UNIT–02

UNIT-02/LECTURE-01

NEED AND TYPES OF MODULATION TECHNIQUES

In a carrier communication system, the baseband signal of a low-frequency spectrum is translated to a high frequency spectrum. This is achieved through modulation. The aim of this topic is to explore the reasons for using modulation.

Modulation is defined as a process by virtue of which, some characteristic of a high frequency sinusoidal wave is varied in accordance with the instantaneous amplitude of the baseband signal.

OR

"Modulation is the process of superimposing a low frequency signal on a high frequency carrier signal."

OR

"The process of modulation can be defined as varying the RF carrier wave in accordance with the intelligence or information in a low frequency signal."

OR

"Modulation is defined as the process by which some characteristics, usually amplitude, frequency or phase, of a carrier is varied in accordance with instantaneous value of some other voltage, called the modulating voltage."

Two signals are involved in the modulation process. The baseband signal and the carrier signal. The baseband signal is to be transmitted to the receiver. The frequency of this signal is generally low. In the modulation process, this baseband signal is called the modulating signal. The waveform of this signal is unpredictable. For example, the waveform of a speech signal is random in nature and cannot be predicted. In this case, the speech signal is the modulating signal.

The other signal involved with the modulation is a high frequency sinusoidal wave. This signal is called the carrier signal or carrier. The frequency of the carrier signal is always much higher than that of the baseband signal. After modulation, the baseband signal of low frequency is transferred to the high frequency carrier, which carries the information in the form of some variations. After the completion of the modulation process, some characteristic of the carrier is varied such that the resultant variations carry the information.

The carrier signal is represented by the equation:

$e_c = E_c \sin(\omega_c t + \phi)$ ---------------- (1)

In Equation (1), c is an indicator that this equation represents the carrier signal. The components of this equation arc as follows:

- ec : Instantaneous amplitude of the carrier
- Ec : Amplitude of the carrier
- Angular frequency of the carrier, such that ωc = 2πfc, Where fc is the frequency carrier, also called the central frequency
- ϕ: Initial phase of the carrier signal

Equation (1) has three parameters namely, amplitudes (Ec), frequency (ωc), and phase (f). In principle, these parameters have constant values for a particular sinusoidal wave. According to the definition of Modulation, some characteristic of the carrier signal is varied in accordance with the modulating signal. After modulation any one of the three parameters of the carrier signal, namely, frequency, or phase, is varied keeping the remaining two constant.

The baseband signal is then carried by these variations. The type of the modulation is decided by the parameter chosen to vary.

For example, if amplitude of the carrier is chosen to vary in accordance with the instantaneous amplitude of the baseband signal, keeping frequency and phase constant, the

Resulting modulation called amplitude modulation. Frequency modulation and phase modulation are also obtained in a similar way.

Low-frequency baseband sign it is thus translated to a high frequency carrier such that the information is coded in the variations in one of the parameters of the carrier. At the receiver side, these variations are detected through the demodulation process to recover the original baseband signal.

The following can be summarized with reference to modulation.

- The baseband signal is known as the modulating signal.
- The baseband signal is a low-frequency signal.
- The carrier signal is always a high frequency sinusoidal wave.
- During the modulation process, the modulating, signal varies the frequency, y, amplitude, or phase of the carrier in accordance with its instantaneous amplitude.
- After modulation, the carrier is said to be modulated by the modulating.
- The output of the modulator is called the modulated signal.

The process of modulation in a communication system increases its cost and complexity. This may be considered as a disadvantage. However, modulation is extensively used in most communication systems. There is a definite need for using modulation. There can be problems if modulation is not used. Scrutinizing these problems can explain why modulation is required.

The baseband signal will be transmitted as it is. If modulation is not employed however, the system designer could confront the fallowing problems:

- Antenna Height

- Narrow Banding
- Poor radiation and penetration
- Diffraction angle
- Multiplexing

Need of modulation:- **(DEC 2013)(7)**

The message signal cannot be transmitted directly through the communication channel. The message signal which has low frequency is modulated with the high frequency carrier i.e. the message signal is shifted to high frequency range. Reasons for modulation:

(a) Height of Antenna
The message signal has a low frequency. Ex. Voice signal has the frequency from 20Hz-20KHz. We know that, where c = speed of light
γ = frequency
λ = wavelength
c = γ λ
Since frequency of message signal is less, its wavelength will be large.

Antenna height is given as, Height = λ / 4
Therefore, the antenna height will be large which is practically impossible. After modulation with a high frequency carrier, the frequency will be large. Hence less wavelength and therefore antenna height will be small.

(b) Energy Since,
where E = energy
h = Planck's constant
γ = frequency
E = h γ
Message signal has less frequency. Hence the energy will be less. Therefore, the signals will not be able to travel long distances. They will die out because of less energy. After modulation with a high frequency carrier, the frequency will be large. Hence energy will be more. Therefore, with increase in the frequency, signals can travel longer distance.

(c) Mixing of signals
Voice and music signals are in range of audio frequency i.e. 20Hz to 20KHz, if different message signals are transmitted from the different transmitters, ex. m1(t) -> 20Hz-20KHz m2(t) -> 20Hz-20KHz m3(t) -> 20Hz-20KHz all the signals will interfere with each other because of the same frequency range. Hence receiver will not be able to separate the message signals. To avoid the interference, the information of message signal is converted to different high frequency band so that they occupy different slots in frequency domain.

(d) Multiplexing
Multiplexing means mixing of signals i.e. more than two signals can be transmitted over the same communication channel simultaneously. Hence many signals use the same channel without any interference with each other

Multiplexing is the set of techniques that allows the simultaneous transmission of multiple signals across a single data link. Whenever the transmission capacity of a medium linking two devices is greater than the transmission needs of the devices, the link can be shared in order to maximize the utilization of the link, such as one cable can carry a hundred channels of TV.

Type of multiplexing:-

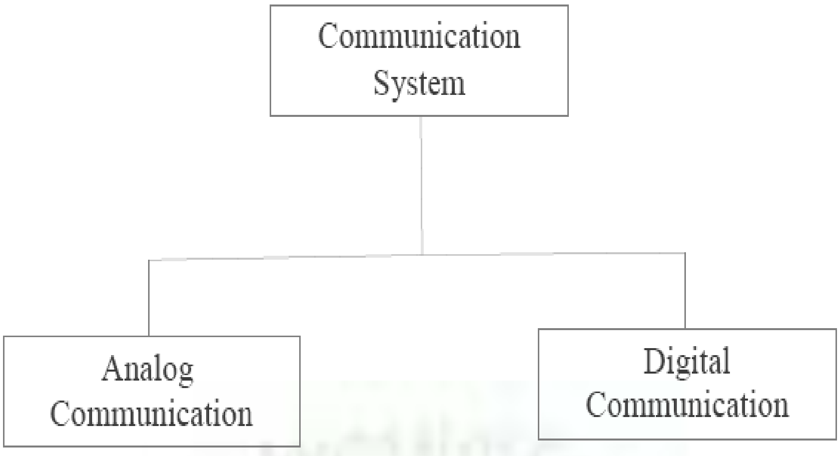
There are two basic techniques:

1. Frequency-Division Multiplexing (FDM)
2. Time-Division Multiplexing (TDM)

- Synchronous TDM
- A-Synchronous TDM

Classification of Communication System:-

Based on the nature of the message signal, the communication system can be classified into two categories:



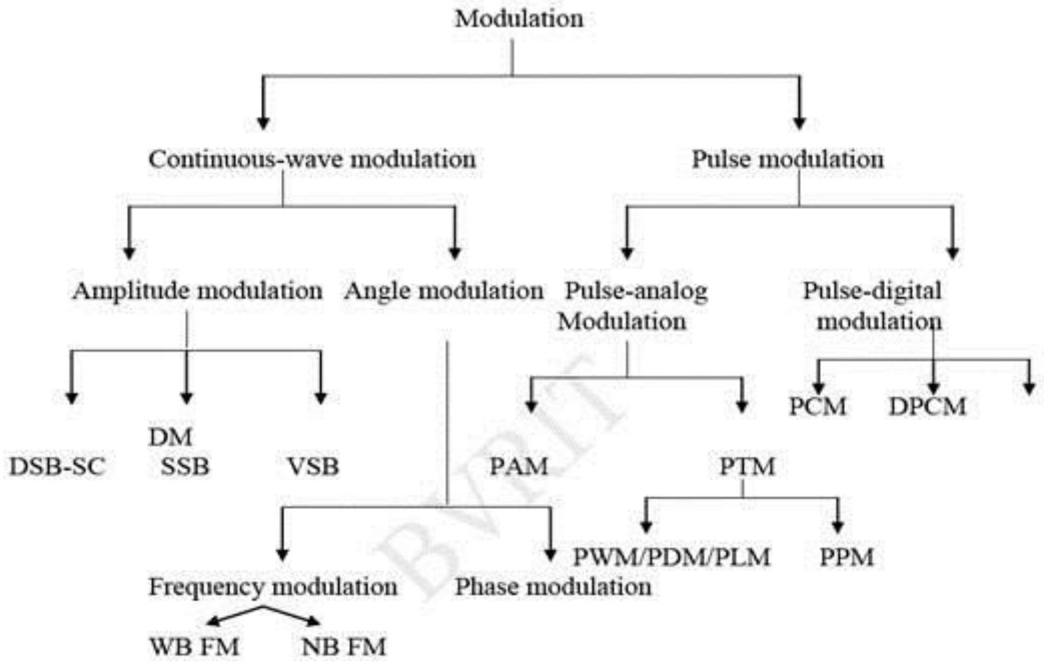
a. Analog Communication:-

In this technique, message to be transmitted is continuous i.e analog in nature. An analog signal is a variable signal which is continuous in both time and amplitude. It is modulated by a high frequency carrier signal. One of the parameters of the carrier signal like amplitude, phase, frequency is varied according to the instantaneous value of the message signal. It can transmit data including voice, image, video etc.

b. Digital Communication:-

In this, the message to be transmitted is in the form of digits 0 and 1 with constant amplitude, constant frequency and constant phase. Both time and amplitude are discrete in nature.

Types of modulation:



	RGPV QUESTIONS	Year	Marks
Q.1	What is the need of modulation?	DEC 2013	7

UNIT-02/LECTURE-02
AMPLITUDE MODULATION,FREQUENCY SPECTRUM

AMPLITUDE MODULATION:-

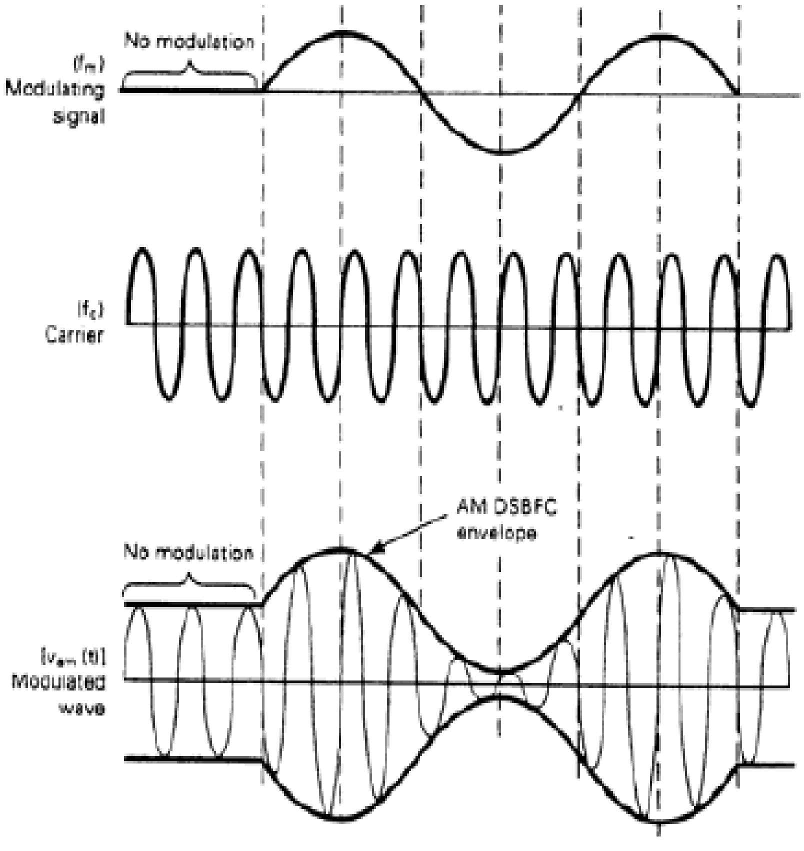
A modulation process in which amplitude of the carrier is varied in accordance with the instantaneous value of the modulating signal is known as amplitude modulation.

