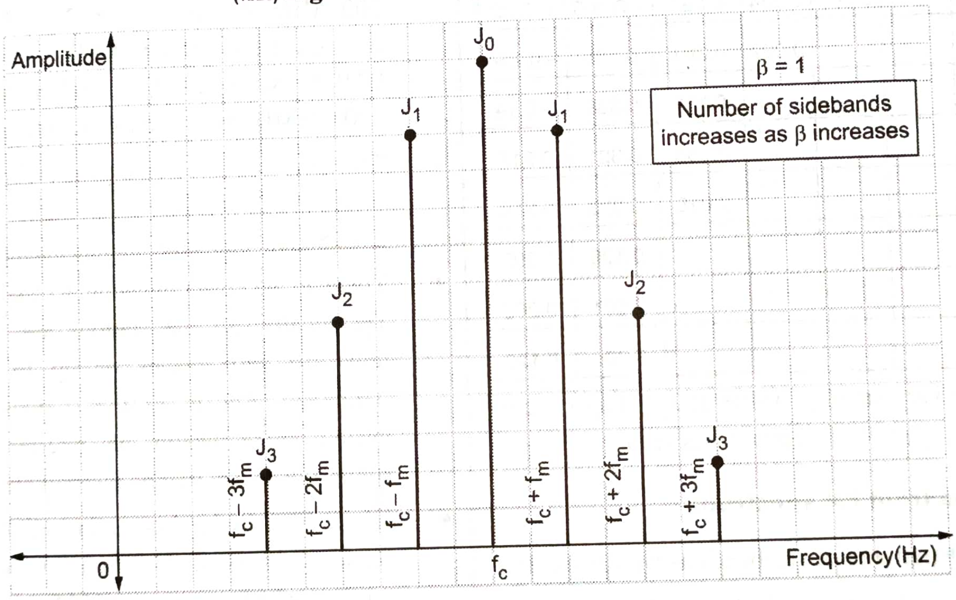
- Edwin Armstrong suggested practical FM system in the year 1936 and it became popular worldwide due to its noise immunity and fidelity advantages.

Definition : It is the process in which frequency of the carrier is changed in accordance with amplitude of modulating signal keeping its amplitude and phase constant.

- Information is carried in variations of carrier frequency.
- It is one of the angle modulation type.
- It has many advantages over AM.



(1b25) **Fig. 2.6.5 : FM spectrum for β = 0.4**



(1b26) **Fig. 2.6.6 : FM spectrum for β = 1**

Deviation ratio

Definition : It is defined as the ratio of maximum frequency deviation to the maximum modulating frequency.

It is denoted by 'D'.

$$\therefore D = \frac{\delta_{max}}{f_{m(max)}}$$

2.6.3 Modulation Index of FM

UQ. Explain / define / clarify the following term : (i) Modulation index in FM **(MU - Q. 4(a), May 19, 2 Marks)**

$$m_f = \beta = \frac{\delta}{f_m}$$

$$\therefore \theta = \omega_c t + \beta \sin \omega_m t \quad ...(2.6.6)$$

Putting this θ in Equation (2.6.4) we get

$$V_{FM} = A \sin [\omega_c t + \beta \sin \omega_m t] \quad ...(2.6.7)$$

- This equation can be further expanded using Bessel's functions to obtain the frequency spectrum of FM.
- Solution of Equation (2.6.7) by Bessel's function is given as,

$$V_{FM} = A\{J_0\beta \sin\omega_c t + J_1\beta[\sin(\omega_c+\omega_m)t - \sin(\omega_c-\omega_m)t] + J_2\beta[\sin(\omega_c+2\omega_m)t + \sin(\omega_c-2\omega_m)t] + J_3\beta[\sin(\omega_c+3\omega_m)t - \sin(\omega_c-3\omega_m)t] + J_4\beta[\sin(\omega_c+4\omega_m)t + \sin(\omega_c-4\omega_m)t]\ ....\}$$

