Analog & Digital Communication — Avijit

MODULE I

Analog Communication: Block diagram of a communication system. Need for analog modulation. Amplitude modulation. Equation and spectrum of AM signal; DSB-SC and SSB systems. Block diagram of SSB transmitter and receiver. Frequency and phase modulation. Narrow and wide band FM and their spectra. FM transmitter and receiver.

Introduction to Communication

The term communication refers to sending, receiving and processing of information by electronic means. Communication is the process of passing or transmitting information from one point to another.Communication is the process of establishing connection or link between two points for information exchange or Communication is simply the basic process of exchanging information.

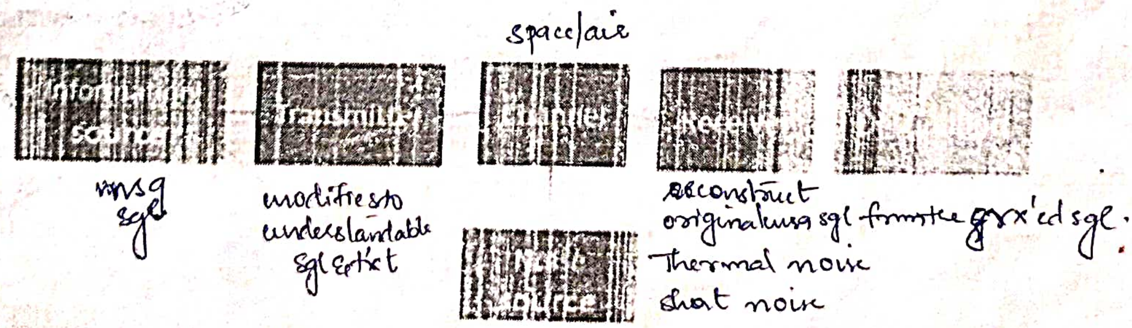
The electronic system used for conveying the information from the source to destination is called the communication system.

Typical examples of communication systems are line telephony and line telegraphy, radio telephony and radio telegraphy, radio broadcasting, mobile communication, computer communication, radar communication, television broadcasting etc.

Elements of a communication system

The fundamental components of any communication system are,

- Source of information or message signal
- Transmitter: The device which sends the signal
- Channel: The medium on which the signal is carried.
- Receiver: The device that receives the transmitted signal from the channel
- Destination: Final block which receives the message.



Information Source → Transmitter → Channel → Receiver → Destination

Noise Source

Source

The source is the location from which the sender sends the physical message. It could be a voice, pictures, text, video, or something else. The communication system should now deliver those messages to their intended recipient. A transducer is a device which converts physical quantities into electrical quantities or electrical quantities into physical quantities.The electrical version of the message signal is the actual input to the transmitter block of the communication system.

Transmitter

The objective of the transmitter block is to collect the incoming message signal and modify it in a suitable fashion (if needed), such that it can be transmitted via the chosen channel to the receiving point. {amplification, filtering, modulation}

A transmitter performs a variety of critical functions. It modulates the signal with the help of a carrier signal. It boosts the signal's strength to allow for long-distance communication. It is necessary to convert the signal. For example, if the signal is to be transmitted via electrical conductors or lines, no conversion is required; simply amplification is sufficient. However, if the signal is to be sent through space, the transmitter will convert the electrical signals into radio waves. The functionality of the transmitter block is mainly decided by the type or nature of the channel chosen for communication.

Channel

Channel is the physical medium which connects the transmitter with that of the receiver.The physical medium includes copper wire, coaxial cable, fibre optic cable, wave guide and free space or atmosphere. The choice of a particular channel depends on the feasibility and also the purpose of the communication system.

Receiver

The receiver block receives the incoming modified version of the message signal from the channel and processes it to recreate the original (non-electrical) form of the message signal. There are a great variety of receivers in communication systems, depending on the processing required to recreate the original message signal and also final presentation of the message to the destination. A receiver's functions are to receive the signal, remove noise or distortion, demodulate if necessary convert, and amplify.

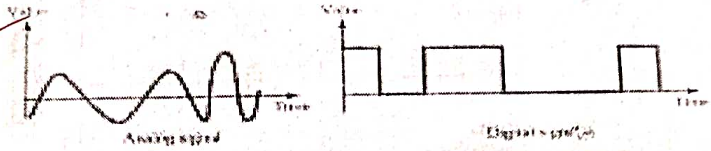
Destination

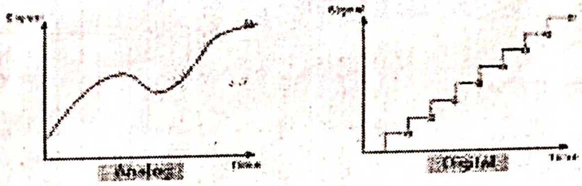
The destination is the final block in the communication system which receives the message signal and processes it to comprehend the information present in it.

Analog & Digital Signals

The analog signals were used in many systems to produce signals to carry information. These signals are continuous in both values and time. The use of analog signals has declined with the arrival of digital signals. In short, to understand analog signals – all signals that are natural or come naturally are analog signals.

Unlike analog signals, digital signals are not continuous, but signals are discrete in value and time. These signals are represented by binary numbers and consist of different voltage values.





Comparison between Analog and Digital Signals

Analog Signals	Digital Signals
Continuous signals	Discrete signals
Represented by sine waves	Represented by square waves
Human voice, natural sound, analog electronic devices are a few examples	Computers, optical drives, and other electronic devices
Continuous range of values	Discontinuous values
Records sound waves as they are	Converts into a binary waveform.
Only used in analog devices.	Suited for digital electronics like computers, mobiles and more.

Analog & Digital System

Digital as well as Analog System, both are used to transmit signals from one place to another like audio/video. Digital system uses binary format as 0 and 1 whereas the analog system uses electronic pulses with varying magnitude to send data.

Following are some of the important differences between Digital System and Analog System.

Sr. No.	Key	Digital System	Analog System
1	Signal Type	Digital System uses discrete signals as on/off representing binary format. Off is 0, On is 1.	Analog System uses continous signals with varying magnitude.
2	Wave Type	Digital System uses square waves.	Analog system uses sine waves.
3	Technology	Digital system first transform the analog waves to limited set of numbers and then record them as digital square waves.	Analog systems records the physical waveforms as they are originally generated.
4	Transmission	Digital transmission is easy and can be made noise proof with no loss at all.	Analog systems are affected badly by noise during transmission.
5	Flexibility	Digital system hardware can be easily modulated as per the requirements.	Analog system's hardwares are not flexible.

6	Bandwidth	Digital transmission needs more bandwidth to carry same information.	Analog tranmission requires less bandwidth.
7	Memory	Digital data is stored in form of bits.	Analog data is stored in form of waveform signals.
8	Power requirement	Digital system needs low power as compare to its analog counterpart.	Analog systems consume more power than digital systems.
9	Best suited for	Digital system are good for computing and digital electronics.	Analog systems are good for audio/video recordings.
10	Cost	Digital system are costly.	Analog systems are cheap.
11	Example	Digital system are: Computer, CD, DVD.	Analog systems are: Analog electronics, voice radio using AM frequency

Modulation:

A message carrying a signal has to get transmitted over a distance and for it to establish a reliable communication, it needs to take the help of a high frequency signal which should not affect the original characteristics of the message signal. The characteristics of the message signal, if changed, the message contained in it also alters. Hence, it is a must to take care of the message signal. A high frequency signal can travel up to a longer distance, without getting affected by external disturbances. We take the help of such a high frequency signal which is called a carrier signal to transmit our message signal. Such a process is simply called Modulation.

msg sgl (LF sgl) is passed to a carrier sgl (HF sgl) and tx'ed/modulated sgl is tx'ed to the destination. ↳ modulation

The destination extracts msg sgl from carrier sgl. → demodulation

Info

Modulation is the process of changing the parameters of the carrier signal, in accordance with the instantaneous values of the modulating signal.

Need for Modulation

- Reduction in the height of antenna
- Avoids mixing of signals
- Increases the range of communication
- Multiplexing is possible
- Improves quality of reception

Reduction in the height of antenna

For the transmission of radio signals, the antenna height must be multiple of λ/4 ,where λ is the wavelength .

$$\lambda = c/f$$

where c : is the velocity of light

f : is the frequency of the signal to be transmitted

The minimum antenna height required to transmit a baseband signal of f= 10 kHz is calculated as follows :

$$\text{Minimum antenna height} = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10 \times 10^3} = 7500 \text{ meters i.e. } 7.5 \text{ km}$$

The antenna of this height is practically impossible to install .

Now, let us consider a modulated signal at f = 1 MHz . The minimum antenna height is given by,

$$\text{Minimum antenna height} = \frac{\lambda}{4} = \frac{c}{4f} = \frac{3 \times 10^8}{4 \times 10 \times 10^6} = 75 \text{ meters}$$

This antenna can be easily installed practically . Thus, modulation reduces the height of the antenna .