There are four types of amplitude modulation

1. DSB-FC (Double Sideband full Carrier)/DSB-LC (Double Sideband large carrier)/ AM-FC /AM-LC/ conventional AM or simply AM.
2. DSB-SC (Double Sideband Suppress Carrier)
3. SSB-SC (Single Sideband Suppress Carrier)
4. VSB (Vestigial Sideband)

DSB-FC (Double Sideband full Carrier)/DSB-LC (Double Sideband large carrier)/AM-FC /AM-LC/ conventional AM or simply AM:-

Vc sin(2πfct) - the carrier;
Vm sin(2πfmt) - the modulating signal;
Vam (t)- the modulated wave.



Fig(1):- AM generation

The output waveform contains all the frequencies that make up the AM signal and it is used to transport the information through the system.
Therefore, the shape of the modulated wave is called the AM envelope.
Note that with no modulating signal, the output waveform is simply the carrier signal

Example:-

A single tone modulating signal em= Emcos wmt amplitude modulates a carrier ec= ECcos wct **(JUNE 2012)(7)**

(i) Derive an expression for AM wave e(t).
(ii) Derive an expression for modulation index.

Solution:-

(i) The general expression for the AM wave is given by

Φ AM(t) = Acoswct + f(t) coswct

Here f(t) = Em coswmt and Acoswct = Ec coswct

Hence e(t) = Ec coswct + Ec coswct coswmt

e(t) = Ec [1 + (Em/Ec) coswmt] coswct

e(t) = Ec [1 + ma coswmt] coswct

where ma= Em/Ec is the modulation index

(ii) the modulation index ma= Em/Ec

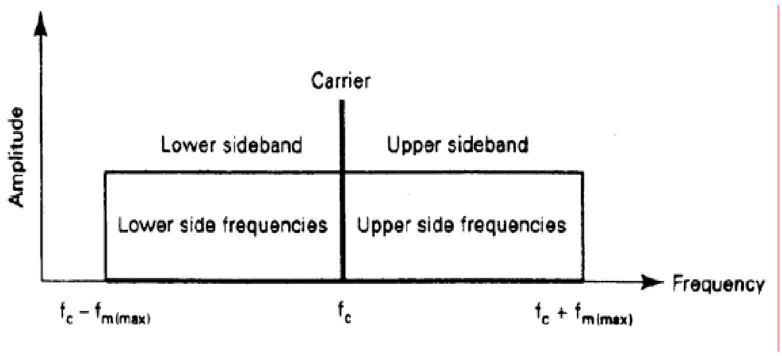
AM Frequency Spectrum and Bandwidth:-

An AM modulator is a nonlinear device. Therefore, nonlinear mixing occurs and the output envelope is a complex wave made up of a dc voltage, the carrier frequency, and the sum (fc+ fm) and difference (fc - fm) frequencies (that is, the cross products). The sum and difference frequencies are displaced from the carrier frequency by an amount equal to the modulating signal frequency.

Therefore, an AM signal spectrum contains frequency components spaced fm Hz on either side of the carrier. The modulated wave does not contain a frequency component that is equal to the modulating signal frequency. The effect of modulation is to translate the modulating signal in the frequency domain so that it is reflected symmetrically about the carrier frequency.

The bandwidth (B) of an AM DSBFC wave is equal to,

B = 2 fm max.



Fig(2):- Frequency Spectrum of an AM DSB-FC WAVE

MODULATION INDEX:-

the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal is important. This relationship, known as the *modulation index m or ma* (also called the modulating factor or coefficient, or the degree of modulation), is the ratio

$$m = \frac{V_m}{V_c}$$

Or

$$m = \frac{E_\mathrm{m}}{E_\mathrm{c}}$$

These are the peak values of the signals, and the carrier voltage is the unmodulated value. Multiplying the modulation index by 100 gives the

Percentage Of Modulation.

$$M = \frac{E_\mathrm{m}}{E_\mathrm{c}} \times 100$$

Example,

if the carrier voltage is 9 V and the modulating signal voltage is 7.5 V, then calculate modulation index.

Solution:-

Given Vm = Em =7.5 v
Vc = Ec = 9 v

$$m = \frac{V_m}{V_c}$$

modulation factor is m = 7.5 / 9 = 0.8333
and the percentage of modulation is M = 0.833 x 100 = 83.33.

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Over modulation and Distortion (ma> 1):-

The modulation index should be a number between 0 and 1. If the amplitude of the Modulating voltage is higher than the carrier voltage; *m* will be greater than 1, causing *distortion* of the modulated waveform. If the distortion is great enough, the intelligence signal becomes unintelligible. Distortion of voice transmissions produces garbled, harsh, or unnatural sounds in the speaker. Distortion of video signals produces a scrambled and inaccurate picture on a TV screen.
Simple distortion is illustrated in Fig 3(a). Here a sine wave information signal is modulating a sine wave carrier, but the modulating voltage is much greater than the carrier voltage, resulting in a condition called over modulation.

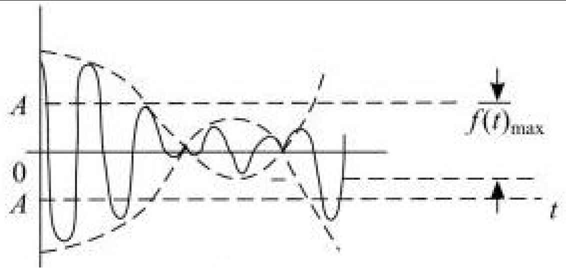

Fig3(a):- AM with ma> 1 or lf(t)lmax > A

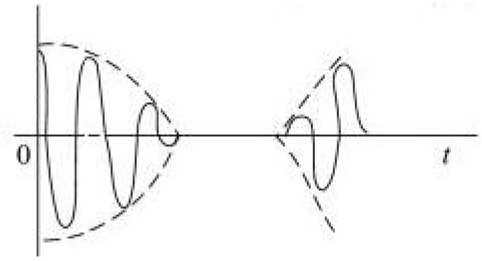

Fig3(b):- Overmodulated AM as observed on CRO.

Ideal Modulation (ma = 1) 100% modulation:-

If the amplitude of the modulating signal is less Than the carrier amplitude, no distortion will occur shown in Fig 3(c).

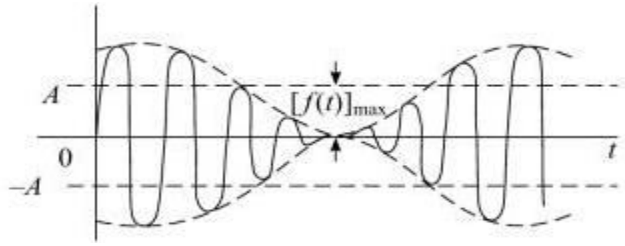

Fig3(c):- AM with ma = 1 or lf(t)lmax = A (Vm = Vc)

Under Modulation (ma < 1):-

The ideal condition for AM is When *Vm* = *Vc* or , *m* = 1, which gives 100 percent modulation. This results in the greatest output power at the transmitter and the greatest output voltage at the receiver, With no distortion illustrated in Fig 3(d).

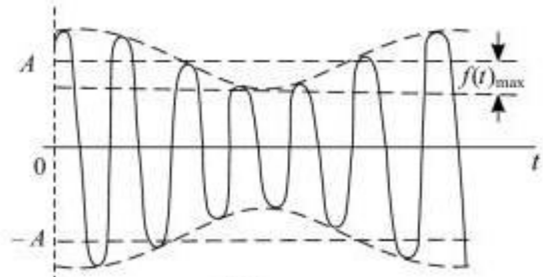

Fig3(d):- AM with ma < 1 or lf(t)lmax < A (Vm < Vc)

Another technique of calculation of Modulation Index and Percentage of Modulation:-

The modulation index can be determined by measuring the actual values of the modulation voltage and the carrier voltage and computing the ratio. However, it is more common to compute the modulation index from measurements taken on the composite modulated wave itself. When the AM signal is displayed on an oscilloscope, the modulation index can be computed from *V*max and *V*min as shown in Fig.4. The peak value of the modulating signal is *Vm* one-half the difference of the peak and trough values:

$$V_m = \frac{V_{\max} - V_{\min}}{2}$$

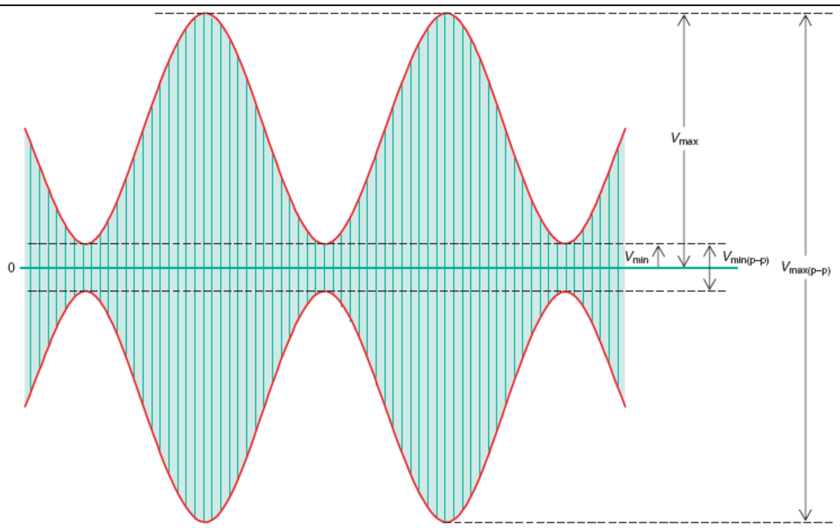

Fig 4:- An AM wave showing peaks (Vmax) and troughs (Vmin)

As shown in Fig., *V*max is the peak value of the signal during modulation, and Vmin is the lowest value, or trough, of the modulated wave. The *V*max is one-half the peak-to-peak value of the AM signal, or *V*max *V*min *V*max (*p* –*p*)/2.Subtracting *V*min from *V*max produces the peak-to- peak value of the modulating signal. One-half of that, of course, is simply the peak value.

The peak value of the carrier signal *Vc* is the average of the *V*max and *V*min and values:

$$V_c = \frac{V_{\max} + V_{\min}}{2}$$

The modulation index is

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

The modulation index or depth, of AM is more commonly expressed as the percentage of modulation rather than as a fractional value. the percentage of modulation is 100 x *m* ,

Example:-

In an AM signal the *V*max (*p-p*) value read from the graticule on the oscilloscope screen is 5.9 divisions and *V*min(*p–p*) is 1.2 divisions.

a. What is the modulation index?

b. Calculate *Vc*, *Vm*, and *m* if the vertical scale is 2 V per division.

Solution:-

M= $$\frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} = \frac{5.9 - 1.2}{5.9 + 1.2} = \frac{4.7}{7.1} = 0.662$$

$$V_c = \frac{V_{\max} + V_{\min}}{2} = \frac{5.9 + 1.2}{2} = \frac{7.1}{2} = 3.55 \ @ \ \frac{2\text{ V}}{\text{div}}$$

$$V_c = 3.55 \times 2\text{ V} = 7.1\text{ V}$$

$$V_m = \frac{V_{\max} - V_{\min}}{2} = \frac{5.9 - 1.2}{2} = \frac{4.7}{2}$$

$$= 2.35 \ @ \ \frac{2\ \text{V}}{\text{div}}$$

$$V_m = 2.35 \times 2\ \text{V} = 4.7\ \text{V}$$

$$m = \frac{V_m}{V_c} = \frac{4.7}{7.1} = 0.662$$

	RGPV QUESTIONS	Year	Marks
Q.1	A single tone modulating signal $e_m = E_m \cos \omega_m t$ amplitude modulates a carrier $e_c = E_c \cos \omega_c t$: (i) derive an expression for AM wave e(t). (ii) derive an expression for modulation index.	JUNE 2012	7

UNIT-02/LECTURE-03

POWER DISTRIBUTION

AM Voltage Distribution:- **(JUNE 2010)(10)**

An unmodulated carrier can be Described mathematically as

$$v_c(t) = E_c \sin(2\pi f_c t)$$

Therefore, the instantaneous amplitude of the modulated wave can be expressed as

$$v_{am}(t) = [E_c + E_m \sin(2\pi f_m t)][\sin(2\pi f_c t)] = [1 + m\sin(2\pi f_m t)][E_c \sin(2\pi f_c t)]$$

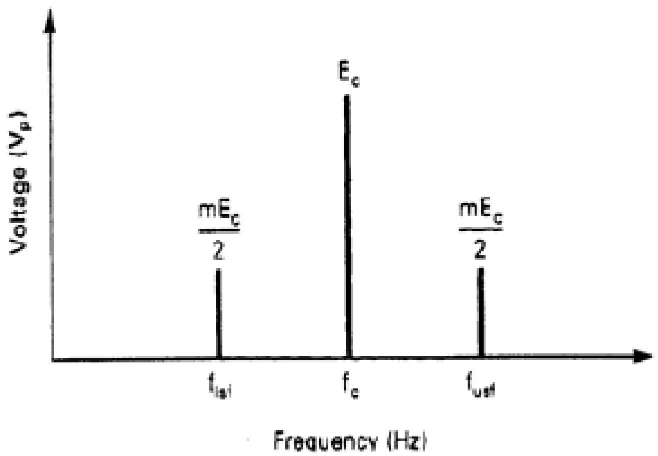

Fig 5:-Voltage spectrum for an DSB-FC

$$v_{am}(t) = E_c \sin(2\pi f_c t) - \frac{mE_m}{2}\cos[2\pi(f + f_m)t] + \frac{mE_m}{2}\cos[2\pi(f - f_m)t]$$

AM Power Distribution:-

The average power dissipated in a load by an unmodulated carrier is equal to the rms carrier voltage squared, divided by the load resistance.