Table 2.6.1 : Short listing of Bessel functions from J_0 to J_{11}

n \ β	0	0.2	0.5	1	2	5	8	10
0	**1.00**	0.99	0.938	0.765	0.224	−0.178	0.172	−0.246
1	0	**0.1**	**0.242**	0.440	0.577	−0.328	0.235	0.043
2		0.005	0.031	**0.115**	0.353	0.047	−0.113	0.255
3				0.02	**0.129**	0.365	−0.291	0.058
4				0.002	0.034	0.391	−0.105	−0.22
5					0.007	0.261	0.186	−0.234
6						**0.131**	0.338	−0.14
7						0.053	0.321	0.217
8						0.018	0.223	0.318
9							**0.126**	0.292
10							0.061	0.208
11							0.026	**0.123**

- Note that for very small β, value of $J_0(\beta)$ approaches unity, while $J_1(\beta)$ to $J_n(\beta)$ approaches zero.

Observations from FM spectrum

1. FM has infinite number of sidebands as well as carrier.
2. As frequency of sideband increases, amplitude decreases. Hence at higher frequency, sidebands, amplitude are very less.
3. If the deviation is kept constant, relative amplitude of distant sidebands increases when modulating frequency is lowered.
4. In FM total transmitted power always remain constant unlike AM, but increase in modulation index results in increased deviation and hence thereby increment in bandwidth.
5. While determining practical bandwidth, only significant amplitude sidebands are considered, rest are ignored.
6. In FM, amplitude of carrier does not remain constant unlike AM.
7. For certain values of modulation index (eigen values), carrier component disappears completely. E.g. modulation index = 2.4, 5.5, 8.6, 11.8, etc.

2.6.4 Concept of Frequency Deviation

GQ. Define the following term with respect to FM (Frequency Modulation) : Frequency deviation. **(2 Marks)**

- The change in the carrier frequency from its original value is called as **frequency deviation.** It is denoted as **delta (δf_c).**
- For example, a transmitter with carrier frequency 100 MHz deviated by ± 25 kHz, then the carrier changes from 99.975 MHz to 100.025MHz. Here, 99.975 MHz is f_{min} (minimum frequency) and 100.025MHz is f_{max} (maximum frequency).
- The total frequency change is called as 'carrier swing'. In above example, carrier swing is 2×25 kHz = 50 kHz.
- There is no technical limit to the frequency change. Technically, all the stations are allowed to deviate down to zero cycles or up to twice the carrier frequency. But if all the stations deviated to zero cycles, there would be interference between the stations and they will be inseparable.
- Hence FCC (federal communications commission) has set legal limits of deviation for each of the different services which make use of FM.
- These deviation limits are based on the quality of the intended transmissions, where wider deviation always provides higher fidelity. (fidelity is faithful reproduction of the input at the receiver. It is one of the important characteristic of radio receiver.)
- For commercial FM radio broadcast (frequency band is 88MHz – 108MHz), maximum frequency deviation allocated is ± 75kHz.

2.6.5 Concept of Modulation Index (β)

GQ. Define modulation index for FM. **(2 Marks)**

- It is the ratio of frequency deviation measured at the antenna to the maximum modulating signal frequency. It is denoted as β.
- It is usually measured in percentage and has no unit as it is a ratio.
- It can be denoted as m_f because it is also known as modulation factor.
- Modulation index is actually the comparison of phase shift of the modulated FM signal output to the phase of the unmodulated carrier.
- Practically the value of modulation index is greater than unity,

$$\beta = \frac{\text{frequency deviation}}{\text{maximum modulating frequency}} \times 100$$

$$\beta = \frac{\delta}{f_m} \times 100$$

2.6.6 Bandwidth of FM

GQ. What is the practical bandwidth of FM ? **(2 Marks)**

UQ. Explain / define / clarify the following term : Total power in AM **(MU - Q. 4(a), May 19, 2 Marks)**

- Theoretically, FM has infinite bandwidth but for practical purposes it is determined by Carson's rule.
- Carson's rule states that bandwidth required to pass FM signal is twice the summation of maximum frequency deviation and maximum modulating frequency.