Avoids mixing of signals

If the baseband sound signals are transmitted without using the modulation by more than one transmitter, then all the signals will be in the same frequency range i.e. 0 to 20 kHz . Therefore, all the signals get mixed together and a receiver can not separate them from each other . Hence, if each baseband sound signal is used to modulate a different carrier then they will occupy different slots in the frequency domain (different channels). Thus, modulation avoids mixing of signals .

Increase the Range of Communication

The frequency of baseband signals is low, and the low frequency signals can not travel long distances when they are transmitted . They get heavily attenuated . The attenuation reduces with increase in frequency of the transmitted signal, and they travel longer distances . The modulation process increases the frequency of the signal to be transmitted . Therefore, it increases the range of communication.

Multiplexing is possible

Multiplexing is a process in which two or more signals can be transmitted over the same communication channel simultaneously . This is possible only with modulation. The multiplexing allows the same channel to be used by many signals . Hence, many TV channels can use the same frequency range, without getting mixed with each other or different frequency signals can be transmitted at the same time .

Improves Quality of Reception

With frequency modulation (FM) and digital communication techniques such as PCM, the effect of noise is reduced to a great extent . This improves the quality of reception .

General Terms Used

Amplitude modulation : Amplitude Modulation is defined as changing the amplitude of the carrier signal with respect to the instantaneous change in message signal.

Frequency modulation : Frequency Modulation is the changing frequency of the carrier signal with respect to the instantaneous change in message signal.

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

Deviation ratio :Deviation ratio is the worst case modulation index and is equal to the maximum peak frequency deviation divided by the maximum modulating signal frequency. Mathematically the deviation ratio is DR= f (max)/fm(max).

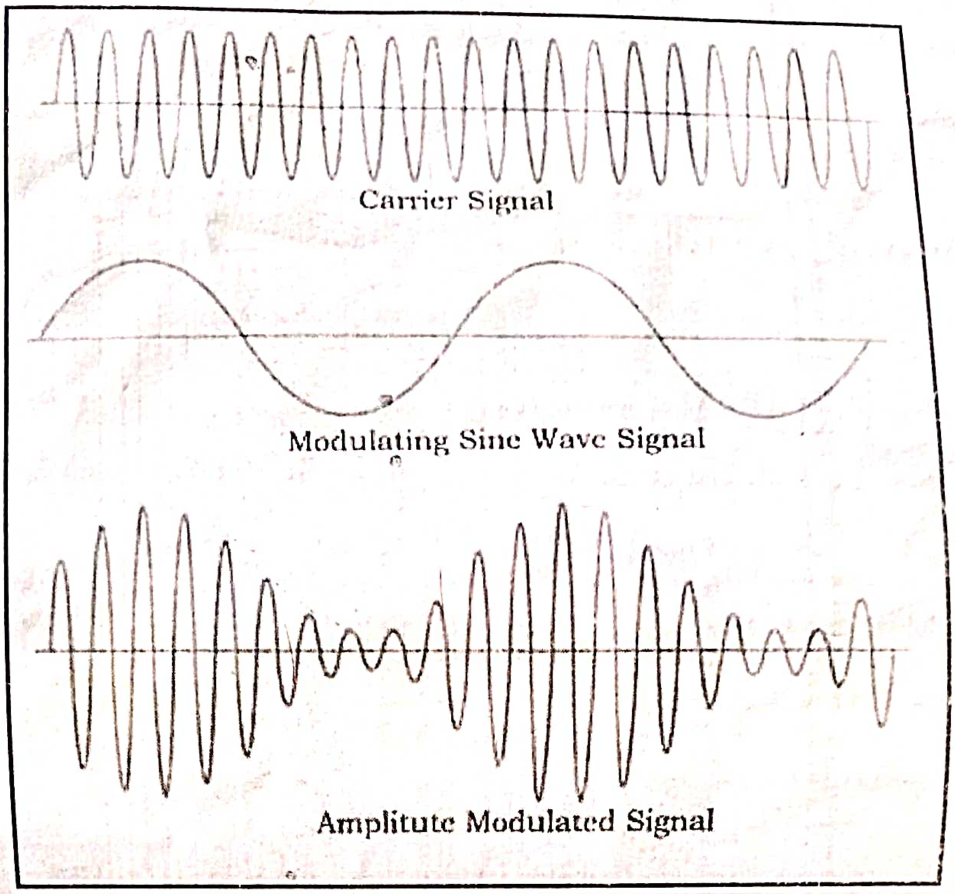
Carson's rule: Carson's rule states that the bandwidth required to transmit an angle modulated wave is twice the sum of the peak frequency deviation and the highest modulating signal frequency. Mathematically Carson's rule is B=2(f +fm) Hz.

Modulation index : It is defined as the ratio of amplitude of the message signal to the amplitude of the carrier signal. m=Em/Ec.

Percentage modulation : It is the percentage change in the amplitude of the output wave when the carrier is acted on by a modulating signal. M=(Em/Ec)*100

Amplitude Modulation

Amplitude Modulation ~~Amplitude Modulation~~ is the changing the amplitude of the carrier signal with respect to the instantaneous change in message signal. The amplitude modulated wave form, its envelope and its frequency spectrum and bandwidth.
Figure below shows the waveforms of AM waveform.



The first figure shows the modulating wave, which is the message signal. The next one is the carrier wave, which is a high frequency signal and contains no information. The last one is the resultant modulated wave. It can be observed that the positive and negative peaks of the carrier wave are interconnected with an imaginary line. This line helps recreating the exact shape of the modulating signal. This imaginary line on the carrier wave is called as Envelope. It is the same as that of the message signal.

AM is inexpensive, low quality form of modulation that is used for commercial broadcasting of both audio and video signals.

The carrier wave is expressed as,

$$e_c(t) = E_{cmax} \sin(2\pi f_c t + \phi_c) \quad \text{--- (1)}$$

The message wave is expressed as,

$$e_m(t) = E_{mmax} \sin(2\pi f_m t + \phi_m) \quad \text{--- (2)}$$

In AM, a v/g propotional to the modulating signal is added to the carrier amplitude and the added component of voltage be represented in functional notation as $e_m(t)$, then the modulated carrier waves is given by,

$$e(t) = \left[\left(E_{cmax} + e_m(t) \right) \cos \left(2\pi f_c t + \phi_c \right) \right] \quad \text{——— (3)}$$

The term $[E_{cmax} + e_m(t)]$ describes the envelope of the modulated wave.

Advantages of AM

→ Simple to Implement.

→ Can be demodulated using a circuit consisting of very few components.

→ AM receivers are very cheap as no specialised components are needed.

Disadvantages of AM

→ It is not efficient interms of its power usage.

→ It is inefficient interms of bandwidth.

→ It is sensitive to noise.

Applications of AM

→ Broadcast transmissions

→ Air band radio

Mathematical Expressions

Following are the mathematical expressions for these waves.

Let the modulating signal, $e_m = E_m \cos \omega_m t$

carrier signal, $e_c = E_c \cos \omega_c t$

where,

E_m = Maximum amplitude of message signal.

E_c = " " " carrier ".

ω_m = Frequency of modulating signal, $\omega_m = 2\pi f_m$

ω_c = Frequency of carrier signal, $\omega_c = 2\pi f_c$

The amplitude modulated wave,

$$E_{AM} = E_c + e_m = E_c + E_m \cos \omega_m t \quad \text{——— (4)}$$

$e_m(t)$

The instantaneous value of AM wave is,

$$e_{AM} = E_{AM} \cos \omega_c t$$
$$= [E_c + E_m \cos \omega_m t] \cos \omega_c t$$
$$= E_c \left[1 + \frac{E_m}{E_c} \cos \omega_m t\right] \cos \omega_c t$$
$$= E_c [1 + m \cos \omega_m t] \cos \omega_c t$$

{where, $\frac{E_m}{E_c} = m$ = modulation index of AM}

$$e_{AM} = E_c [1 + m \cos 2\pi f_m t] \cos 2\pi f_c t \quad \text{——— (5)}$$

Modulation Index of AM

A carrier wave, after being modulated, if the modulated level is calculated, then such an attempt is called Modulation Index or Modulation Depth. It states the level of modulation that a carrier wave undergoes.

For sinusoidal AM, the modulating waveform is of the form

$$e_m(t) = E_{mmax} \cos(2\pi f_m t + \phi_m) \cong E_m \cos \omega_m t \quad \text{——— (6)}$$

The carrier is expressed as;

$$e_c(t) = E_{cmax} \cos(2\pi f_c t + \phi_c) \cong E_c \cos \omega_c t \quad \text{——— (7)}$$

AM is independent of these phase angles ϕ_m & ϕ_c which may therefore be set equal to zero to simplify the algebra and trignometry used in the analysis.

Modulation Index is the ratio of amplitude of message s/g to carrier. It is also called modulation factor, modulation coefficient or the degree of modulation.

For AM, the value of m lies between 0 & 1.