Mathematically, power in an unmodulated carrier is

$$P_c = \frac{(0.707E_c)^2}{R} = \frac{E_c^{\ 2}}{2R}$$

The upper and lower sideband powers are expressed mathematically as:

$$P_{usb} = P_{lsb} = \frac{(mE_c/2)^2}{2R} = \frac{m^2 P_c}{4}$$

The total power in an amplitude-modulated wave is equal to the sum of the powers of the carrier, the upper sideband, and the lower sideband:

$$P_t = P_c + P_{usb} + P_{lsb}$$

The total power in an AM signal when the carrier power and the percentage of modulation are known:

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

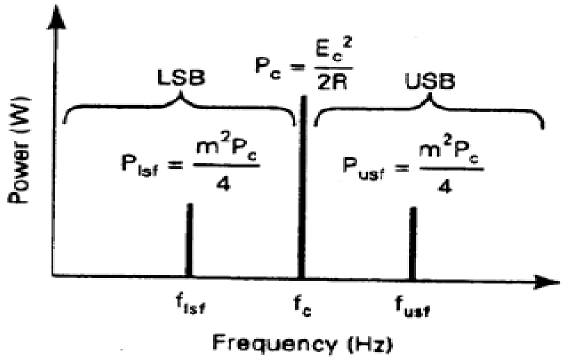

Fig 6:-Power Spectrum for an AM DSBFC wave with a single-frequency modulating signal

- Note that with 100% modulation the maximum power in the upper or lower sideband is equal to only one-fourth the power in the carrier.
- Thus, the maximum total sideband power is equal to one-half the carrier power.
- One of the most significant disadvantages of AM DSBFC transmission is the fact that the information is contained in the sidebands although most of the power is wasted in The carrier.
- Actually, the power in the carrier is not totally wasted because it does allow for the use of relatively simple, inexpensive demodulator circuits in the receiver, which is the predominant advantage of AM DSBFC.

Example:-

A carrier Acoswct is modulated by a single tone modulating signal f(t)=Emcoswmt. Find

(a) Total modulated power
(b) RMS (root mean square) value of the modulated signal,and
(c) Transmission efficiency for a 100 percent modulation.

Solution:-

i) Carrier power (unmodulated) Pc =mean square value of Acoswct =$A^2/2$
Sideband power Ps= $Em^2/4$
Total power P is the sum of Pc and Ps
Pt = Pc + Ps
Pt= $A^2/2 + Em^2/4$
Pt= $A^2/2\ [1 + ½\ (Em/A)^2]$
Putting Em/A = ma and $A^2/2$ = Pc
Total modulated power P= Pc [1 + ½ $(ma)^2$]
Where ma is the modulation index
Pt=Pc + Pc$(ma)^2/2$
Where second term Pc$(ma)^2/2$ is known as sideband power

ii) The rms value is under root of the ms value (power) of the AM signal

$$V_{rms} = \sqrt{P} = \sqrt{P_c\,(1 + \frac{m_a^2}{2})}$$

Now, $\sqrt{P_c} = V_{c_{rms}}$ by putting

$$V_{rms} = Vc_{rms}\sqrt{1+\frac{m_a^2}{2}}$$

(i) Transmission efficiency is given by

Eff =(useful power /total power) x 100

Eff =(side band power / total power) x 100

Eff =(Ps / Pt) x 100

Eff =($Pc(ma)^2/2$ / $Pc[1 + ½ (ma)^2]$) x 100

Eff =$[(ma)^2/[2 + (ma)^2]$]x 100

For a 100 percent modulation ma= 1

Eff =$1^2/[2 + 1^2]$ x 100

Eff =(1 /3) x 100

Eff =33.3%

It means for a 100 percent modulation the sidebands carry only one third of the total power. This is the maximum power which can be carried by the sidebands in AM. If ma is less than 100 percent the sideband power will be further reduced.

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Example:-

if the carrier of an AM transmitter is 1000 W and it is modulated 100 percent. Find the total power and sideband power.

Solution:-

Given Pc = 1000W and ma = 1

the total AM power is Of the total power

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

$$P_T = 1000\left(1 + \frac{1^2}{2}\right) = 1500\text{ W}$$

1000 W of it is in the carrier. That leaves 500 W in both sidebands. Since the sidebands are equal in size, each sideband has 250 W.For a 100 percent modulated AM transmitter, the total sideband power is always one-half that of the carrier power.

Psb = 500 W

Plsb = Pusb =250

It is also calculated by formule

$$P_{usb} = P_{lsb} = \frac{(mE_c/2)^2}{2R} = \frac{m^2P_c}{4}$$

Plsb = Pusb = (1^2x 1000) /4 =1000/4 = 250 w

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Example:- A 50-kW transmitter carrier that is 100 percent modulated will have a sideband power of 25 kW, with 12.5 kW in each sideband. Calculate The total Power.

Solution:-

Carrier Power Pc = 50 kW

Modulation index ma= 1
Sideband power Psb =25 kW
Upper sideband /lLower sideband Power Plsb = Pusb =12.5 W
Total power Pt = Pc + Psb =50 + 25 = 75 kW
When the percentage of modulation is less than the optimum 100, there is much less power in the sidebands.

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Example:-
An AM transmitter has a carrier power of 30 W. The percentage of modulation is 85 percent. Calculate (a) the total power and (b) the power in one sideband.

Solution:-

a. $P_T = P_c\left(1 + \frac{m^2}{2}\right) = 30\left[1 + \frac{(0.85)^2}{2}\right] = 30\left(1 + \frac{0.7225}{2}\right)$

$P_T = 30(1.36125) = 40.8\text{ W}$

b. $P_{\text{SB}}\text{ (both)} = P_T - P_c = 40.8 - 30 = 10.8\text{ W}$

$$P_{\text{SB}}\text{ (one)} = \frac{P_{\text{SB}}}{2} = \frac{10.8}{2} = 5.4\text{ W}$$

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Example:- For a 70 percent modulated 250-W carrier, find the total power and power in each sideband.
Solution:-
Given Pc (Carrier power)= 250W
ma (Modulation Index)= 0.7

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

$$P_T = 250\left(1 + \frac{0.7^2}{2}\right) = 250(1 + 0.245) = 311.25\text{ W}$$

PT (Total power) = 311.25 W
As we know
Total power = Carrier Power + Side band Power
PT = Pc +Psb
311.25 = 250 + Psb
Psb = 311.25 -250
Psb (Side band Power) = 61.25
Power in each sideband (Plsb =Pusb) =61.25/2 =30.625

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it is difficult to determine AM power by measuring the output voltage and calculating the power with the expression $P = V^2/R$.

However, it is easy to measure the current in the load. For example, you can use an RF ammeter connected in series with an antenna to observe antenna current. When the antenna impedance is
known, the output power is easily calculated by using the formula
PT = IT ^{2} R

where $I_T = I_c\sqrt{(1 + m^2/2)}$. Here *Ic* is the un modulated carrier current in the load, and *m* is the modulation index.

Example:-
The total output power of an 85 percent modulated AM transmitter, whose unmodulated carrier current into a antenna load impedance is 10 A. Calculate Total carrier power.

Solution:-

Given ma = 0.85
Ic = 10amp

$$I_T = I_c\sqrt{(1 + m^2/2)}$$

$$I_T = 10\sqrt{\left(1 + \frac{0.85^2}{2}\right)} = 10\sqrt{1.36125} = 11.67 \text{ A}$$

$$P_T = 11.67^2(50) = 136.2(50) = 6809 \text{ W}$$

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One way to find the percentage of modulation is to measure both the modulated and
the unmodulated antenna currents. Then, by algebraically rearranging the formula above,
m can be calculated directly:

$$m = \sqrt{2\left[\left(\frac{I_T}{I_c}\right)^2 - 1\right]}$$

Example:-
The unmodulated antenna current is 2.2 A. That is the current produced by the carrier only, or Now, if the modulated antenna current is 2.6 A, Find the modulation index.
Solution:-

$$m = \sqrt{2\left[\left(\frac{I_T}{I_c}\right)^2 - 1\right]}$$

$$m = \sqrt{2\left[\left(\frac{2.6}{2.2}\right)^2 - 1\right]} = \sqrt{2[(1.18)^2 - 1]} = \sqrt{0.7934} = 0.89$$

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Example:-

An antenna has an impedance of 40 Ω .An unmodulated AM signal produces a current of 4.8 A. The modulation is 90 percent. Calculate

(*a*) the carrier power,

(*b*) the total power, and

(*c*) the sideband power.

Solution:-

a. $P_c = I^2R = (4.8)^2(40) = (23.04)(40) = 921.6\text{ W}$

b. $I_T = I_c\sqrt{1 + \frac{m^2}{2}} = 4.8\sqrt{1 + \frac{(0.9)^2}{2}} = 4.8\sqrt{1 + \frac{0.81}{2}}$

$I_T = 4.8\sqrt{1.405} = 5.7\text{ A}$

$P_T = I_T{}^2\text{R} = (5.7)^2(40) = 32.49(40) = 1295\text{ W}$

c. $P_{\text{SB}} = P_T - P_c = 1295 - 921.6 = 373.4\text{ W}$ (186.7 W each sideband)

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Example:-

The transmitter experiences an antenna current change from 4.8 A unmodulated to 5.1 A. What is the percentage of modulation?

Solution:-

$$\begin{aligned} m &= \sqrt{2\left[\left(\frac{I_T}{I_c}\right)^2 - 1\right]} \\ &= \sqrt{2\left[\left(\frac{5.1}{4.8}\right)^2 - 1\right]} \\ &= \sqrt{2[(1.0625)^2 - 1]} \\ &= \sqrt{2(1.13 - 1)} \\ &= \sqrt{2(0.13)} \\ &= \sqrt{0.26} \\ m &= 0.51 \end{aligned}$$

The percentage of modulation is 51.