Practical bandwidth B $= 2\,(\delta_{max} + f_{m\,(max)})$

2.6.7 Problems based on FM

Ex. 2.6.1 : A single tone FM is represented by the voltage equation as $v(t) = 12 \cos (6 \times 10^8 t + 5 \sin 1250\, t)$ determine the following :

(i) carrier frequency (ii) modulating frequency

(iii) modulation index (iv) maximum deviation

(v) What power will this FM wave dissipate in 10 Ω resistors?

☑ **Soln. :**

Given :

1. $V(t) = 12 \cos (6 \times 10^8\, t + 5 \sin 1250t)$ 2. $R = 10\ \Omega$

To find

1. f_c 2. f_m 3. m_f or β
4. δ 5. Power

▶ **Step I :** Standard equation of FM is,

$$V_{FM}(t) = E_c \cos [\omega_c t + m_f \sin \omega_m t]$$

Given equation is,

$$V(t) = 12 \cos [6 \times 10^8 t + 5 \sin 1250\, t]$$

Comparing both equations we get,

carrier frequency $\quad f_c = \dfrac{\omega_c}{2\pi}$

Since $\omega_c = 6 \times 10^8$ rad/sec

$\therefore\ 2\pi f_c = 6 \times 10^8$

$\therefore\ f_c = \dfrac{6 \times 10^8}{2\pi}$

$\therefore$ $\mathbf{f_c = 95.4929\ MHz}$

▶ **Step II :** $\omega_m = 2\pi f_m$

$f_m = \dfrac{\omega_m}{2\pi}$

$\because\ \omega_m = 1250$

$\therefore\ f_m = \dfrac{1250}{2\pi}$

$\therefore$ $\mathbf{f_m = 198.9436\ Hz}$

▶ **Step III :** $\boldsymbol{\beta = 5}$

▶ **Step IV :** $\delta = \beta \times f_m$

$\therefore\ \delta = 5 \times 198.9436$

$\therefore$ $\mathbf{\delta = 994.7183\ Hz}$

▶ **Step V :** $\quad \text{Power} = \dfrac{(V_{rms})^2}{R} = \dfrac{\left[\dfrac{E_c}{\sqrt{2}}\right]^2}{R} = \dfrac{\left[\dfrac{12}{\sqrt{2}}\right]^2}{10}$

$\therefore$ **P = 7.2 watts**

Ex. 2.6.2 : A 107.6 MHz carrier signal is frequency modulated by a 7 kHz sinewave. The resultant FM signal has a frequency deviation of 50 kHz. Determine the following :

(i) The carrier swing of the FM signal.

(ii) The highest and the lowest frequency attained by the modulated signal.

(iii) The modulation index of FM wave.

☑ **Soln. : Given :**

1. $f_c = 107.6$ MHz 2. $f_m = 7$ kHz 3. $\delta = 50$ kHz

To find :

1. carrier swing = ? 2. f_{max}, f_{min} = ? 3. β = ?

2. Telemetry, radar and seismic prospecting, EEG monitoring, etc.
3. In music synthesis, some systems that use video-transmission.

2.7 PRE-EMPHASIS AND DE-EMPHASIS IN FM

Definition : Emphasis is the process of boosting the Amplitude Vs Frequency characteristics of a signal to reduce the effects caused by noise while transmission or reception of message signal over the channel.

- From the FM spectrum, it is observed that at higher frequencies the amplitude of sidebands gets reduced. As the amplitude is lesser, obviously higher frequency components become more prone to noise.
- Hence noise has greater effect on higher modulating frequencies than the lower ones in FM. Higher frequencies in FM system have low SNR (Signal-to-Noise Ratio).
- By emphasis, approximately a 12dB of improvement in noise can be achieved in FM.