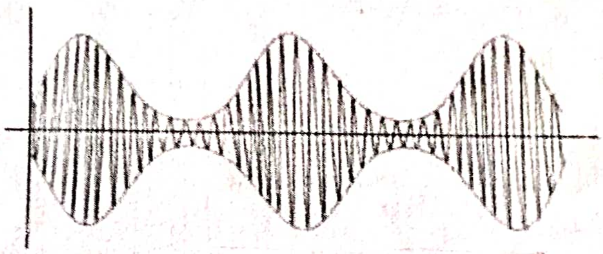
$$\text{Modulation Index, } m = \frac{E_m}{E_c} \quad \text{——— (8)}$$

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \quad \text{——— (9)}$$

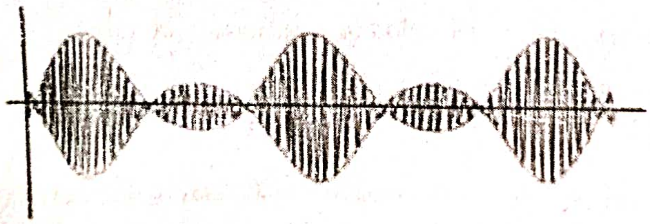
Percentage of modulation index,

$$\% m = m \times 100 = \frac{E_m}{E_c} \times 100 \quad \text{——— (10)}$$

The modulation index or modulation depth is often denoted in percentage called as Percentage of Modulation. We will get the percentage of modulation, just by multiplying the modulation index value with 100. For a perfect modulation, the value of modulation index should be 1, which implies the percentage of modulation should be 100%. For instance, if this value is less than 1, i.e., the modulation index is 0.5, then the modulated output would look like the following figure. It is called Under-modulation. Such a wave is called an under-modulated wave.

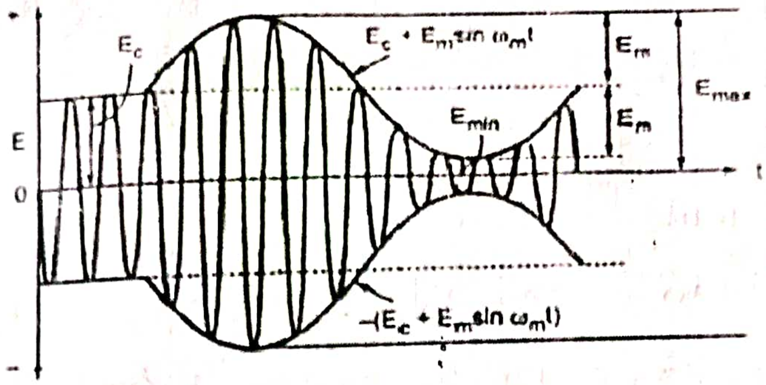


If the value of the modulation index is greater than 1, i.e., 1.5 or so, then the wave will be an over-modulated wave.



As the value of the modulation index increases, the carrier experiences a 180o phase reversal, which causes additional sidebands and hence, the wave gets distorted. Such an over modulated wave causes interference, which cannot be eliminated.

Calculation of modulation index from AM waveform



The above waveform represents the AM Wave.

~~The maximum amplitude of message signal is,~~

We know that, $m = \frac{E_m}{E_c}$, with this relation the modulation index can be calculated.

$$E_m = \frac{E_{max} - E_{min}}{2} \quad \text{--- (11)} \quad \& \quad E_c = E_{max} - E_m \quad \text{--- (12)}$$

By putting the value of E_m in E_c,

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

$$= \frac{E_{max} + E_{min}}{2} \quad \text{--- (13)}$$

Taking the ratio of E_m and E_c,

$$\text{modulation index, } m = \frac{E_m}{E_c} = \frac{\frac{E_{max} - E_{min}}{2}}{\frac{E_{max} + E_{min}}{2}}$$

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

Frequency spectrum

Although the modulated waveform contains two frequencies, the modulation process generates new frequencies that are the sum and differences of these frequencies.

We know that,

$$e_{AM} = E_c\left[1 + m\cos 2\pi f_m t\right]\cos 2\pi f_c t$$

$$= E_c\cos 2\pi f_c t + m E_c \cos 2\pi f_m t \cos 2\pi f_c t$$

$$= E_c\cos 2\pi f_c t + \frac{mE_c}{2}\cos(2\pi(f_c - f_m)t) + \frac{mE_c}{2}\cos 2\pi (f_c + f_m)t \quad \text{--- (14)}$$

$$e_{AM} = \underbrace{E_c\cos 2\pi f_c t}_{(1)} + \underbrace{\frac{mE_c}{2}\cos 2\pi f_{LSB} t}_{(2)} + \underbrace{\frac{mE_c}{2}\cos 2\pi f_{USB} t}_{(3)} \quad \text{--- (15)}$$

where f_{LSB} → Lower side band frequency, $f_{LSB} = f_c - f_m$ --- (16)

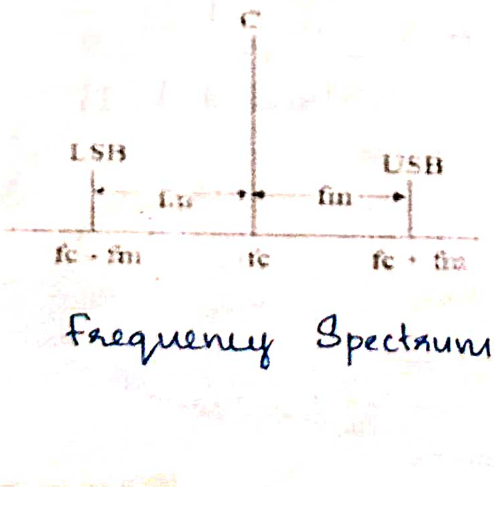
f_{USB} → Upper side band frequency, $f_{USB} = f_c + f_m$ --- (17)

∴ The eqn. (15) of AM, e_{AM} consists of 3 components.

1st term :- Carrier wave of amplitude E_c and frequency f_c.

2nd term :- Lower side frequency of amplitude $\frac{mE_c}{2}$ & frequ. $f_c - f_m$.

3rd term :- Upper side frequency of amplitude $\frac{mE_c}{2}$ & frequency $f_c + f_m$



Frequency Spectrum of AM

Power relation in Modulated wave

The average power in a sine (or cosine) voltage wave of peak value E_{max} developed as a resistor, R is $P = \frac{E_{max}^2}{R}$ —— (18) $\left(P = \frac{V^2}{R}\right)$

The total average power, $P_t = P_c + P_{LSB} + P_{USB}$ —— (19)

$$P_t = \frac{E_c^2}{R} + \frac{E_{LSB}^2}{R} + \frac{E_{USB}^2}{R} \quad \text{—— (20)}$$

All voltages in eqn (20) are rms values. The 1st term of eqn. give the unmodulated carrier power.

$$P_c = \frac{E_c^2}{2} = \frac{\left(\frac{E_{cmax}}{\sqrt{2}}\right)^2}{R} = \frac{E_{cmax}^2}{2R} \quad \text{—— (21)}$$

The 2nd & 3rd terms give the side band power. As $P_{LSB} = P_{USB}$, the power of side band is,

$$P_{LSB} = P_{USB} = \left(\frac{m E_{cmax}/2}{\sqrt{2}}\right)^2 \div R = \frac{m^2}{4} \cdot \frac{E_{cmax}^2}{2R} = \frac{m^2 P_c}{4} \quad \text{—— (2}$$

$$\therefore P_t = P_c + P_{LSB} + P_{USB}$$

$$= \frac{E_{cmax}^2}{2R} + \frac{m^2}{4}\frac{E_{cmax}^2}{2R} + \frac{m^2}{4}\frac{E_{cmax}^2}{2R} \quad \text{—— (23)}$$

From eqn. (21) i.e., $P_c = \frac{E_{cmax}^2}{2R}$, we can write, eqn (23) as,

$$P_t = P_c + \frac{m^2}{4}P_c + \frac{m^2}{4}P_c$$

$$= P_c\left(1 + \frac{m^2}{4} + \frac{m^2}{4}\right) = P_c\left(1 + \frac{m^2}{2}\right) \quad \text{—— (24)}$$

$$\boxed{\frac{P_t}{P_c} = 1 + \frac{m^2}{2}} \quad \text{—— (25)}$$

For 100% modulation, where m=1, the total power is, $\boxed{P_t = 1.5 P_c}$

The ratio of power in any one side frequency to the total power txd is therefore 1/6.

Effective voltage and current for sinusoidal AM

The effective or rms voltage E of the modulated wave is defined by,

$$\frac{E^2}{R} = P_t \quad \text{—— (26)}$$

The effective or rms voltage E_c of the ~~modulated wave~~ carrier component is defined by the equation.

$$\frac{E_c^2}{R} = P_c$$

We know that, $P_t = P_c\left[1+\frac{m^2}{2}\right]$

$$\frac{E^2}{R} = P_c\left[1+\frac{m^2}{2}\right] = \frac{E_c^2}{R}\left[1+\frac{m^2}{2}\right]$$

$$E = E_c\sqrt{\left(1+\frac{m^2}{2}\right)} \quad \text{——} \quad (27)$$

A similar argument applied to current yields,

$$I = I_c\sqrt{1+\frac{m^2}{2}} \quad \text{——} \quad (28)$$

where,

I = ~~RMS~~ rms current of modulated wave

I_c = rms current of unmodulated wave.