*****

Example:-

Find total modulated power, sideband power and net modulation index for the AM signal

$$\varphi_{\text{AM}} = 10\cos(2\pi\cdot10^6 t) + 5\cos(2\pi\cdot10^6 t)\cos(2\pi\cdot10^3 t) + 2\cos(2\pi\cdot10^6 t)\cos(4\pi\cdot10^3 t)$$

Solution:-

$$\varphi_{\text{AM}} = 10\cos(2\pi\cdot10^6 t) + 5\cos(2\pi\cdot10^6 t)\cos(2\pi\cdot10^3 t) + 2\cos(2\pi\cdot10^6 t)\cos(4\pi\cdot10^3 t)$$

The expression can be written as

$$\varphi_{AM} = 10[1 + 0.5\cos 2\pi \cdot 10^3 t + 0.2\cos 4\pi \cdot 10^3 t]\cos 2\pi \cdot 10^6 t$$

The signal is equivalent to the expression

$$\varphi_{AM} = A[1 + m_1 \cos\omega_1 t + m_2 \cos\omega_2 t]\cos\omega_c t$$

Here

$$A = 10\text{ V},\ m_1 = 0.5,\ \text{and}\ m_2 = 0.2$$

Unmodulated carrier power

$$P_c = \frac{A^2}{2} = \frac{10^2}{2} = 50\text{ W}$$

The power of the modulated signal is given by

$$P = P_c\left(1 + \frac{m_1^2 + m_2^2}{2}\right) = 50\left(1 + \frac{0.25 + 0.04}{2}\right) = 57.25\text{ W}$$

Sideband power

$$P_s = P - P_c = 57.25 - 50 = 7.25\text{ W.}$$

Net modulation index m is given by

$$m = \sqrt{m_1^2 + m_2^2} = \sqrt{0.5^2 + 0.2^2} = 0.539$$

*****

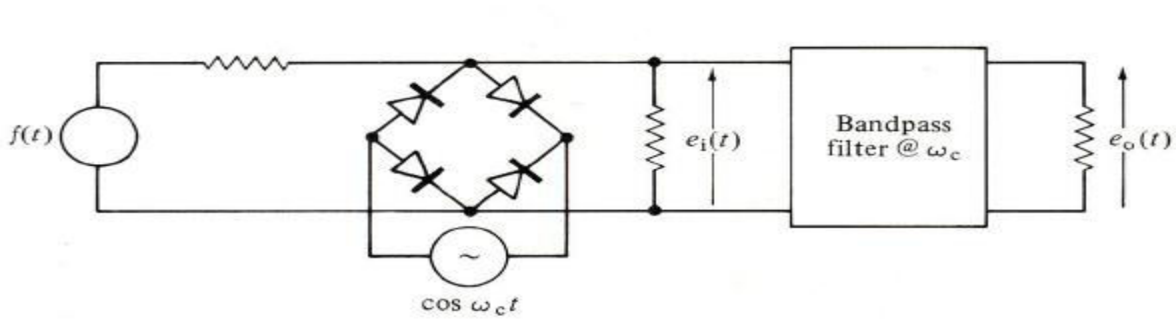
	RGPV QUESTIONS	Year	Marks
Q.1	Prove that after amplitude modulation, the carrier power increases from P_c to P $P_c(1+ ma/2)$ where m_a is the modulation index.	JUNE 2010	10

UNIT-02/LECTURE-04
BALANCE/CHOPPER MODULATOR

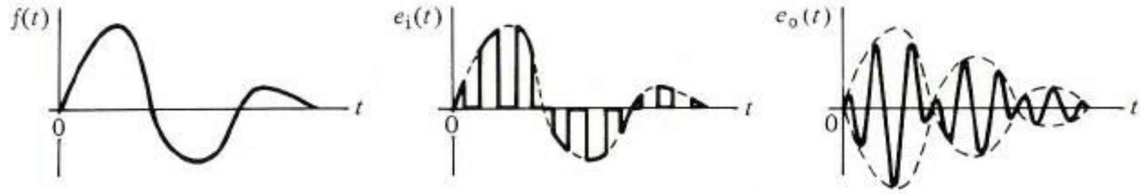
Generation of DSB-SC:-

Chopper type balanced modulator/Ring Modulator:-

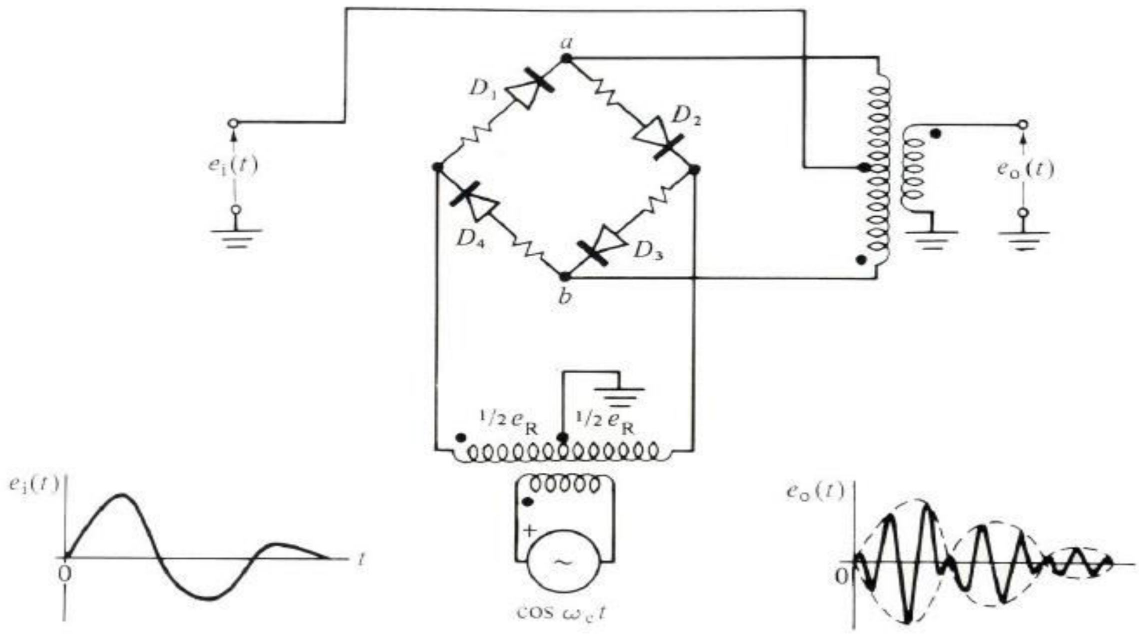
The chopper modulator The chopper modulator or ring modulator is a common type of modulator. A diagram is shown below



Cos(wct) is a square wave. During the positive half cycle f(t) is switched on to the other side. When Cos(wct) is 0 the waveform is switched off. The bandpass filter will remove higher frequency components which are not needed. The corresponding waveforms are shown below



This is a theoretical model of a chopper modulator. A popular configuration is the double-balanced ring modulator. The modulator is popular as it does not require ideal components , provided that they have matched characteristics (i.e. use the same part numbers).



Assuming that ei(t) is 0. During the positive half cycles diodes D1 and D2 will conduct and the point a is connected to the out put transformer secondary. If the secondary of the reference transformer is accurately centre tapped and if the impedances of D1 and D2 are identical than no current will flow through the output transformer and no voltage will be developed at the output. During the next half cycle D3 and D4 conduct and point b is connected to the input through the opposite half cycle of the output transformer secondary. Again no current will flow and no output will result. Thus we see that the carrier is suppressed.

Now let ei(t) have the modulating input. Let us apply a positive polarity input signal whose peak amplitude is much smaller than that of the reference eR. On the positive half-cycles of Coswct, point a is essentially at ground potential and a current will flow upward through half of the output transformer secondary, inducing a positive output voltage. On the negative half-cycles of Coswct, point b is essentially at ground potential and a current will flow downward through the opposite half of the output transformer secondary, inducing a negative output voltage.

The peak positive and negative output voltages will be identical for a given fixed signal amplitude if the output transformer is accurately centre tapped. Therefore we have developed a signal that alternates in sign at a rate determined by the carrier frequency and whose amplitude is proportional to the input signal amplitude. For DSB-SC modulation to occur

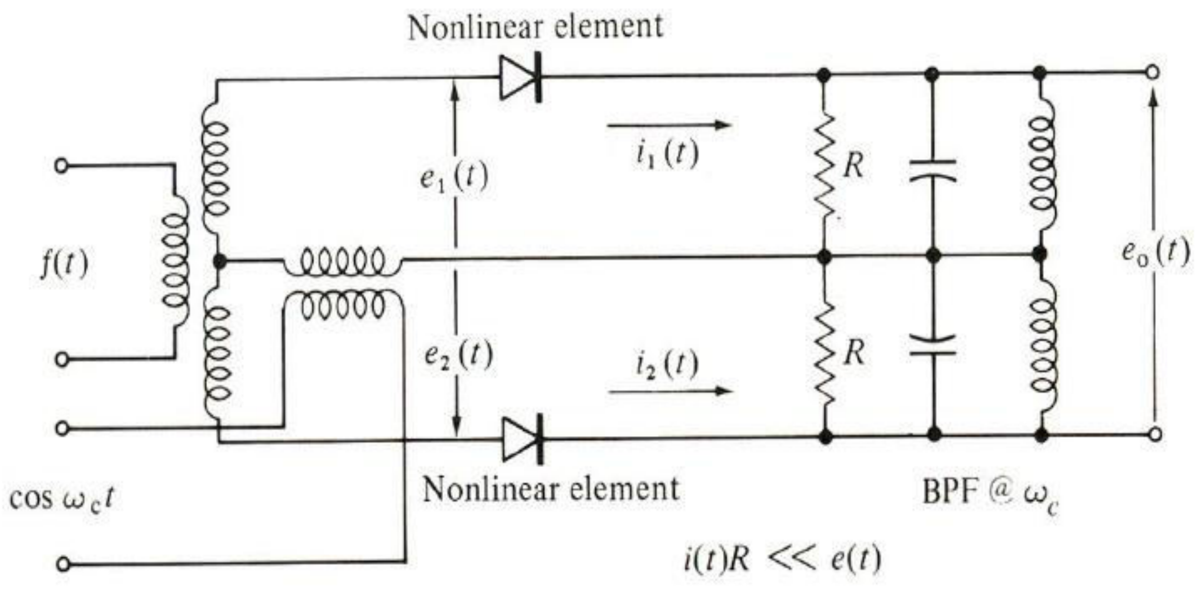
$$\left[e_i(t)\right]_{\max} < \frac{1}{2}[e_R(t)]_{MAX}$$

In practice, an imbalance between diode characteristics and inaccuracies in the transformer centre taps will result in non-ideal performance and carrier leakage. Balancing controls can be added to fully tune out carrier leakage.

Non linear devices:-

Balanced Modulator:- **(DEC 2013)(7)**

Amplitude modulation can also arise in non linear systems. Diodes are good examples of non linear devices and may be used as a modulator. The following balanced modulator uses non linear devices to generate a DSB-SC AM.



The non linearity can be approximated by the following power series

$$i(t) = a_1 e(t) + a_2 e^2(t) + a_3 e^3(t) + \ldots\ldots$$

Referring to the above figure. By the transformer actions

$$e_1(t) = Cosw_c t + f(t)$$

$$e_2(t) = Cosw_c t - f(t)$$

Retaining up to the power of $e^2(t)$ the current than becomes

$$i_1(t) = a_1\left[Cosw_c t + f(t)\right] + a_2\left[Cosw_c t + f(t)\right]^2$$

$$i_2(t) = a_1\left[Cosw_c t - f(t)\right] + a_2\left[Cosw_c t - f(t)\right]^2$$

For a resistive load the net voltage is [i1(t) –i2(t)]R the output is

$$\left[i_i(t) - i_2(t)\right]R = 4a_2R\left[f(t)Cosw_c t + \frac{a_1}{2a_2}f(t)\right]$$

The output at the BPF centered around Wc is given by

eo(t) = 4aRf(t) Coswct

eo(t) = k f(t) Coswct

this is the desired expression for AM-SC or DSB-SC

	RGPV QUESTIONS	Year	Marks
Q.1	Write short note on balanced modulator.	DEC 2013	7
Q.2	With the help of a circuit diagram, explain the working of Balance Modulator for DSB-SC generation.	DEC 2010	10

UNIT-02/LECTURE-05

SSB GENERATOR (PHASE AND FREQUENCY DISCRIMINATION METHOD),VSB TRANSMISSION

Single Side Band (SSB) Modulation:-

In DSB-SC it is observed that there is symmetry in the band structure. So, even if one half is transmitted, the other half can be recovered at the received. By doing so, the bandwidth and power of transmission is reduced by half. Depending on which half of DSB-SC signal is transmitted,

there are two types of SSB modulation
1. Lower Side Band (LSB) Modulation
2. Upper Side Band (USB) Modulation