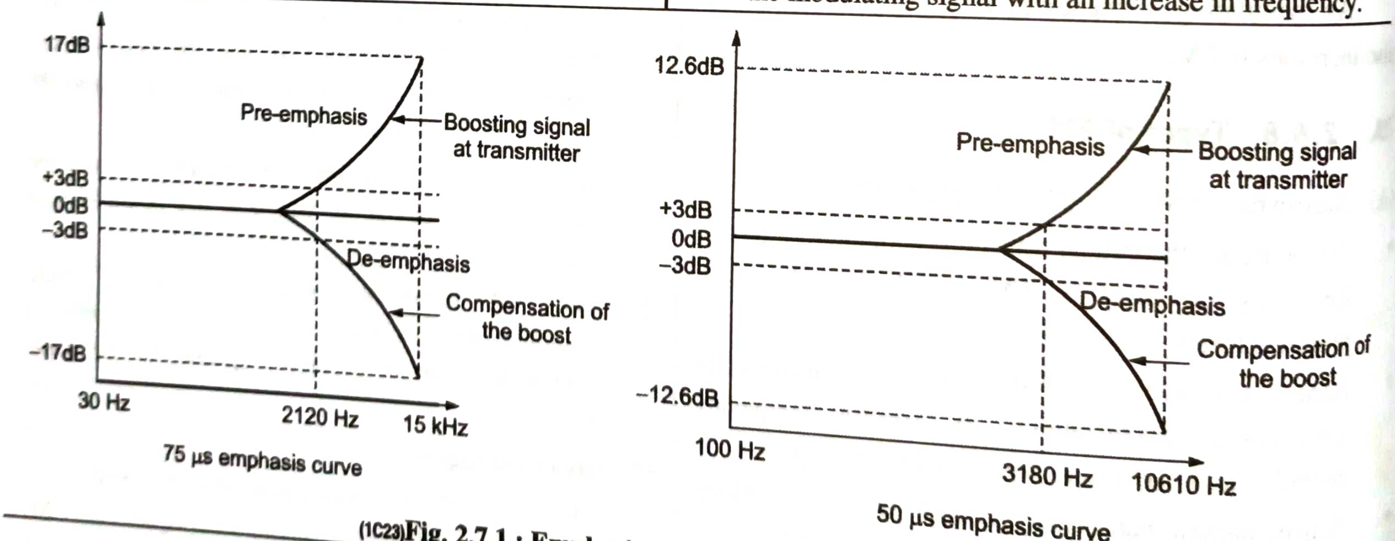
2.7.1 Pre-emphasis

GQ. Define pre-emphasis. Why is it used? Sketch a typical pre-emphasis circuit. **(3 Marks)**

UQ. Explain pre-emphasis. **(MU - Q. 1(a) May 18, Q. 1(d)-Dec. 19, 3 Marks)**

Definition : The process of boosting of high frequencies before modulation at the transmitter in FM system is known as **pre-emphasis**.

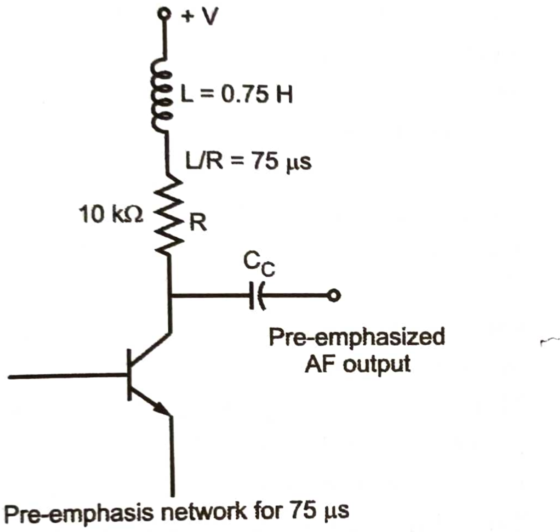
- Signals with higher modulation frequencies have lower SNR.
- In order to compensate this, the high frequency signals are emphasized or boosted in amplitude at the transmitter section of a communication system prior to the modulation process.
- The pre-emphasis network allows the high frequency modulating signal to modulate the carrier at higher level, this causes more frequency deviation.
- The amount of pre-emphasis in USA, FM broadcasting is standardised as 75 μs whereas Europe, Australia has this amount equal to 50 μs.
- Fig. 2.7.2 shows pre-emphasis network. It is actually a high pass filter or a differentiator. A pre-emphasis circuit produces a constant increase in the amplitude of the modulating signal with an increase in frequency.