The current equation provides a method of monitoring modulation index, by measuring the antenna current with and without modulation applied.

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

Transmission efficiency of the AM wave

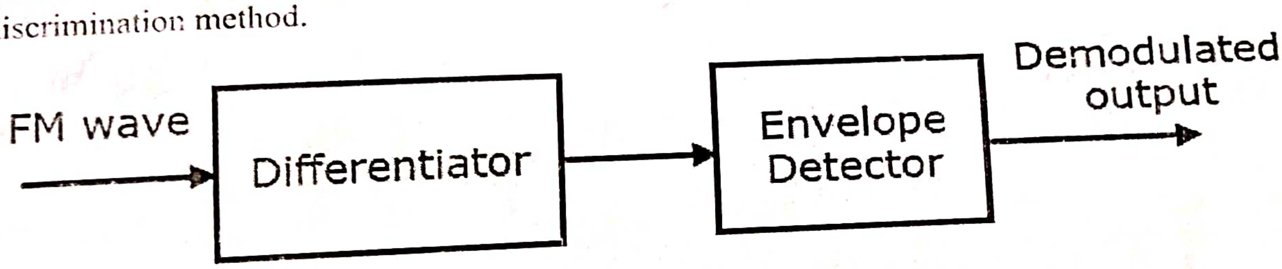
Transmission efficiency of the AM wave is defined as the ratio of the transmitted power which contains the information (the sum of lower and upper side band power) of the total transmitted power (P_T).

$$\text{Transmission efficiency, } \eta = \frac{P_{LSB}+P_{USB}}{P_{total}} \quad \text{——} \quad (29)$$

...quency Discrimination Method

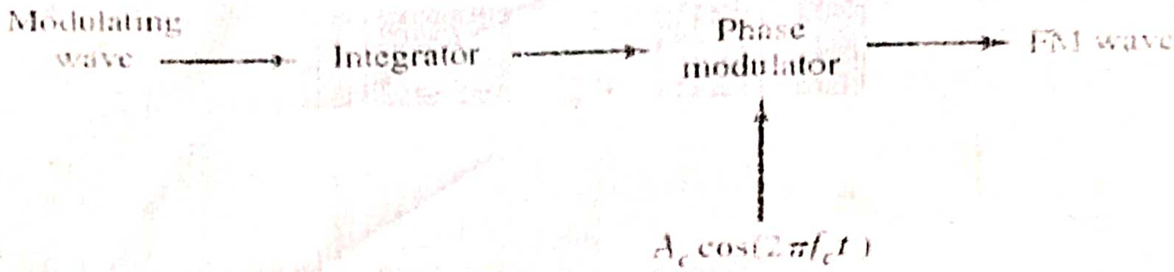
In the above equation, the amplitude term resembles the envelope of the AM wave and the angle term resembles the angle of the FM wave. Here, our requirement is the modulating signal m(t). Hence, we can recover it from the envelope of the AM wave.

The following figure shows the block diagram of FM demodulator using frequency discrimination method.

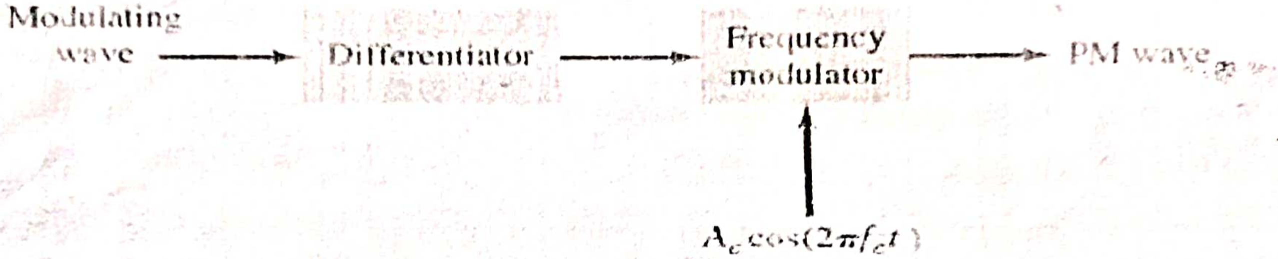


This block diagram consists of the differentiator and the envelope detector. Differentiator is used to convert the FM wave into a combination of AM wave and FM wave. This means, it converts the frequency variations of FM wave into the corresponding voltage (amplitude) variations of AM wave. We know the operation of the envelope detector. It produces the demodulated output of AM wave, which is nothing but the modulating signal.

Scheme for generating FM wave by using phase modulator



Scheme for generating PM wave by using frequency modulator



Bandwidth of an FM Signal

The following formula, known as Carson's rule, is often used as an estimate of the FM signal bandwidth:

$$B_T = 2(\Delta f + f_m)$$

where Δf is the peak frequency deviation and f_m is the maximum baseband message frequency component.

FM Demodulation

The following two methods demodulate FM waves.

- Frequency discrimination method
- Phase discrimination method

Frequency discrimination Method

The equation of FM wave is,

$$s(t) = A_c \cos\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt\right)$$

Differentiate above eqn. w.r.t. to 't'.

$$\frac{d\,s(t)}{dt} = -A_c\left(2\pi f_c + 2\pi k_f m(t)\right)\sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt\right)$$

We know that $-\sin\theta = \sin(\theta - 180^\circ)$

$$\Rightarrow \frac{d\,s(t)}{dt} = A_c\left(2\pi f_c + 2\pi k_f m(t)\right)\sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt - 180^\circ\right)$$

$$= A_c (2\pi f_c)\left[1 + \left(\frac{k_f}{k_c}\right) m(t)\right] \sin\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt - 180\right)$$

Module - I - PART II

Anit

$$\eta = \frac{\frac{m^2}{4} P_c + \frac{m^2}{4} P_c}{\left[1 + \frac{m^2}{2}\right] P_c} = \frac{\frac{m^2}{2}}{\left[1 + \frac{m^2}{2}\right]}$$

$$\boxed{\eta = \frac{m^2}{2 + m^2}} \quad \text{——— (30)}$$

The percentage transmission efficiency is,

$$\boxed{\% \eta = \frac{m^2}{2 + m^2} \times 100\%}$$

Bandwidth of AM wave

Bandwidth is the range of frequencies over which modulation takes place. It is obtained by taking the difference between highest and lowest frequencies.

$$\text{B.W of AM} = f_{USB} - f_{LSB}$$

$$= (f_c + f_m) - (f_c - f_m) = 2f_m$$

$$\boxed{\text{B.W} = 2f_m}$$

Thus the bandwidth of AM signal is twice the maximum frequency of modulating signal.

Types of AM

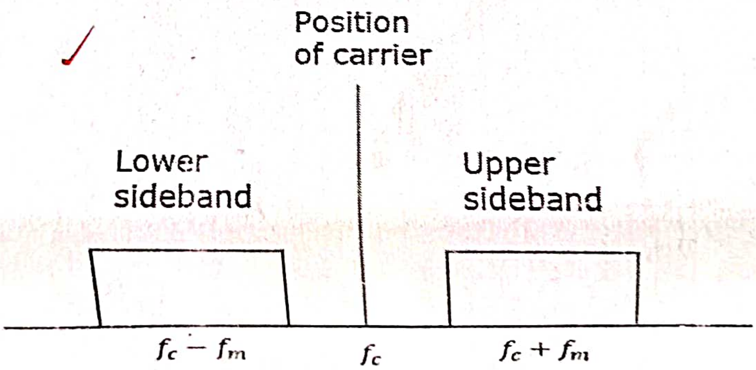
1. DSBFC : Double Side Band Full Carrier
2. DSBSC : Double Side Band Suppressed Carrier
3. SSBFC : Single Side Band Full Carrier
4. SSBSC : Single Side Band Suppressed Carrier
5. SSBRC : Single Side Band Reduced Carrier
6. ISB : Independent Side Band
7. VSB : Vestigial Side Band (Used in TV Broadcasting)

1/11/22

Double Side Band Suppressed Carrier (DSBSC)

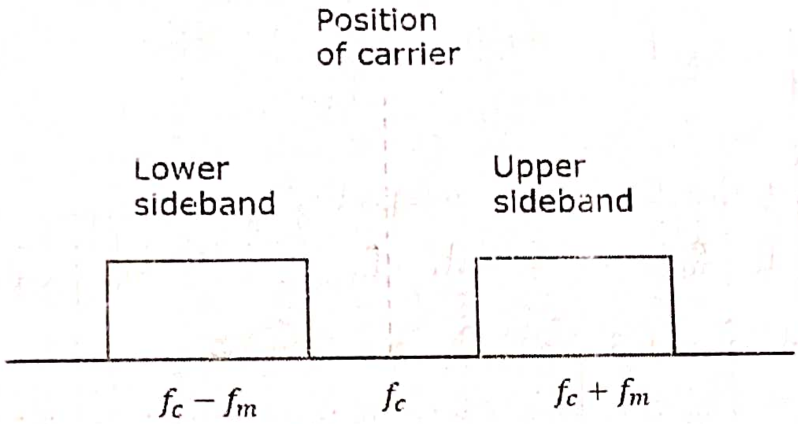
In the process of Amplitude Modulation, the modulated wave consists of the carrier wave and two sidebands. The modulated wave has the information only in the sidebands. Sideband is nothing but a band of frequencies, containing power, which are the lower and higher frequencies of the carrier frequency.