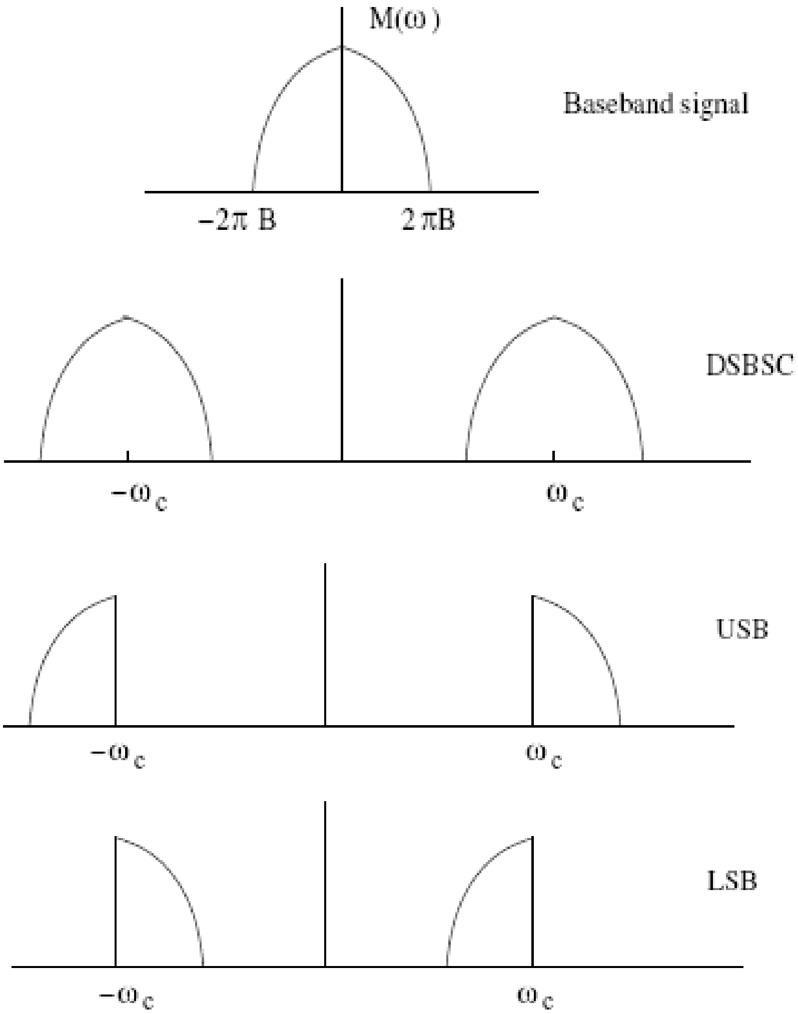


Fig 12:- SSB signals from original signal

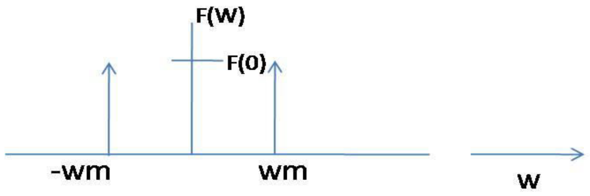


Fig 13(a):- Spectrum of coswmt

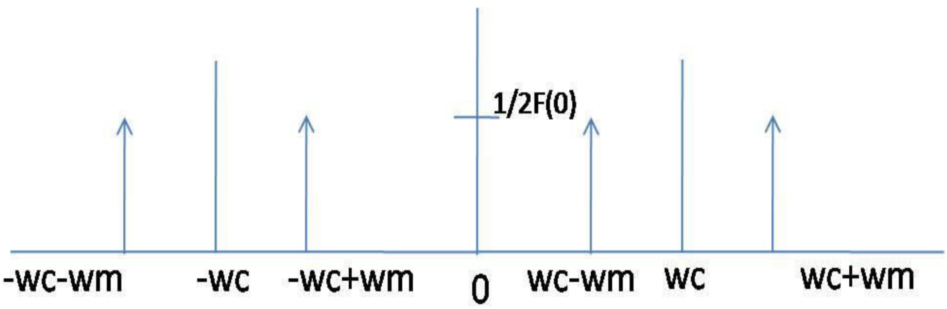


Fig 13(b) :- Spectrum of AM-SC

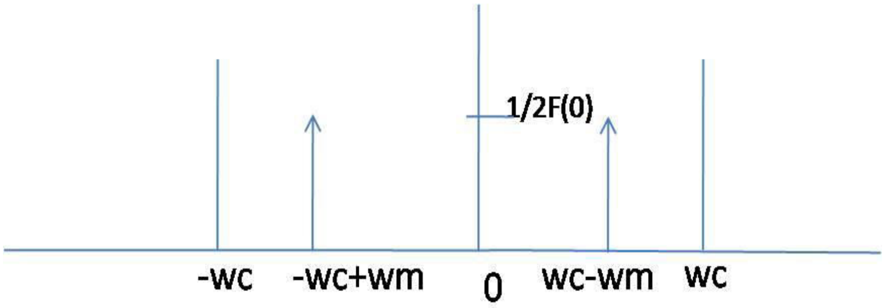


Fig 13(c):- Spectrum of SSB-SC with lower sideband

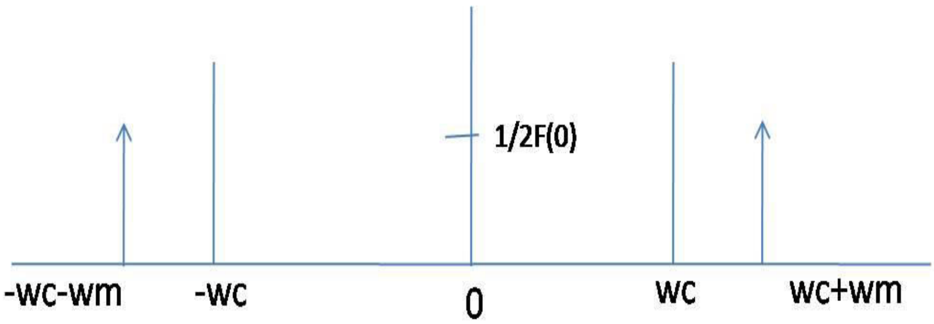


Fig 13(d) :- Spectrum of SSB-SC with upper sideband

Consider a single tone modulating signal is given by F(t) = coswmt

The spectrum of this modulating signal is a pair of impulses at w=+wm and w=-wm as shown in above fig (a) .let this signal modulate a carrier coswct, the resulting AM-SC (DSB-SC) spectrum is shown in (b) . in order to get the SSB-SC waveform ,one of the sideband is eliminated. Fig (c) represented the spectrum of SSb-SC with lower sidebands. It is obvious from the spectrum that this corresponds to a time domain signal cos (wc-wm)t, since the spectrum of cosine function consists of two impulses in its frequency domain. thus the SSb-SC (lower sideband) signal may be expressed as

cos(wc-wm)t = coswmt coswct + sinwmt sinwct ………….(i)

similarly.yhe expression for the single tone SSB-SC with upper sidebands (fig:d) may be given as

cos(wc +wm)t = coswmt coswct - sinwmt sinwct …………….(ii)

equation (i) and (ii) may be combined to be written as

Φ ssb (t) = coswmt coswct (+ -)sinwmt sinwct …………(iii)

Where (+) sign indicated the lower sideband and (-) sign indicates the upper sideband.

The terms sinwmt and sinwct may be written as

sinwmt = cos (wmt – π/2) ………………(iv)

sinwct = cos (wct – π/2) ………………(v)

thus, the sine terms can be obtained from the corresponding terms, by giving a phase shift of

(- π/2) . Equation (iii) is an expression for SSB-SC for a specific case of single tone modulation.

In equation (iii) the term sinwmt is obtained by giving a phase shift of (- π/2) to the modulating frequency coswmt.

Similarly, in a general modulating signal f(t) ,if all the frequency components are shifted by

(- π/2), it may lead to a SSB-SC signal.

Thus equation (iii) may be extended for a SSB-SC signal modulated by a general modulating signal f(t) as given below:

Φ ssb (t) = f(t) coswct (+ -) fh(t) sinwct …………….(vi)

Where fh(t) is a signal obtained by shifting the phase of every component present in f(t) by

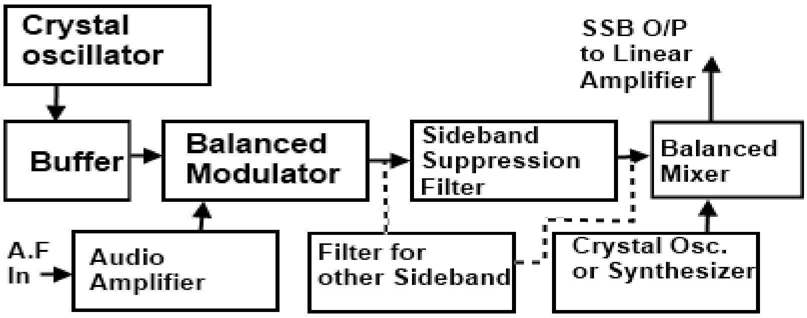
(- π/2). Similarly equation (iii) (+) sign indicated the lower sideband and (-) sign indicates the upper sideband.

There are two methods used for SSB Transmission:-

1. Filter Method
2. Phase Shift Method

Filter Method/frequency discrimination method:-

This is the filter method of SSB suppression for the transmission. Fig



illustrates the block diagram of this method.

1. A crystal controlled master oscillator produces a stable carrier frequency fc (say 100 KHz)
2. This carrier frequency is then fed to the balanced modulator through a buffer amplifier which isolates these two satges.
3. The audio signal from the modulating amplifier modulates the carrier in the balanced modulator. Audio frequency range is 300 to 2800 Hz. The carrier is also suppressed in this stage but allows only to pass the both side bands. (USB & LSB).
4. A band pass filter (BPF) allows only a single band either USB or LSB to pass through it. It depends on our requirements.
   Let we want to pass the USB then LSB will be suppressed. Inthis case.
   fc = 100 KHz
   Audio range = 300 - 2800 Hz
   USB frequency range = fc + 300 to fc + 2800
   = 100000 + 300 to 100000 + 2800
   = 100300 to 102800 Hz
   So this band of frequency will be passed on through the USB filter section
5. This side band is then heterodyned in the balanced mixer stage with 12 MHz frequency produced by crystal oscillator or synthesizer depends upon the requirements of our transmission. So in mixer stage, the frequency of the crystal oscillator or synthersizer is added to SSB signal. The output frequency thus being raised to the value desired for transmission.
6. Then this band is amplified in driver and power amplifier stages and then fed to the aerial for the transmission.

Advantages:- The advantages of single side band SSB transmission are as follows.

1. It allows better management of the frequency spectrum. More transmission can fit

into a given frequency range than would be possible with double side band DSB signals.

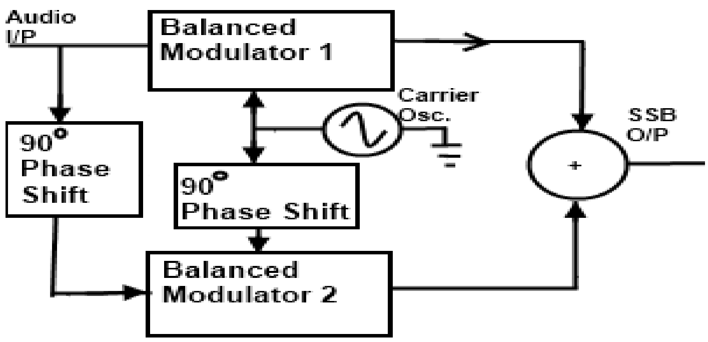
2. All of the transmitted power is message power none is dissipate as carrier power.
3. The noise content of a signal is an exponential function of the bandwidth: the noise will decrease by 3dB when the bandwidth is reduced by half. There fore, single side band SSB signals have less noise contamination than DSB double side band.

Disadvantages:-

1. The cost of a single side band SSB reciver is higher than the double side band DSB counterpart be a ratio of about 3:1.
2. The average radio user wants only to flip a power switch and dial a station. Single side band SSB recievers require several precise frequency control settings to minimize distortion and may require continual readjustment during the use of the system.

Phase Shift Method/phase discrimination method:- **(DEC 2012)(7)**

The phaseing method of SSB generation uses a phase shift technique that causes one of the side bands to be conceled out. A block diagram of a phasing type SSB generator is shown in fig.



1. It uses two balanced modulators instead of one. The balanced modulators effectively eliminate the carrier. The carrier oscillator is applied directly to the upper balanced modulator along with the audio modulating signal. Then both the carrier and modulating signal are shifted in phase by 90^o and applied to the second, lower, balanced modulator. The two balanced modulator output are then added together algebraically. The phase shifting action causes one side band to be canceled out when the two balanced modulator outputs are combined.
2. The carrier signal is $V_c Sin2\pi f_c t$ the modulating signal is $V_m Sin2\pi f_m t$. Balanced modualtor produces the product of these two signals.
   $(V_m Sin2\pi f_m t)(V_c Sin2\pi f_c t)$
   Applying a trignometric identity.
   $(V_m Sin2\pi f_m t)(V_c Sin2\pi f_c t) = 1/2[Cos(2\pi f_c - 2\pi f_m)t - Cos(2\pi f_c + 2\pi f_m)t]$
   Note that these are the sum and diffrence frequencies or the upper and lower side bands.

It is important to remember that a cosine wave is simply a sine wave shifted by 90^o A cosine wave has exactly the same shape as a sine wave, but it occurs 90^o

The 90^o phase shifters create cosine waves of the carrier and modulating signal whichare multiplied in balanced modulator to produce
$(V_m - Cos2\pi f_m t)(V_c Cos2\pi f_c t)$
$(V_m - Cos2\pi f_m t)(V_c Cos2\pi f_c t)$
Another common trigonometric identity translates this to
$(V_m Cos2\pi f_m t)(V_c Cos2\pi f_c t) = 1/2[Cos(2\pi f_c - 2\pi f_m)t + Cos(2\pi f_c + 2\pi f_m)t]$
Now if you add these two expressions together the sum frequencies cancel while the difference frequencies add producing only the lower side band:
$Cos(2\pi f_c - 2\pi f_m)t$

Vestigial Side Band (VSB) Modulation:- **(DEC 2013)(7)**
The following are the drawbacks of SSB signal generation:
1. Generation of an SSB signal is difficult.
2. Selective filtering is to be done to get the original signal back.
3. Phase shifter should be exactly tuned to 900.
To overcome these drawbacks, VSB modulation is used. It can viewed as a compromise between SSB and DSB-SC. Figure 14 shows all the three modulation schemes.