(1C23)**Fig. 2.7.1 : Emphasis curves for 75 μS and 50 μS**

- The Break Frequency is determined by the RC or L/R time constant of the network. Normally, the break frequency occurs at the frequency, where X_C or X_L equals R. Break Frequency is the Frequency where Pre-emphasis or De-emphasis just begins.
- This 75 μs or 50 μs refers to the time constant of high pass filter at the transmitter.
- This gives frequency of 2120 Hz. The higher modulating signals should not be overemphasized.

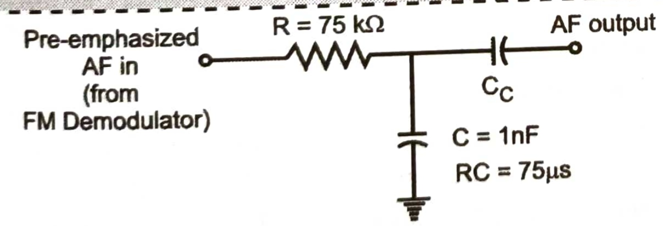
- By the use of an active pre-emphasis network, we can reduce the signal loss and distortion with the increase of SNR. Also the output amplitude of the network increases with frequencies above Break Frequency.
- Refer Fig. 2.7.1.
- Fig. 2.7.2 shows that a 15 kHz signal is pre-emphasized to 17 dB for 75 μs curve. Fig. 2.7.2 shows that the same 15kHz signal is pre-emphasized to 12.6 dB for 50 μs.



(1C24)**Fig. 2.7.2 : Pre-emphasis network**

2.7.2 De-emphasis

GQ. Draw and label de-emphasis characteristics.**(3 Marks)**
UQ. Explain de-emphasis.
(MU - Q. 1(a), May 18, Q. 1(d), Dec. 19, 3 Marks)



(1C25)**Fig. 2.7.3 : De-emphasis network for 75 μs**

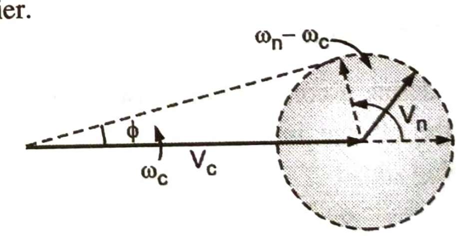
Definition : De-emphasis is the inverse process of pre-emphasis. The compensation of the boosted frequencies at the receiver is called as **'de-emphasis'**.

- The process of de-emphasis is done after demodulation in FM receiver.
- The pre-emphasis and de-emphasis produces a more uniform SNR throughout the modulating signal frequency spectrum.
- The boosted signal is attenuated at the receiver with the same factor with which it is boosted.
- When the signal is de-emphasised, the noise sidebands if present also get de-emphasised with it and hence noise can have comparatively low effect on the signal.
- Refer Fig. 2.7.3.
- It is a low pass filter design typically designed to get the RC time constant of 75 μs. The Break Frequency is determined by the RC time constant. Refer Fig. 2.7.3.
- The 75 μs curve refers to frequency response curve that is 3 dB down at the frequency whose RC time constant is 75 μs and therefore 2120 Hz. The 50 μs curve shows frequency would be 3180 Hz. 50 μs provides noise figure of 4.5dB and it increases for 75 μs.
- Fig. 2.7.3 shows a passive de-emphasis network consisting of a resistor and a capacitor. It is basically a Low Pass Filter or an Integrator.
- Thus, this emphasis process produces a more uniform SNR at the output of demodulator.

2.8 FM NOISE TRIANGLE

UQ. Explain in brief noise triangle in FM.
(MU - Q. 1(d), Dec. 18, 5 Marks)
UQ. Write short note on : FM Noise triangle.
(MU - Q. 6(f), May 19, 5 Marks)

- ***Refer Fig. 2.8.1.*** It shows vector effect of noise on carrier.



(4C1)**Fig. 2.8.1 : Vector effect of noise on carrier**

- If single noise voltage is considered vectorially, it is observed that the noise vector is superimposed on carrier. It is rotating about it with relative angular velocity $\omega_n - \omega_c$.
- Let V_n be the maximum deviation in amplitude from the average value and the ϕ be the maximum phase deviation.