The transmission of a signal, which contains a carrier along with two sidebands can be termed as Double Sideband Full Carrier system or simply DSBFC. It is plotted as shown in the following figure.



However, such a transmission is inefficient. Because, two-thirds of the power is being wasted in the carrier, which carries no information.

If this carrier is suppressed and the saved power is distributed to the two sidebands, then such a process is called as Double Sideband Suppressed Carrier system or simply DSBSC. It is plotted as shown in the following figure.



Carrier is suppressed and sidebands are allowed for transmission

Mathematical Expressions

Let the modulating signal,

$$e_m(t) = E_m \cos(2\pi f_m t) \quad \text{——} \quad (31)$$

and carrier signal, $e_c(t) = E_c \cos(2\pi f_c t)$ —— (32)

Mathematically we can represent the equation of DSBSC wave as the product of modulating and carrier signals.

$$s(t) = e_m(t)\, e_c(t) \quad \text{——} \quad (33)$$

$$\Rightarrow s(t) = E_m E_c \cos(2\pi f_m t) \cos(2\pi f_c t) \quad \text{——} \quad (34)$$

Bandwidth of DSBSC Wave

The formula for bandwidth (BW) is $= f_{max} - f_{min}$

Consider the equation of DSBSC modulated wave.

$$s(t) = E_m E_c \cos(2\pi f_m t) \cos(2\pi f_c t)$$

$$\Rightarrow s(t) = \frac{E_m E_c}{2} \cos(2\pi (f_c + f_m) t) + \frac{E_m E_c}{2} \cos(2\pi (f_c - f_m) t) \quad \text{——} \quad (35)$$

The DSBSC modulated wave has only two frequencies. So, the maximum and minimum frequencies are $f_c + f_m$ & $f_c - f_m$ respectively. ie, $f_{max} = f_c + f_m$ and $f_{min} = f_c - f_m$ substitute f_{max} & f_{min} values in the

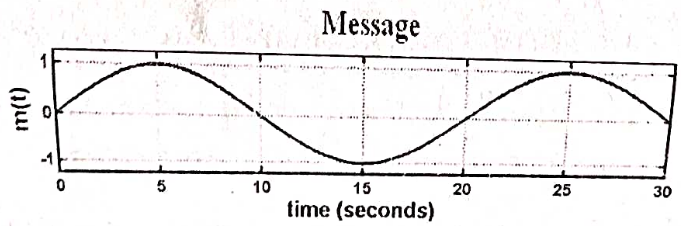
$$B.W = (f_c + f_m) - (f_c - f_m)$$

$$B.W = 2f_m$$

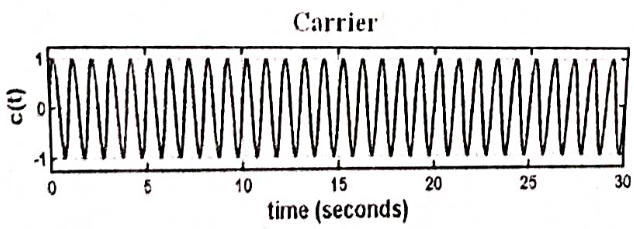
Thus, the bandwidth of DSBSC wave is same as that of AM wave and it is equal to twice the frequency of the modulating signal.

DSBSC Waveforms

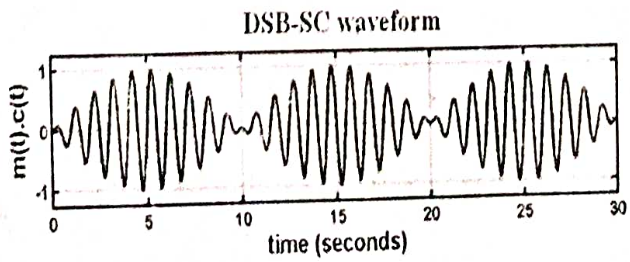
(a)



(b)



(c)



a) Message signal

b) Carrier signal

c) DSBSC Waveform

Few Points

1. It is obvious from the figure, that the DSBSC signal exhibits phase reversal at zero crossings. ie, whenever the base band signal $x(t)$ crosses 0. Because of this, the envelope of a DSBSC modulated signal is different from the message signal. This is unlike the case of AM Wave.

2. ~~From~~ The Impulses at $\pm\omega_c$ are missing which means that the carrier term is suppressed in the spectrum and only two side band terms, USB & LSB are left. ∴, It is called double side band suppressed carrier (DSB-SC) system.

3. Considering only positive side, the upper side band frequency is $\omega_c + \omega_m$ whereas the lower side band frequency is $\omega_c - \omega_m$. The difference of these two is equal to the transmission B.W of a DSBSC signal. ie, Bandwidth, $B = (\omega_c + \omega_m) - (\omega_c - \omega_m)$

$B = 2\omega_m$.

Bandwidth of DSBSC is same as that of AM Wave.

Advantages of DSB-SC modulation

1. It provides 100% modulation efficiency.
2. Due to suppression of the carrier, it consumes less power.
3. It provides a larger bandwidth.

Disadvantages of DSB-SC modulation

1. It involves a complex detection process.
2. Using this technique it is sometimes difficult to recover the signal at the receiver.
3. It is an expensive technique when it comes to demodulation of the signal.

Applications of DSB-SC modulation

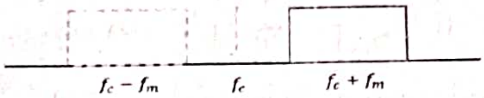
1. During the transmission of binary data, DSB-SC system is used in phase shift keying methods.
2. In order to transmit 2 channel stereo signals, DSB signals are used in Television and FM broadcasting.

DSB-SC technique allows us to have a transmission that reduces overall power consumption rate, thereby ensuring a stronger signal at the output.

SSBSC : Single Side Band Suppressed Carrier

The DSBSC modulated signal has two sidebands. Since the two sidebands carry the same information, there is no need to transmit both sidebands. So it is possible to eliminate one sideband.

The process of suppressing one of the sidebands along with the carrier and transmitting a single sideband is called a Single Sideband Suppressed Carrier system or simply SSBSC. It is plotted as shown in the following figure.



Carrier and a sideband are suppressed and a single sideband is allowed for transmission

Here the carrier and the lower sideband are suppressed. Hence, the upper sideband is used for transmission. Similarly, we can suppress the carrier and the upper sideband while transmitting the lower sideband. This SSBSC system, which transmits a single sideband has high power, as the power allotted for both the carrier and the other sideband is utilized in transmitting this Single Sideband.

Mathematical Expressions

The AM modulated signal from balanced modulator is,

$$e(t) = k\, e_m(t) \cos \omega_c t$$

where, k = multiple constant

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

$$\therefore e(t) = k E_m \cos \omega_m t \cos \omega_c t$$

$$= \frac{k E_m}{2} \left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t \right]$$

$$e(t) = E_{max} \left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t \right]$$ where, $E_{max} =$

The upper side frequency (USF) s/g is given by,

$$e_{USF} = E_m \cos(\omega_c + \omega_m)t$$

The lower side frequency (LSF) s/g is given by,

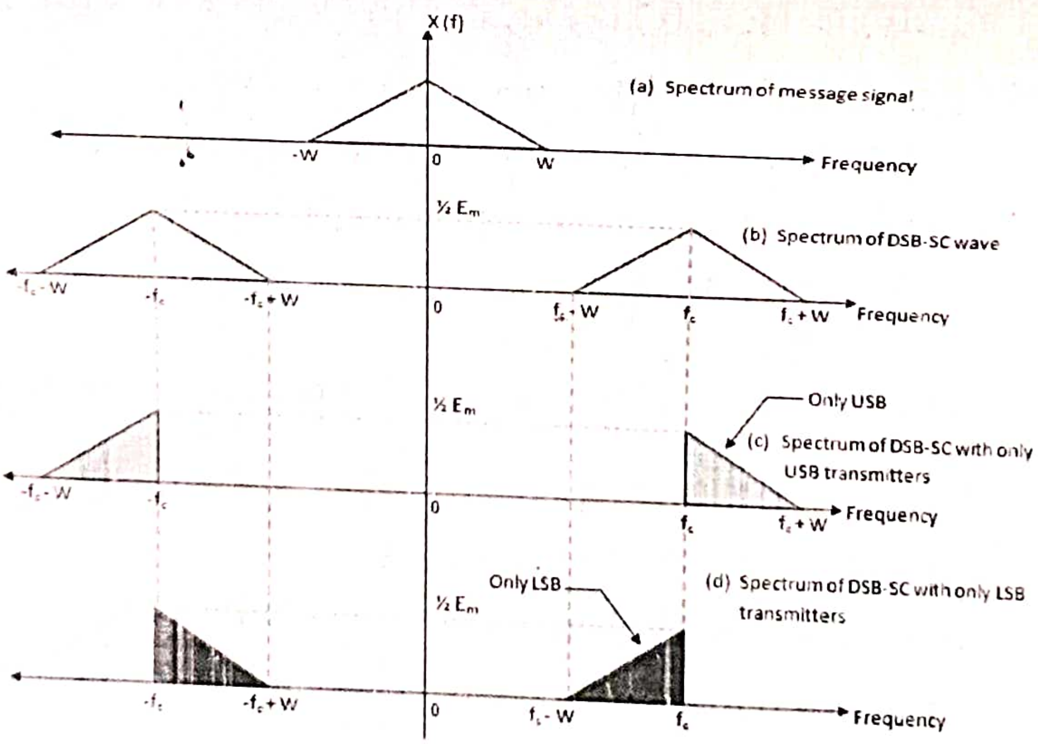
$$e_{LSF} = E_m \cos(\omega_c - \omega_m)t$$

One of the side band frequencies can be removed by filtering.