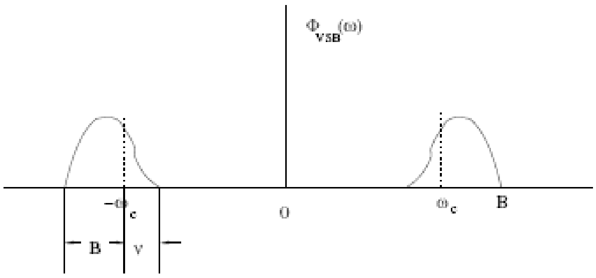


Figure 14: VSB Modulation

In VSB
1. One sideband is not rejected fully.
2. One sideband is transmitted fully and a small part (vestige)
of the other sideband is transmitted.
The transmission BW is BW= B + v. where, v is the vestigial frequency band.

The generation of VSB signal is shown in Figure 15

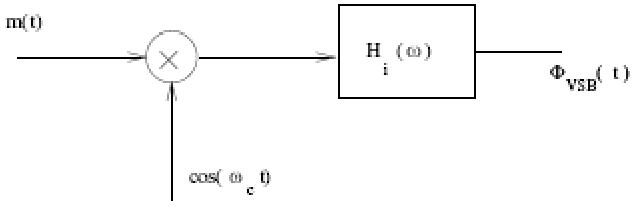


Figure 15: Block Diagram - Generation of VSB signal

Here, Hi(w) is a filter which shapes the other sideband.
ΦVSB(w) = [M(w -wc) +M(w + wc)] Hi(w)

To recover the original signal from the VSB signal, the VSB
Signal is multiplied with cos(wct) and passed through an LPF such that original signal is recovered.

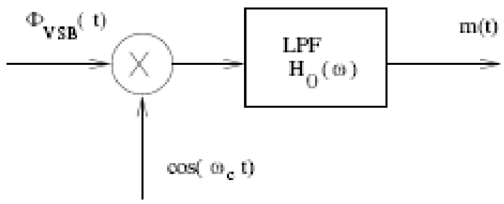


Figure 16: Block Diagram - Demodulation of VSB signal

From Figure 15 and Figure16, the criterion to choose LPF is:
M(w) = [ΦVSB(w + wc) + ΦVSB(w-wc)] H0(w)
= [Hi(w + wc) + Hi(w-wc)] .M(w).H0(w)

$$H_0(\omega) \quad = \quad \frac{1}{H_i(\omega + \omega_c) + H_i(\omega - \omega_c)}$$

Application:-
Vestigial SideBand. It is a type of signal modulation (filtering) used in the television communication industry. It is used to help remove signal redundancy in Pulse Amplitude Modulated (PAM) signals.

	RGPV QUESTIONS	Year	Marks
Q.1	Explain about VSB transmission in detail?	DEC 2013 DEC 2012	7 7
Q.2	Explain the phase discrimination method for generating SSB signals.	DEC-2012	7

UNIT-02/LECTURE-06

DETECTION OF AM SIGNALS

Demodulation of AM waves:-

There are two methods to demodulate AM signals. They are:

- Square-law detector
- Envelope detector

Square-law detector:-

A Square-law modulator requires nonlinear element and a low pass filter for extracting the desired message signal. Semi-conductor diodes and transistors are the most common nonlinear devices used for implementing square law modulators. The filtering requirement is usually satisfied by using a single or double tuned filters.

When a nonlinear element such as a diode is suitably biased and operated in a restricted portion of its characteristic curve, that is ,the signal applied to the diode is relatively weak, we find that transfer characteristic of diode-load resistor combination can be represented closely by a square law :

$V0\ (t) = a1Vi\ (t) + a2\ Vi^2\ (t)$ ……………….(i)

Where a1, a2 are constants

Now, the input voltage Vi (t) is the sum of both carrier and message signals

i.e., $Vi\ (t) = Ac\ [1+kam\ (t)]\ \cos 2\pi fct$ …………….(ii)

Substitute equation (ii) in equation (i) we get

$V0\ (t) = a1Ac\ [1+kam\ (t)]\ \cos 2\pi fct + 1/2\ a2Ac^2\ [1+2\ kam\ (t) + ka^2m^2\ (t)]\ \cos 4\pi fct]$………..(iii)

Now design the low pass filter with cutoff frequency f is equal to the required message signal bandwidth. We can remove the unwanted terms by passing this output voltage V0 (t) through the low pass filter and finally we will get required message signal.

$V0\ (t) = Ac^2\ a2\ m\ (t)$

The Fourier transform of output voltage VO (t) is given by

$VO\ (f) = Ac^2\ a2\ M\ (f)$

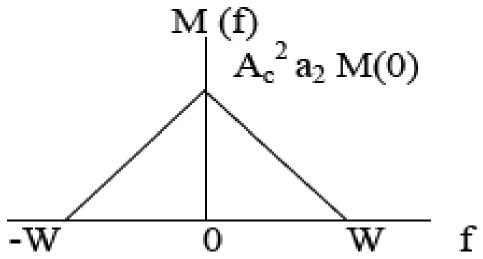


Fig 17:- Spectrum of output signal

Envelope Detector:- **(DEC 2013)(7)**

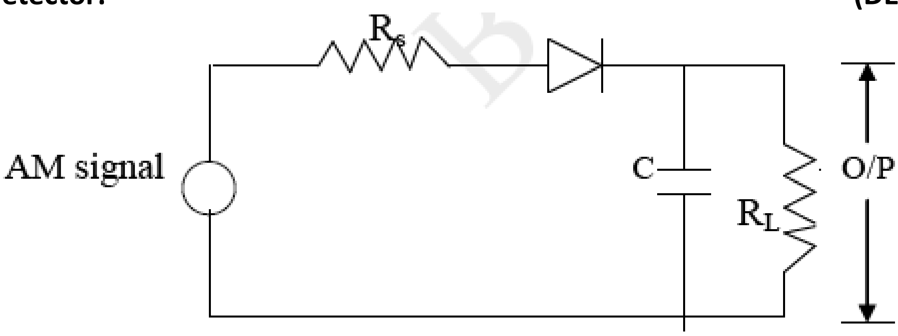


Fig 18:- Envelope Detector

Envelope detector is used to detect high level modulated levels, whereas square-law detector is used to detect low level modulated signals (i.e., below 1v). It is also based on the switching action or switching characteristics of a diode. It consists of a diode and a resistor-capacitor filter.

The operation of the envelope detector is as follows. On a positive half cycle of the input signal, the diode is forward biased and the capacitor C charges up rapidly to the peak value of the input signal. When the input signal falls below this value, the diode becomes reverse biased and the capacitor C discharges slowly through the load resistor Rl . The discharging process continues until the next positive half cycle. When the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.

The charging time constant RsC is very small when compared to the carrier period 1/fc i.e.,

$$\mathbf{RsC << 1/f_c}$$

Where Rs = internal resistance of the voltage source.
C = capacitor
fc = carrier frequency

i.e., the capacitor C charges rapidly to the peak value of the signal. The discharging time constant RC is very large when compared to the charging time constant i.e.,

$$\mathbf{1/f_c << RC << 1/W}$$

Where R = load resistance value
W = message signal bandwidth
i.e., the capacitor discharges slowly through the load resistor.

	RGPV QUESTIONS	Year	Marks
Q.1	Explain envelope detector with the help of suitable circuit diagram.	DEC 2013	7

UNIT-02/LECTURE-07

SYNCHRONOUS DETECTION TECHNIQUE,ERROR IN SYNCHCRONOUS DETECTION

Synchronous detection:- **(JUNE 2013)(7)**

The AM-SC system is used at the transmitter for shifting the baseband signal (with maximum frequency wm) to a higher carrier frequency (+-wc). This modulated signal is transmitted from the transmitter and it reaches the receiver via a propagating media. At the receiver, the original baseband signal f (t) is desired to be recovered from the modulated signal. This is achieved by retranslating the baseband signal from a higher spectrum (centered around +-wc) to the original spectrum. This process of retranslation is known as demodulation or detection. The original baseband is recovered from the modulated signal by the detection process.

A method for detecting the AM-SC signal shown in fig 20 (a),is used at the receiver end for recovery of the message signal.

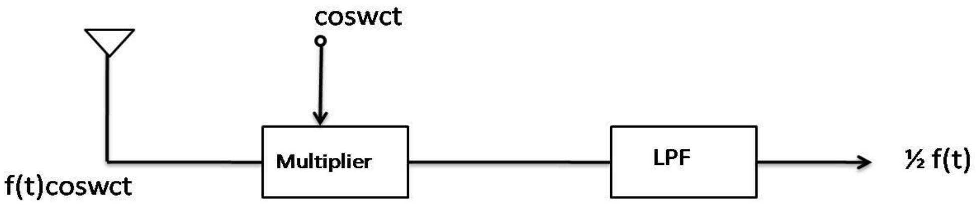


Fig 20 (a): Block Diagram

The method of retranslation is similar to that of translation. Here modulated signal f(t) coswct is multiplied with coswct and passed through a low pass filter. The signal f(t) coswct when multiplied with coswct. Yields

$$f(t)\cos wct \cos wct = f(t)\cos^2 wct$$
$$= \tfrac{1}{2} f(t)\,[1+\cos 2wct]$$
$$= \tfrac{1}{2} f(t) + \tfrac{1}{2} f(t)\cos 2wct \qquad \text{.........................(i)}$$

It is clear from right hand side of equation (i) that the term ½ f(t) cos2wct centered around (+-2wc) can be bypassed by a low pass filter, and at the output of the low pass filter original baseband signal ½ f(t) is recovered. The spectrum of $f(t)\cos^2 wct$ is obtained by taking Fourier transform of RHS of equation (i)

$$f(t)\cos^2 wct \longleftrightarrow \tfrac{1}{2} F(w) + \tfrac{1}{4}\,[\,F(w+2wc) + F(w-2wc)\,] \qquad \text{..................(ii)}$$

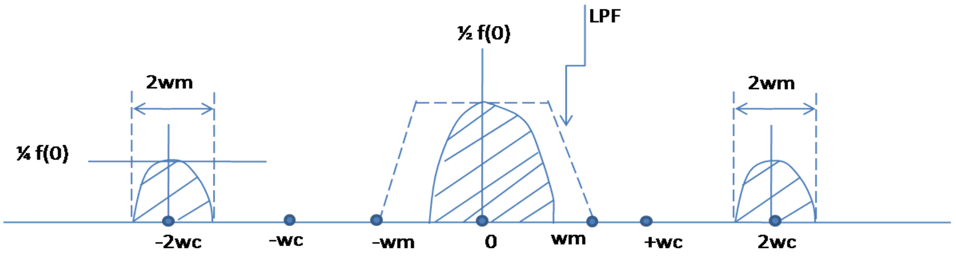


Fig 20 (b):Spectrum of f(t) coswct

The spectrum is shown in fig(b). The spectrum reveals that the original baseband signal (0 to wm) is present along with another spectrum centered around (+-2wc).when passed through a low pass filter (with a cutoff frequency wm), the original baseband signal appears at the output of the filter. The spectrum centered near (+-2wc) is not allowed to pass through low pass filter. Note that wc >> wm and 2wc is still greater than wm, and is easily filtered out. Thus the original message signal f(t) is recovered from AM-SC signal .

Effect of Phase and frequency errors in synchronous detection:-

The frequency and phase of the local oscillator signal in synchronous detection must be identical to the transmitted carrier. Any discrepancy in frequency and/or phase causes a distortion in the detected output at the receiver. Let us examine the nature of distortion Caused by phase or frequency discrepancy.

Let a modulated signal reaching the receiver the receiver signal be f(t) coswct. Assuming, a locally generated signal with frequency and phase error equal to Δw and ϕ respectively, the product of the two signals in the synchronous detector yields,

$$ed(t) = f(t)\cos w_c t \cdot \cos[(w_c + \Delta w)t + \phi]$$
$$= \tfrac{1}{2} f(t)\{\cos[(\Delta w)t + \phi] + \cos[(2w_c + \Delta w)t + \phi]\} \qquad \text{..................(iii)}$$

When this signal is passed through a low pass filter with a cut off frequency wm,the terms centered around (+-2wc) are filtered out and the filter output is given by

$$eo(t) = \tfrac{1}{2} f(t)\cos[(\Delta w)t + \phi] \qquad \text{............(iv)}$$

the baseband signal f(t) is multiplied by a slow time varying function $\cos[(\Delta w)t + \phi]$ that distorts the message signal f(t). let us consider the following special cases,

(i) When the frequency error Δw and phase error ϕ are both zero

$\Delta w = 0, \quad \phi = 0$

Equation (iv) yields,

$$eo(t) = \tfrac{1}{2} f(t)$$

i.e. there is no distortion in the detected output

(ii) When there is only the phase error ϕ ,

$\Delta w = 0, \quad \phi \neq 0$

i.e. then equation (iv) becomes

$$eo(t) = \tfrac{1}{2} f(t)\cos\phi$$

which shows that output is multiplied of $\cos\phi$ .when ϕ is time independent, there is no distortion ,rather there is only attenuation. the output is maximum when $\phi = 0$, and minimum when $\phi = 90'$.