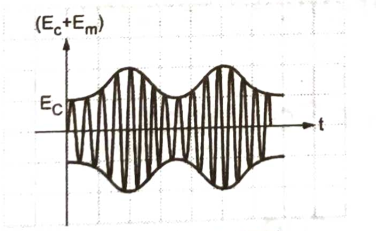
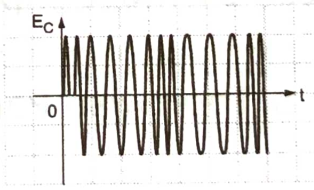
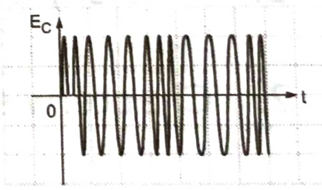
$$\therefore \phi = \sin^{-1}\left(\frac{V_n}{V_c}\right)$$

- In FM, ratio of noise to carrier voltage remains constant.

2.10 COMPARISON OF AM, FM AND PM SYSTEMS

UQ. Compare AM, FM with PM. **(MU - Q. 1(c), Dec. 19, 5 Marks)**

Table 2.10.1 : Comparison of AM, FM and PM

Sr. No.	Parameter	AM	FM	PM
1.	Variable parameter of carrier wave	Amplitude	frequency	Phase
2.	Mathematical equation	$E_c \cos \omega_c t + \frac{mE_2}{2} \cos (\omega_c - \omega_m) t - \frac{mE_c}{2} \cos (\omega_c + \omega_m) t$	$S(t) = E_c \sin [\omega_c t + m_f \sin\omega_m t]$	$S(t) = E_c \sin [\omega_c t + m_p \sin \omega_m t]$
3.	Modulation index	Less than unity	More than unity for WBFM	Changes of phases
4.	Number of sidebands	2	infinite	
5.	Bandwidth	$2 f_m$	$2(\delta_{max} + f_{m\,(max)})$	Moderate
6.	Information is carried by	Changes in amplitude	Changes in frequency	Complex
7.	Noise immunity	Poor	Better	Better
8.	Wastage of transmission power	Yes	No	Moderate
9.	Mode of wave propagation	Space wave propagation	Ground wave and sky wave propagation	Digital forms of PM are widely used in data communication
10.	Waveform	 (1b31) Fig. 2.10.1	 (1b32) Fig. 2.10.2	 (1b30) Fig. 2.10.3
11.	Applications	Radio broadcasting	Radio, TV	

Chapter Ends...

□□□

(III) Power section

5. **Power section :** It sets the level of transmission power required by antenna system.
6. **Power amplifier :** The power amplifier takes in the energy from the DC power supply and converts it to the AC which is to be radiated. For obtaining high efficiency, class-C power amplifier is used.

   As low power level is desired, class-B push-pull linear power amplifier is used at final stage. It has less efficiency.

GQ. Enlist advantages, disadvantages and Application of Low Level AM Transmitter

(C) Advantages of Low level AM Transmitter

1. Low power modulating signal is sufficient to fully modulate the carrier.
2. Modulation can take place at any point in system after buffer amplifier.

(D) Disadvantages of Low level AM Transmitter

1. **Efficiency :** Less efficiency.
2. To improve efficiency class-B amplifier needs to be used, which increases complexity and increment in hardware components.

(E) Application of Low level AM Transmitter

TV transmitters.

3.1.3 Comparison between High Level and Low Level AM Transmitter

GQ. 3 Compare High Level and Low Level AM Transmitter.

Sr. No.	Parameters	High level AM Transmitter	Low level AM Transmitter
1.	Input modulating signal power requirement	High	low
2.	Efficiency	High	low
3.	Modulation take place at	Final stage power amplifier using collector modulated Class-C power amplifier	Can take place at any point in the carrier chain after buffer amplifier
4.	Circuit complexity	Complex	Simple
5.	Power handling capacity	High	Low
6.	Applications	Broadcast AM transmitters	TV transmitters

3.2 FM TRANSMITTER

FM transmitter is the whole unit, which takes the audio signal as an input and delivers FM wave to the antenna as an output to be transmitted. The block diagram of FM transmitter is shown in the following figure.