Demodulation of a SSB s/g is achieved by multiplying it with a locally generated synchronous carrier signal. Detectors using this principle are called product detectors and balanced modulated circuits are used for this purpose.

Frequency Spectrum of SSBSC

The transmission bandwidth of standard AM as well as DSB-SC modulated wave is 2W Hz i.e., twice the message bandwidth W. Therefore, both these systems are bandwidth inefficient systems . In both these systems, one half of the transmission bandwidth is occupied by the upper sideband (USB) and the other half is occupied by the lower sideband (LSB) as shown in figure below.



However, the information contained in the USB is exactly identical to that carried by the LSB . So, by transmitting both the sidebands we are transmitting the same information twice .

multiplexing

Hence, we can transmit only one sideband (USB or LSB) without any loss of information . So, it is possible to suppress the carrier and one sideband completely . When only one sideband is transmitted, the modulation is called as **single sideband modulation** . It is also known as SSB **or SSB-SC modulation** .

Frequency Domain Description

Fig. (a) represents the spectrum X(f) of the message signal x(t) .

This spectrum is limited to the band :

$$-W \leq F \leq W$$

The spectrum of DSB-SC wave which is obtained by taking the product of x(t) and c(t) is shown in fig.(b) . It contains the USB as well as LSB .

When only USB is transmitted by the SSB system, then the corresponding spectrum is as shown in fig. (c) . And when only LSB is transmitted, the frequency spectrum is as shown in fig. 1 (d) .

Thus, the essential function of SSB modulation is to translate the spectrum of the message signal to a new location in the frequency domain .

Bandwidth of SSBSC Wave

The DSBSC modulated wave contains two sidebands and its bandwidth is $2f_m$ .Since the SSBSC modulated wave contains only one sideband, its bandwidth is half of the bandwidth of DSBSC modulated wave.

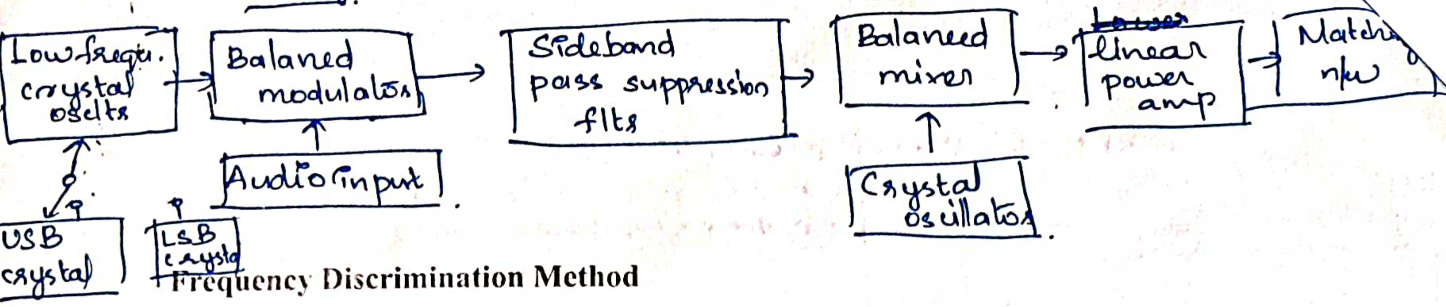
Therefore, the bandwidth of SSBSC modulated wave is f_m and it is equal to the frequency of the modulating signal.

Generation of SSBSC

It is possible to generate SSBSC wave using the following three methods.

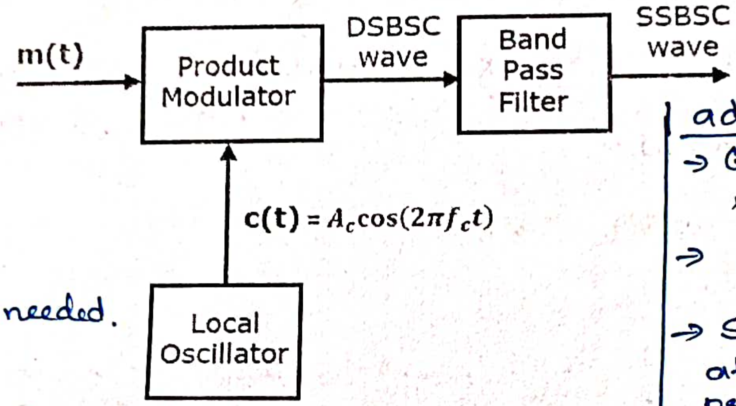
1. Frequency discrimination method(Filter Method)
2. Phase discrimination method
3. Third Method (Weaver's Method)

Another block diagram of Flts Mtd.



Frequency Discrimination Method

The following figure shows the block diagram of SSBSC modulator using frequency discrimination method.



Disadv
- Bulky ckt.
- Expensive
- Stable Oscillator is needed.

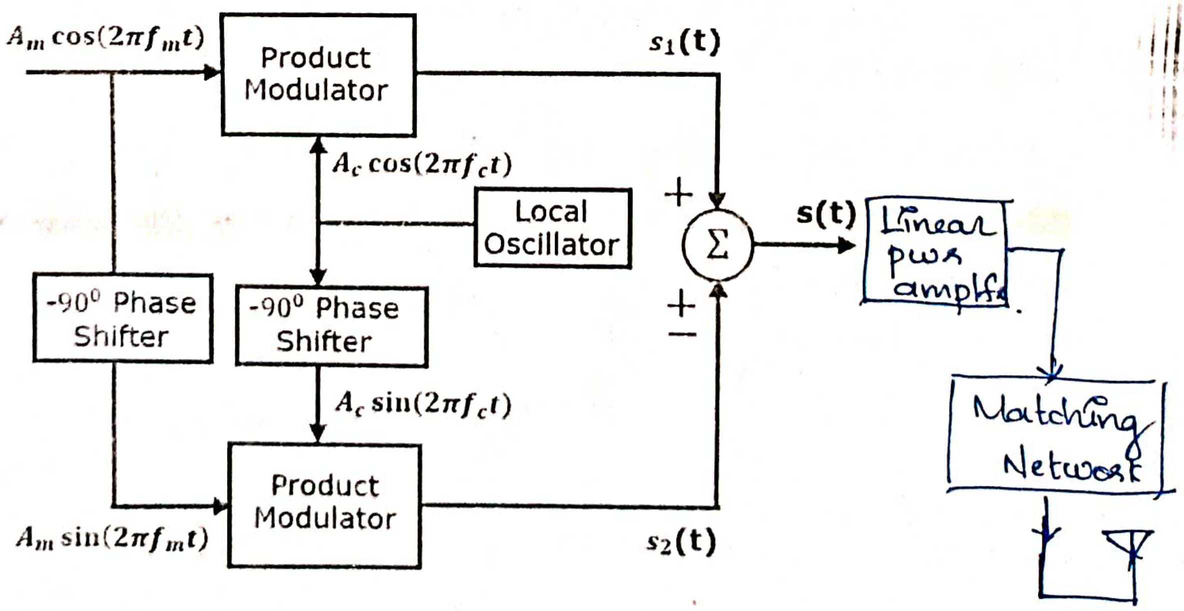
adv.
- Gives side band suppr... upto 50dB.
- Bandwidth is flat & wide.
- Side band filters helps to attenuate carrier if it is present in the o/p of pdt. modltr.

In this method, first we will generate DSBSC wave with the help of the product modulator. Then, apply this DSBSC wave as an input of band pass filter. This band pass filter produces an output, which is SSBSC wave.

Select the frequency range of the band pass filter as the spectrum of the desired SSBSC wave. This means the band pass filter can be tuned to either upper sideband or lower sideband frequencies to get the respective SSBSC wave having upper sideband or lower sideband.

Phase Discrimination Method

The following figure shows the block diagram of SSBSC modulator using phase discrimination method. [Product / Balanced]



This block diagram consists of two product modulators, two -90° phase shifters, one local oscillator and one summer block. The product modulator produces an output, which is the product of two inputs. The -90° phase shifter produces an output, which has a phase lag of -90° with respect to the input.