Quadarature Null Effect:-

The detected output is zero when $\phi = 90'$.this is called a quadarature null effect, because the signal is zero when the local carrier is in phase quadrature with the transmitted carrier.

(iii) When there is only the Frequency error Δw ,

$\Delta w \neq 0, \quad \phi = 0$

i.e. then equation (iv) becomes

$$eo(t) = \tfrac{1}{2} f(t)\cos(\Delta w)t$$

Here the multiplying factor $\cos(\Delta w)t$ is time dependent and causes distortion in the detected output. the error Δw is usually small, and hence a message f(t) is multiplied by a slow varying sinusoidal signal. This is a more serious distortion. Hence frequency error should be avoided.

(iv) When both errors are non-zero

$$\Delta w \neq 0, \qquad \phi \neq 0,$$

Equation (iv) itself provides the detected output. In this case,the constant phase error provides attenuation and the frequency error causes distortion in the detected output. thus we get an attenuated and distorted output in the receiver.

	RGPV QUESTIONS	Year	Marks
Q.1	Explain the synchronous detection method of DSB-SC signals. Explain the effect of phase and frequency errors in synchronous detection.	JUNE 2013 DEC 2011	7 10

UNIT-02/LECTURE-08

ANGLE MODULATION

Angle modulation:- **(JUNE 2013)(7)**

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.
Let us consider an unmodulated carrier wave is given by

$\Phi(t) = A\ \cos[\ \omega_c t + \theta_0\ ]$

$\Phi(t) = A\ \cos\Psi$

Where *A* is the amplitude of the carrier wave and $\Psi = \omega_c t + \theta_0$ I s the total phase angle of the carrier

$\Psi = \omega_c t + \theta_0$

By differentiating the Ψ we get,the costant angular velocity ω_c

$$\frac{d\Psi}{dt} = \omega_c$$

$\frac{d\Psi}{dt}$ is constant with time for an unmodulated carrier, but in general this derivative may not be constant with time, rather it may vary with time.
This time dependent angular velocity is called instantaneous angular velocity and denoted by ω_i

$$\frac{d\Psi}{dt} = \omega_i$$

$$\Psi = \int \omega_i\ dt$$

Where ω_i is time dependent

Types of Angle Modulation:-
There are two commonly used methods of angle modulation:

1. Frequency Modulation, and
2. Phase Modulation

An important feature of FM and PM is that they can provide much better protection to the message against the channel noise as compared to the linear (amplitude) modulation schemes. Also, because of their constant amplitude nature, they can withstand nonlinear distortion and amplitude fading. The price paid to achieve these benefits is the increased bandwidth requirement; that is, the transmission bandwidth of the FM or PM signal with constant amplitude and which can provide noise immunity is much larger than 2W , where W is the highest frequency component present in the message spectrum.

Phase Modulation (PM):-

In this type of angle modulation the phase angle $\Psi(t)$ is varied linearly with a modulating signal f(t) about an unmodulated carrier $\omega_c t$. the instantaneous value of phase angle Ψ_i is equal to the phase of an unmodulated carrier $\omega_c t$ plus a time varying component proportional to f(t)

$$\Psi_i\,(t) = \omega_c t + Kp\, f(t)$$

Note that θ_0 is time independent and hence has been ignored

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

Thus the phase modulated signal is defined as

$$\Phi_{PM} = A\,\cos\Psi_i\,(t)$$

$$\Phi_{PM} = A\cos\,[\omega_c t + Kp\, f(t)]$$

Frequency Modulation (FM):-

In frequency modulation the instantaneous frequency ω_i is varied linearly with message signal, f(t) as:

$$\omega_i = \omega_c + k_f\, f(t)$$

where k_f is the frequency sensitivity of the modulator in hertz per volt.

The total phase angle of the FM wave can be obtained by

$$\Psi_i = \int \omega_i\, dt$$

$$\Psi_i = \int [\,\omega_c + k_f\, f(t)\,]dt$$

$$\Psi_i = \omega_c t + k_f \int f(t)\; dt$$

and thus the frequency modulated signal is given by

$$\Phi_{FM} = A\,\cos\Psi_i$$

$$\Phi_{FM} = A\,\cos\,\left[\omega_c t + k_f \int f(t)\; dt\right]$$

If we assume that the phase angle of the carrier at t=0 is zero, then the limit of integration will be 0 to t, represented by

$$\Phi_{FM} = A\,\cos\,\left[\omega_c t + k_f \int_0^t f(t)\; dt\right]$$

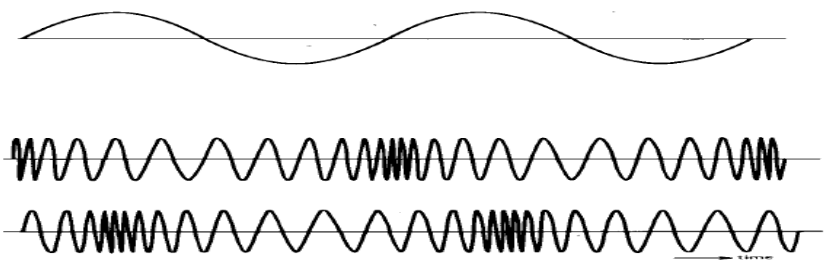


Fig (1):-PM and FM waveforms with a message signal

Relation between Frequency Modulation and 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 fig-5.2(a).

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 fig-5.2(b).

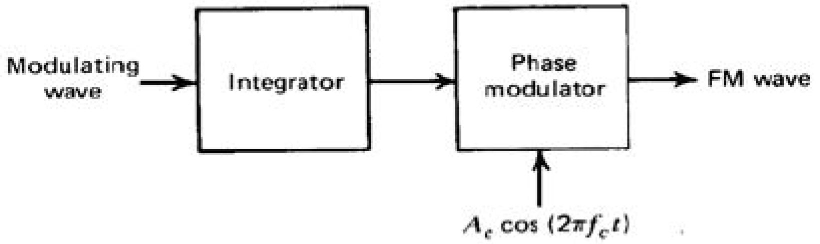


Fig: 5.2 (a)

$$\Phi_{FM} = A \cos \left[\omega_c t + k_f \int_0^t f(t) \ dt \right]$$

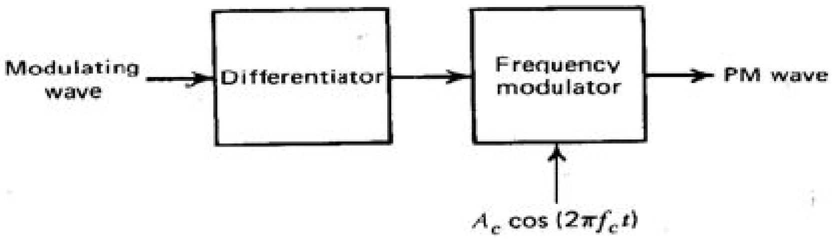


Fig: 5.2 (b)

$$\Phi_{PM} = A \cos \left[\omega_c t + Kp \ f(t) \right]$$

Fig: 5.2 – Scheme for generation of FM and PM Waveforms

Frequency deviation:-

The instantaneous frequency of FM signal varies with time. the maximum change in instantaneous frequency from the average i.e. ω_c is known as frequency deviation

$\omega_i = \omega_c + k_f \ f(t)$

The maximum change in ω_i from the average value will depend on the magnitude and sign of $k_f f(t)$.

The frequency deviation $\Delta\omega$ denoted by will be either positive or negative depending on the sign of $k_f f(t)$.

$$\Delta\omega = |k_f f(t)|\ max$$

Example:-

A single tone modulating signal $f(t) = E_m cosw_m\ t$ frequency modulates a carrier $Acosw_c\ t$,Find the frequency deviation.

Solution:-

The deviation $\Delta\omega = |k_f f(t)|\ max$

$\Delta\omega = |k_f E_m cosw_m\ t|\ max$

Hence the maximum magnitude of $cosw_m\ t = 1$,the deviation is

$\Delta\omega = k_f E_m$

And the frequency sensitivity is

$k_f = \frac{\Delta\omega}{E_m}$ radian per volt

Types of frequency modulation:-

The bandwidth of an FM signal depends on the deviation $k_f f(t)$. When the deviation is high,the bandwidth will be large ,and vice versa.

Thus for a given f(t) ,the deviation and hence bandwidth will depend on frequency sensitivity k_f .

If k_f is too small then the bandwidth will be narrow and vice versa. thus depending on the value of k_f,we can divide FM in to two categories,

(i) Narrowband FM (NBFM) :- When k_f is small the bandwidth of FM is narrow. The bandwidth of a narrow band FM is same as that of AM, which is twice the baseband.

(ii) Wideband FM (WBFM) :- When k_f has an appreciable value, then the FM signal has a wide bandwidth. The bandwidth of a wideband FM is too large; ideally infinite

	RGPV QUESTIONS	Year	Marks
Q.1	What is angle modulation? How FM signal can be generated with PM signal? Discuss in detail	JUNE 2013	7

UNIT-02/LECTURE-09

NARROWBAND FM AND WIDEBAND FM

NARROWBAND FM:- **(JUNE 2013)(7)**

The general expression for FM

$$\Phi_{FM} = A\cos\left[\omega_c t + k_f \int_0^t f(t)\; dt\right]$$

$$\int f(t)dt = g(t)$$

$$\Phi_{FM} = A\cos\left[\omega_c t + k_f\, g(t)\right]$$

in the phasor form (considered only real part)

$$\widetilde{\Phi_{FM}} = A\; e^{j[\omega_c t + k_f\, g(t)]}$$

$$\widetilde{\Phi_{FM}} = A\left[e^{j\omega_c t} . e^{jk_f\, g(t)}\right]$$

$$e^{jk_f\, g(t)} = \cos\{k_f\, g(t)\} + j\sin\{k_f\, g(t)\}$$

For a narrowband FM,

$k_f f(t) << 1$ for all vaues of t.

$\cos\{k_f\, g(t)\} \cong 1$

$\sin\{k_f\, g(t)\} \cong k_f\, g(t)$

$e^{jk_f\, g(t)} \cong 1 + j\, k_f\, g(t)$

And FM phasor expression becomes

$$\widetilde{\Phi_{FM}} = A\, e^{j\omega_c t} .[1 + j\, k_f\, g(t)]$$

$$\widetilde{\Phi_{FM}} = A[1 + j\, k_f\, g(t)]\,[coswct + jsinwct]$$

$$\widetilde{\Phi_{FM}} = A\,[coswct + jsinwct + j\, k_f\, g(t)coswct + j^2 k_f\, g(t)sinwct]$$

$$\widetilde{\Phi_{FM}} = A\,[coswct + jsinwct + j\, k_f\, g(t)coswct - k_f\, g(t)sinwct]$$

The FM signal is the real part of its phasor representation

$$\Phi_{FM}(t) \cong Re\,[\widetilde{\Phi_{FM}}(t)] = [A\, coswct - Ak_f\, g(t)sinwct]$$

Similarly, the narrowband PM is given by,

$$\Phi_{PM}(t) \cong [A\, coswct - A\, k_p\, f(t)sinwct]$$

The expression for FM and PM are very much similar to the expression of the AM signal, with only a slight modification.
Hence, the bandwidth of narrowband FM is same as that of the AM. it can be seen that g(t) and f(t) have the same bandwidth.

Example :-

A carrier $Acoswct$ is frequency modulated by a single tone modulating signal $f(t) = E_m \, cos_{wm} t$. find

(a) An expression for FM wave,and

(b) An expression for a narrowband FM.

Solution:

(a) The modulating signal is given by

$f(t) = E_m \, cos_{wm} t$

The instantaneous frequency of the resulting modulated signal can be obtained

$\omega_i = \omega_c + k_f \, f(t)$

$\omega_i = \omega_c + k_f \, E_m \, cos_{wm} t$.

We find that $\Delta\omega = k_f E_m$,the frequency deviation

$\omega_i = \omega_c + \Delta\omega cos_{wm} t$.