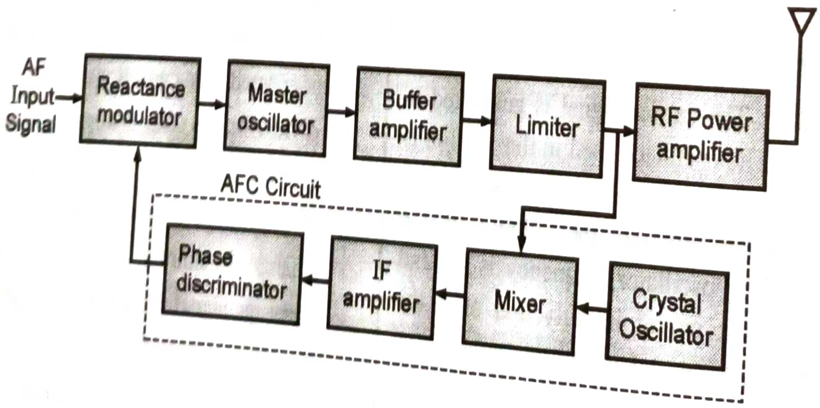


Fig. 3.2.1 : FM Transmitter

The master oscillator

- The function of the master oscillatoris to generatea stable sine wave signal at the rest frequency, when no modulation is applied.
- It must be able to linearly change frequency when fully modulated, with no measurable change in amplitude.

The buffer amplifier

The buffer amplifier acts as a constant high-impedance load on the master oscillator to help stabilize the oscillator frequency. The buffer amplifier may have a small gain.

The reactance modulator

- The frequency modulation is achieved by the reactance modulator.
- In reactance modulator is a voltage variable reactance which isplaced across the tank circuit of the master oscillator. It can be a varactor diode, FET, BJT or vacuum tube.
- The tank is tuned so that the oscillating frequency is equal to the desired carrier frequency. When we apply the modulating voltage, the reactance of the voltage variable reactance changes and hence the tank circuit reactance also varies. This changes the frequency of oscillation of the oscillator.
- When the modulating voltage is increasing positively, the oscillator frequency is also increasing. When the modulating voltage is zero, there is no reactance oscillation and the frequency of oscillation remains unchanged. When the modulating voltage is increasing negatively, the oscillator frequency will be decreasing. Thus the frequency modulation is obtained.

➤ AFC circuit

- Since the reactance modulator operates on the tank circuit of an LC oscillator, the master oscillator cannot be crystal controlled. But it must have the stability of a crystal oscillator since it is the part of a commercial transmitter. If the frequency of the master oscillator shifts, the output frequency of the whole system must drift equally. Hence automatic frequency control (AFC) must be employed.
- AFC circuit consists of crystal oscillator, mixer, IF amplifier, and a phase discriminator.
- In AFC circuit, the master oscillator frequency is mixed with the frequency obtained from a crystal oscillator. The output of the mixer will be the intermediate frequency (IF) signal .
- This intermediate frequency (IF) signal from the output of the mixer is amplified by the IF amplifier and fed to the input of a phase discriminator.
- The output of a phase discriminator is a dc voltage connected to the reactance modulator. The dc voltage is used to correct any drift in the average frequency of an LC master oscillator.
- The phase discriminator will not react to normal frequency changes due to frequency modulation, since they are very small frequency changes. Discriminator will react only to slow changes in the incoming frequency.

The RF power amplifier

The RF power amplifier raises the power of the frequency modulated signal to a required level for transmission through the antenna. It will be a class C amplifier.

The transmitting antenna

The transmitting antenna radiates the RF power in to space.

3.3 RADIO RECEIVERS

☞ Functions of the radio receiver

- It should pick up only the wanted signal frequency rejecting all the other frequencies.
- It should amplify the desired signal to the defined level.
- It should detect the information signal back from the carrier and pass it to the destination.

There are two types of radio receivers :

1. TRF (Tuned Frequency Receivers)
2. Superheterodyne receivers