The local oscillator is used to generate the carrier signal. Summer block produces an output, which is either the sum of two inputs or the difference of two inputs based on the polarity of inputs.

The modulating signal $A_m \cos(2\pi f_m t)$ and the carrier signal $A_c \cos(2\pi f_c t)$ are directly applied as inputs to the upper product modulator. So, the upper product modulator produces an output, which is the product of these two inputs.

The output of upper product modulator is

$$s_1(t) = A_m A_c \cos(2\pi f_m t)\cos(2\pi f_c t) = \frac{A_m A_c}{2}\left[\cos(2\pi(f_c+f_m)t + \cos(2\pi(f_c-f_m)t\right]$$

The modulating signal and the carrier signal are phase shifted by before applying as inputs to the lower product modulator. So, the lower product modulator produces an output, which is the product of these two inputs.

The output of lower product modulator is

$$s_2(t) = A_m A_c \cos(2\pi f_m t - 90^\circ)\cos(2\pi f_c t - 90^\circ)$$

$$= A_m A_c \sin(2\pi f_m t)\sin(2\pi f_c t)$$

$$= \frac{A_m A_c}{2}\left[\cos(2\pi(f_c-f_m)t - \cos(2\pi(f_c+f_m)t\right]$$

Add $s_1(t)$ & $s_2(t)$ inorder to get the SSBSC modulated wave $s(t)$ having a lower side band.

$$s(t) = \frac{A_m A_c}{2}\left\{\cos[2\pi(f_c+f_m)t] + \cos[2\pi(f_c-f_m)t]\right\} + \frac{A_m A_c}{2}\left\{\cos[2\pi(f_c-f_m)t] - \cos[2\pi(f_c+f_m)t]\right\}$$

$$= A_m A_c \cos[2\pi(f_c-f_m)t]$$

Subtract $s_2(t)$ from $s_1(t)$ inorder to get the SSBSC modulated wave $s(t)$ having a upper side band.

$$s(t) = \frac{A_m A_c}{2}\left\{\cos[2\pi(f_c+f_m)t] + \cos[2\pi(f_c-f_m)t]\right\} - \frac{A_m A_c}{2}\left\{\cos[2\pi(f_c-f_m)t] - \cos[2\pi(f_c+f_m)t]\right\}$$

$$s(t) = A_m A_c \cos[2\pi(f_c+f_m)t]$$

Hence by properly choosing the polarities of i/ps at summer block, it will get SSBSC wave having a upper side band or a lower side band.

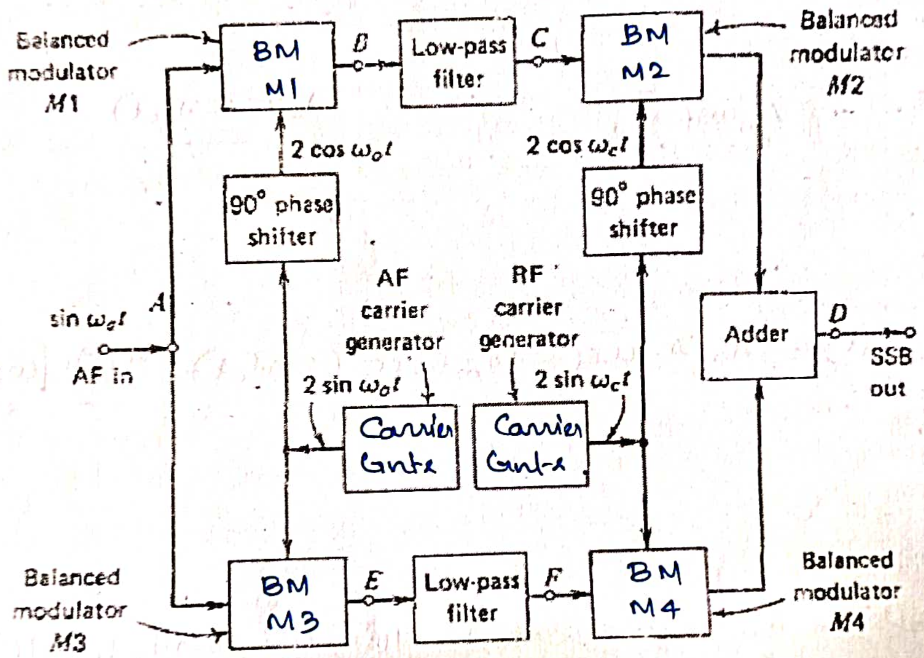
Adv

-> Small filters are required.
-> Able to generate SSB at any frequency.
-> Switching from one SB to another is possible.
-> Low Audio frequencies are used for modln.

Disad.

-> Design is critical.
-> Requires complex AF phase shift n/w.
-> o/p of BM must be same otherwise cancellation is impossible.

Third Method - Weaver's Method



Operation:

- The third method of generating SSB was developed by Weaver.
- From the block diagram, we see that the latter part of this circuit is identical to that of the phase-shift method, but the way in which appropriate voltages are fed to the last two balanced modulators at points C and F has been changed.
- Instead of trying to phase-shift the whole range of audio frequencies, this method combines them with an AF carrier fo, which is a fixed frequency in the middle of the audio band, 1650 Hz.
- A phase shift is then applied to this frequency only, and after the resulting voltages have been applied to the first pair of balanced modulators, the low-pass filters whose cut-off frequency is fo ensure that the input to the last pair of balanced modulators results in the proper eventual sideband suppression.
- It may be shown that all lower sideband signals will be canceled for the configuration of the given Figure, regardless of whether audio frequencies are above or below fo.

- If a lower sideband signal is required, the phase of the carrier voltage applied to M1 may be changed by 180°.

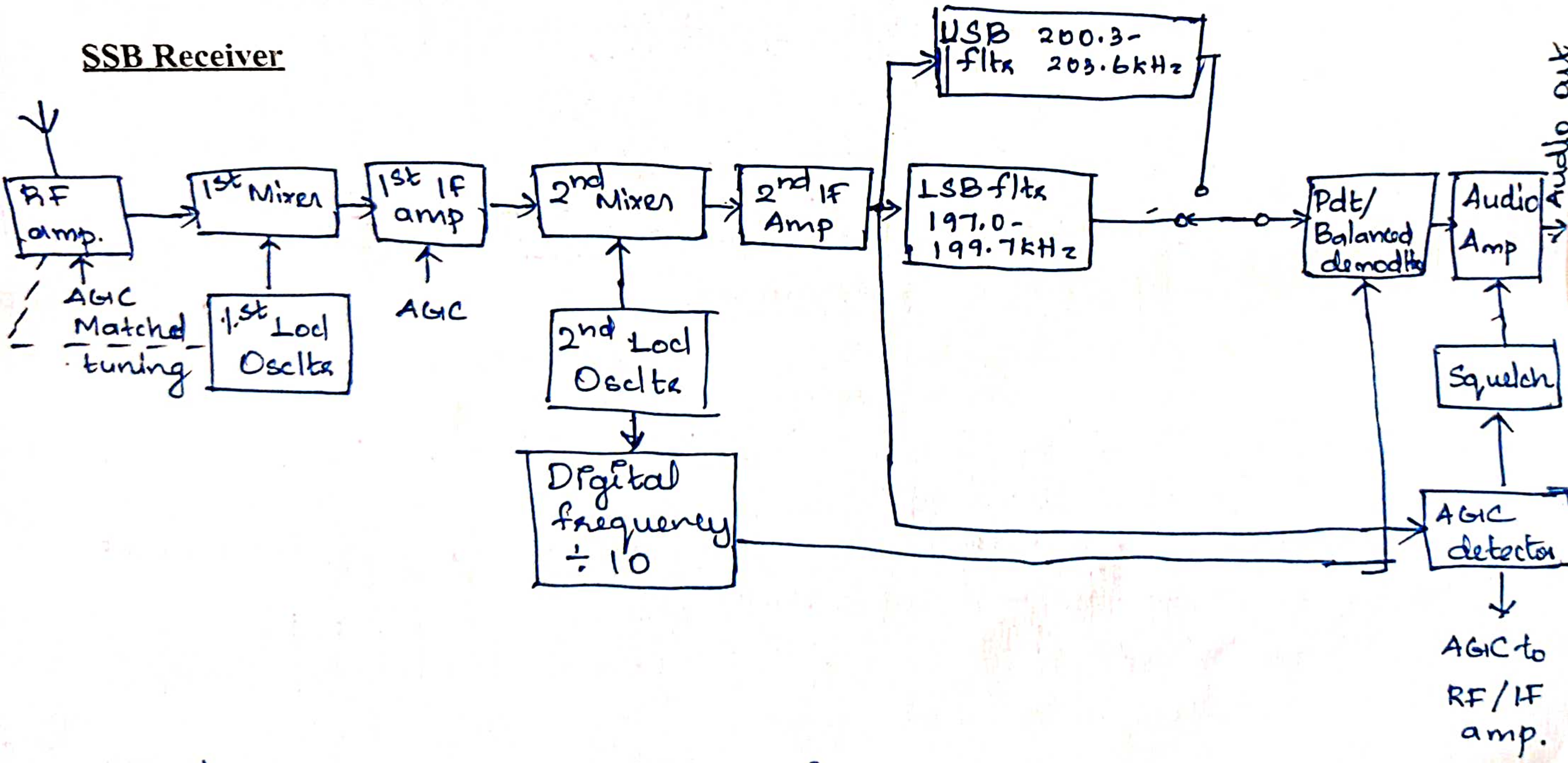
Advantages:

- It has the advantages of the phase-shift method, such as its ability to generate SSB at any frequency.
- It uses low audio frequencies, without the associated disadvantage of an AF phase-shift network required to operate over a large range of audio frequencies.