The phase angle of the modulated wave is obtained by integrating

$$\Psi_i = \int \omega_i \, dt$$

$$\Psi_i = \int [\, \omega_c + \Delta\omega cos_{wm} t \,] \; dt$$

$$\Psi_i = \omega_c t + \frac{\Delta\omega}{w_m} sinw_m \, t$$

$$\frac{\Delta\omega}{w_m} = m_f$$

$$\frac{K_f \, E_m}{w_m} = m_f$$

$$\Psi_i = \omega_c t + m_f \, sinw_m \, t$$

The term m_f is known as the modulation index of the FM wave. it is defined as “the ratio of frequency deviation to the modulating frequency”

The FM signal is given by

$\Phi_{FM} = A \, \cos \Psi_i$

$\Phi_{FM}(t) = A \, \cos[\omega_c t + m_f \, sinw_m \, t]$

This is the expression for a single tone Fm.

The maximum change in total phase angle from the centre phase $\omega_c t$ is known as phase deviation,in FM denoted by $\Delta\theta$.

$$\Delta\theta = m_f$$

Thus a phase deviation equal to m_f is produced in FM.

$$\Delta\theta = \frac{\Delta\omega}{w_m} = \frac{K_f \, E_m}{w_m} = m_f$$

The modulation index m_f decides whether an FM wave is narrowband or a wideband because it is directly proportional to frequency deviation $\Delta\omega$.

$m_f = 0.5$it is the transition point between a narrowband and wideband FM.

If $m_f < 0.5$ then FM is a narrowband, otherwise it is a wideband.

(b) The narrowband FM is defined as

$$\Phi_{FM}(t) = [A\, coswct - Ak_f\, g(t) sinwct]$$

$$g(t) = \int f(t)dt$$

$$f(t) = E_m\, cos_{wm} t$$

$$g(t) = \int E_m\, cos_{wm} t\; dt$$

$$g(t) = \frac{E_m}{wm}\, sin_{wm} t$$

By substituting the value of g(t) in the expression of FM,we get

$$\Phi_{FM}(t) = A\, coswct - Ak_f \frac{E_m}{wm}\, sin_{wm} t\; sinwct$$

Since

$$\frac{K_f\, E_m}{w_m} = m_f$$

so

$$\Phi_{FM}(t) = A\, coswct - Am_f\, sin_{wm} t\; sinwct$$

This is the desired expression for a narrowband single tone FM.

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WIDEBAND FM:- **(JUNE 2012)(7)**

When m_f is large ,the FM produces a large number of sidebands and the bandwidth of FM is quite large. such systems are called wideband FM.

Example :-

A sinusoidal wave of amplitude 10volts and frequency of 1 kHz is applied to an FM generator that has a frequency sensitivity constant of 40 Hz/volt. Determine the frequency deviation and modulating index.

Solution:

Message signal amplitude Am = 10 volts
Frequency fm = 1000 Hz
frequency sensitivity k f = 40 Hz/volt

Frequency deviation $\Delta f = kf\ Am$

$\Delta f = 40\ x\ 10$

$\Delta f = 400\ Hz$

Modulation index

$$m_f = \frac{\Delta f}{fm}$$

$$m_f = \frac{400}{1000}$$

$m_f = 0.4$ (indicates a narrow band FM)

****

Example-:A modulating signal m(t) =10 Cos(10000πt) modulates a carrier signal, A_c Cos($2\pi f_c t$). Find the frequency deviation and modulation index of the resulting FM signal. Use
k_f = 5kHz/volt.

Solution:

Message signal amplitude Am = 10 volts
Cos (10000πt) = Cos(2πfmt)
Cos (2 x 5000 πt) = Cos(2πfmt)
So Frequency fm = 5000 Hz
frequency sensitivity k f = 5 kHz/volt
Frequency deviation

$$\Delta f = kf\ Am$$
$$\Delta f = 5\ x\ 1000\ x\ 10$$
$$\Delta f = 50\ kHz$$

Modulation index

$$m_f = \frac{\Delta f}{fm}$$

$$m_f = \frac{50\ x\ 1000}{5000}$$

$m_f = 10$ (indicates wide band FM)

****

Example:-
A single tone modulating signal $\cos 15\pi 10^3 t$ frequency modulates a carrier of 10mhz and produces a frequency deviation of 75 kHz.
Find:

(i) The modulation index.

(ii) Phase deviation produced in the fm wave.

(iii) if another modulating signal produces a modulation index of 100 while maintaining the same deviation,find the frequency and amplitude of the modulating signal assume kf = 15 khz per volt.

Solution:-

Given Δf = 75 kHz

Cos ($15\pi 10^3$t) = Cos(2πfmt)

$15\pi 10^3 = 2\pi fm$

So Frequency

$$fm = \frac{15 \ x \ 10^3}{2}$$

$$fm = 7.5 \ kHz$$

(i) The modulation index.

$$\beta = mf = \frac{\Delta f}{fm}$$

$$mf = \frac{75 \ x \ 10^3}{7.5 \ x \ 10^3}$$

$$mf = 10$$

(ii) Phase deviation produced in the fm wave.

The phase deviation in FM is equal to the modulation index

$$\Delta\theta = mf = 10 \, rad$$

(iii) $\Delta\theta = mf = \frac{\Delta f}{fm}$

If mf = 100 and Δf = 75kHz

Now

$$100 = \frac{75 \, x \ 10^3}{fm}$$

$$fm = \frac{75 \, x \ 10^3}{100}$$

$$fm = 750 \ Hz$$

As we know

$$\Delta f = kf \ Am$$

$$Am = \frac{\Delta f}{kf}$$

$$Am = \frac{75 \ x \ 10^3}{15 \ x \ 10^3}$$

$$Am = 5 \ volt$$

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	RGPV QUESTIONS	Year	Marks
Q.1	What do you mean by FM? Derive an expression for NBFM?	JUNE 2013 DEC 2012	7 7
Q.2	Discuss the effect of variation in mf on the spectrum of FM	JUNE 2012	7

	wave. Also explain NBFM and WBFM.		
Q.3	Derive the expression of wide band FM (WBFM).	DEC 2011	10
Q.4	Derive the expression for FM & NBFM along with phasor diagram.	DEC 2010	10

UNIT-02/LECTURE-10

Transmission Bandwidth of FM waves:-

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.

Carson's Rule:-

An empirical formula for the bandwidth of a single tone wideband FM is given by carson's rule. According to this rule, the Fm bandwidth is given by

$$BW = 2(\Delta\omega + w_m\,)$$

$$BW = 2\ \Delta\omega\ (1\ +\ \frac{w_m}{\Delta\omega}$$

Since $\frac{\Delta\omega}{w_m} = m_f$

So $\frac{w_m}{\Delta\omega} = \frac{1}{m_f}$

$BW = 2\ \Delta\omega\ (1\ +\ \frac{1}{m_f})$ radians

Or

$BW = 2\ \Delta f\ (1\ +\ \frac{1}{m_f})$ Hz

(i) When

$\Delta\omega\ \ll\ w_m$ (narrowband FM) i.e. $m_f\ \ll\ 1$

Then

$BW = 2\ w_m$

Which is equivalent to AM

(ii) When

$\Delta\omega\ \gg\ w_m$ (wideband FM) i.e. $m_f\ \gg\ 1$

Then

$BW = 2\ \Delta\omega$

DEVIATION RATIO:-

$$D = \frac{\text{Peak frequency deviation corresponding to the maximum possible amplitude of } f(t)}{\text{the maximum frequency component present in the modulating signal } f(t)}$$

$$D = \frac{\Delta w}{w_m}$$

Example:-

A carrier Acoswct is modulated by a signal f(t)= 2cos 10^4 2πt +5 cos10^3 2πt + 3 cos10^4 4πt Find the bandwidth of the fm signal by using Carson's rule. Assume Kf=15 x 10^3 Hz per volt. Also find modulation index m_f.

Solution:-

The maximum frequency component in f (t) is 20 kHz.

The second term in f(t) has the maximum amplitude i.e. Em= 5 volts

Therefore the frequency deviation Δf is given by,

And devation ratio is given by

$$m_f = \frac{\Delta f}{w} = \frac{\Delta f}{fm}$$

$$m_f = \frac{75 \ X \ 10^3}{20 \ X \ 10^3}$$

$$m_f = \frac{7.5}{2}$$

And the bandwidth is given as

$$BW = 2\,\Delta f\,(1 + \frac{1}{m_f})$$

$$B = 2\left(\frac{2}{7.5} + 1\right)75$$

$$B = 190 \ kHz$$

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SOME REMARKS ABOUT PHASE MODULATION:-

The total phase angle of the PM signal is given by

$$\Psi_i\,(t) = \omega_c t + Kp\, f(t)$$

For a single tone modulating signal

$f(t) = E_m \, cos_{wm} t$

Hence

$$\Psi_i\,(t) = \omega_c t + Kp\, E_m \, cos_{wm} t$$

the maximum departure in the phase is $Kp\ E_m$. This is known as phase deviation denoted by θd . thus $\theta_d = Kp\ E_m$ and the expression for the PM wave is

$$\Phi_{PM} = A\ \cos\Psi_i\,(t) = A cos[\omega_c t + \theta_d cos_{wm} t]$$

The instantaneous frequency corresponding to Ψ_i is given by

$$\omega_{i=}\frac{d\Psi}{dt}= \omega_c - KpE_m\ \omega_m sin_{wm}t$$

The maximum departure in the frequency from ω_c is $KpE_m\ \omega_m$ .Therefore ,a frequency deviation produced in PM is given as

$(\Delta w)_{PM} = Kp\ E_m\, w_m$
Which is independent on the modulating frequency w_m.
The frequency deviation in FM is,

$(\Delta w)_{FM} = Kf\ E_m$.
There fore,for an equivalent bandwidth in PM and FM

$Kf\ E_m = Kp\ E_m\, w_m$
$Kf = Kp\ w_m$

BANDWIDTH OF PM:-

The PM bandwidth is given by carson's rule
$(BW)_{PM} \cong 2(\Delta w) = 2Kp\ E_m\, w_m$

The phase modulatin index m_p is the same as the deviation θ_d and is given by
$m_p = Kp\ E_m = \theta_d$

Example:-

A modulating signal 5cos2π15x10^{3}t,angle modulates carrier A coswct:
(i) Find the modulation index and the bandwidth for fm and pm system.
(ii) Determine the change in the bandwidth and the modulation index for both fm and pm ,if fm is reduced to 5 kHz.

Solution:-

Given Am =5 , fm = 15 kHz
I)

FM system

Frequency deviation
$\Delta f = kf\ Am$
Assume kf = kp = 15 kHz/volt
So
$\Delta f = 15\ x\ 10^3\, x\ 5$
$\Delta f = 75\ kHz$

Therefore, modulation index

$$mf = \frac{\Delta f}{fm}$$
$$mf = \frac{75}{15}$$
$$mf = 5$$

$Bandwidth = 2(mf + 1)fm$
$Bandwidth = 2(5 + 1)15$
$Bandwidth = 2x\ 6\ x15$
$Bandwidth = 180\ kHz$

PM system
Frequency deviation
$\Delta f = kp\ Am\ fm$
$\Delta f = 15\ x\ \ 10^3\ \ x\ 5\ x15\ x\ \ 10^3$
$\Delta f = 1125\ \ MHz$

modulation index
$mp = \ kpAm$
$mp = 15\ x\ \ 10^3\ \ x\ 5$
$mp = 75000$
Corresponding band width
$Bandwidth = 2\ \Delta f$ since Δf is so much greater than fm
$Bandwidth = 2\ X\ 1125\ MHz$
$Bandwidth = 2250\ MHz$

The band width is quite large as compared to FM.this is because the Modulation index in PM is quite large

(i) Now, if fm = 5kHz

For FM: The deviation Δf is independent of fm, and remains 75 KHz.

$$mf = \frac{75}{5}$$

$mf = 15$

$Bandwidth = 2(mf + 1)fm$
$Bandwidth = 2(15 + 1)5$
$Bandwidth = 2x\ 16\ x\ 5$
$Bandwidth = 160\ kHz$
Thus in FM the modulation index changes considerably with a change in the modulating frequency, but the bandwidth changes only slightly.
For PM:
Deviation Δf is dependent on fm and is given by
$\Delta f = kp\ Am\ fm$
$\Delta f = 15\ x\ \ 10^3\ x\ \ 5\ x\ 5\ x\ \ 10^3$
$\Delta f = 375\ MHz$
Hence
$Bandwidth = 2\ \Delta f$ since Δf is so much greater than fm $Bandwidth = 2\ x\ 375\ MHz$
$Bandwidth = 750\ MHz$

The modulation index is independent of fm,so

$mp = kpAm$

$mp = 15\ x\ 10^3\ x\ 5$

$mp = 75000$

$mp = 75\ kHz$

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