Disadvantages:

- The third method is in direct competition with the filter method, but is very complex.
- It is expensive and so cannot be used commercially.

SSB Receiver



The recieved SSB s/g is multipled with a synchronous carrier & the result contains the original modulation s/g as one component. Balanced pdt modulators are used for demodulation. The carrier s/g for the demodulation must be locally generated if the signals are true. SSB signals with the carrier completely suppressed. This requires ~~extremely~~ extreme stability for the local oscillator s/gs for demodulating & for the superhetrodyne converter.

Double Conversion is often used in SSB recievers. Since very good adjacent channel. Selectivity must be provided since SSB signals are usually packed closely together in the frequency spectrum.

The 1st Local Oscillator and RF amplifier are manually tuned in two switched bands. The output of 2nd crystal oscillator is divided by 10 in a digital

counter to provide the carrier s/g for the demodulator.
The o/p from the detector is passed through a gated audio amplifier that turns off the o/p to keep the noise down when the s/g level di below a preset threshold. This is called squelch. The amplified IF s/g is rectified to provide the AGC voltage for the RF & IF amplifiers and for squelch circuit.
The 2nd IF amplifier is followed by two filters, USB & LSB filters. USB filter passes IF upperside band and rejects the lower side band. The LSB filter passes IF lower side band. The approximate sideband is selected by a switch that connects the o/p of the desired filter to the product detector.

One of the largest application of this type of SSB is multichannel citizen's band (CB) transceivers.

Advantages

- Bandwidth or spectrum space occupied is lesser than AM and DSBSC waves.
- Transmission of more signals is allowed.
- Power is saved.
- High power signals can be transmitted.
- Less noise is present.
- Signal fading is less likely to occur.

Disadvantages

- The generation and detection of SSBSC wave is a complex process.
- The quality of the signal gets affected unless the SSB transmitter and receiver have an excellent frequency stability.

Applications

- For power saving requirements and low bandwidth requirements.
- In land, air, and maritime mobile communications.
- In point-to-point communications.
- In radio communications.
- In television, telemetry, and radar communications.
- In military communications, such as amateur radio, etc.

Angle Modulation

The other type of modulation in continuous-wave modulation is the Angle Modulation. Angle Modulation is the process in which the frequency or the phase of the carrier varies according to the message signal. This is further divided into frequency and phase modulation.

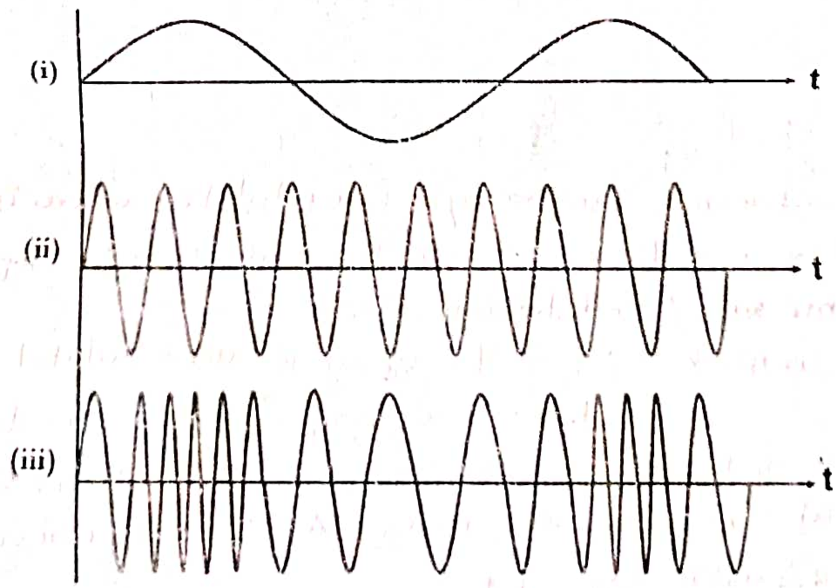
Frequency Modulation is the process of varying the frequency of the carrier signal linearly with the message signal.

Phase Modulation is the process of varying the phase of the carrier signal linearly with the message signal.

Frequency Modulation

In amplitude modulation, the amplitude of the carrier varies. But in Frequency Modulation (FM), the frequency of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.

The amplitude and the phase of the carrier signal remains constant whereas the frequency of the carrier changes. This can be better understood by observing the following figures.



(i) Modulating signal
(ii) Carrier waveform
(iii) Frequency modulated signal

The frequency of the modulated wave remains constant as the carrier wave frequency when the message signal is at zero. The frequency increases when the message signal reaches its maximum amplitude. Which means, with the increase in amplitude of the modulating or message signal, the carrier frequency increases. Likewise, with the decrease in the amplitude of the modulating signal, the frequency also decreases.

Mathematical Representation

Let the carrier frequency be f_c.

The frequency at maximum amplitude of the message signal = $f_c + \Delta f$

The frequency at minimum amplitude of the message signal = $f_c - \Delta f$

The difference between FM modulated frequency and normal frequency is termed as Frequency Deviation and is denoted by Δf.

The deviation of the frequency of the carrier signal from high to low or low to high can be termed as the Carrier Swing.

Carrier Swing = 2 × frequency deviation

= 2 × Δf

Equation for FM WAVE

The equation for FM wave is;

The new instantaneous frequency of modulated wave is,

$f_i(t) = f_c + k_f\, e_m(t)$ & in terms of ω as; $\omega_i = \omega_c + k_f \cdot x(t)$

where $e_m(t)$ = message / modulating signal

ie, $e_m(t) = E_m \cos \omega_m t$; f_c – frequency of unmodulated carrier

k_f – frequency deviation constant in hertz/volt.

$f_i(t) = f_c + k_f(E_{m\,max} \cos 2\pi f_m t) = f_c + \Delta f \cos 2\pi f_m t$

where the peak frequency deviation Δf is proportional to the peak modulating s/g and is $\Delta f = k E_{m\,max}$

FM can be divided into Narrowband FM and Wideband FM.

Narrowband FM

The features of Narrowband FM are as follows –

- This frequency modulation has a small bandwidth.
- The modulation index is small.
- Its spectrum consists of carrier, USB, and LSB.
- This is used in mobile communications such as police wireless, ambulances, taxicabs, etc.

Modulation Index of FM

$$\beta = m_f = \frac{\text{Frequency deviation}}{\text{Modulating frequency}} = \frac{\Delta f}{f_m}$$

; for FM, mod. index is >1.

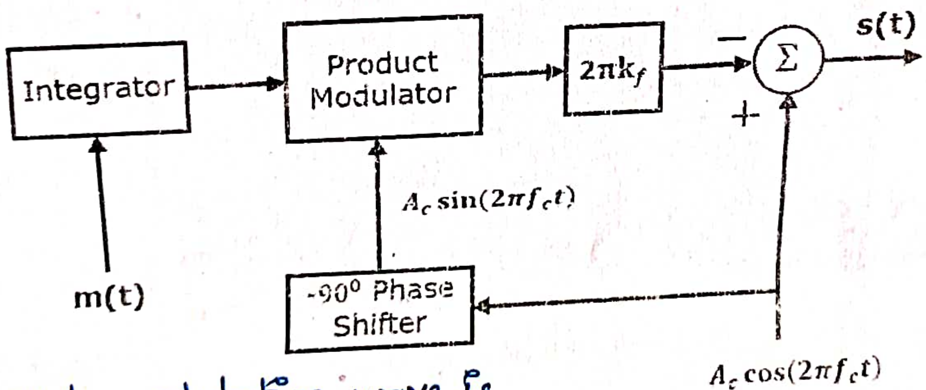
Wideban
The feature

Wideband FM

The features of Wideband FM are as follows –

- This frequency modulation has infinite bandwidth.
- The modulation index is large, i.e., higher than 1.
- Its spectrum consists of a carrier and infinite number of sidebands, which are located around it.
- This is used in entertainment broadcasting applications such as FM radio, TV, etc.

Generation of NBFM



→ The Sinusoidal modulating wave is
$m(t) = A_m \cos(2\pi f_m t)$

→ Carrier wave $A_c \cos(2\pi f_c t)$ is split into two; one portion is −90° phase shifted and one portion direct to the adder.

→ The integrated modulating wave & −90° phase shifted carrier wave is given to the product modulator producing DSBSC signal.

→ This is further multiplied with $2\pi k_f$.

→ The difference between carrier and DSBSC is taken to produce the NBFM signal.

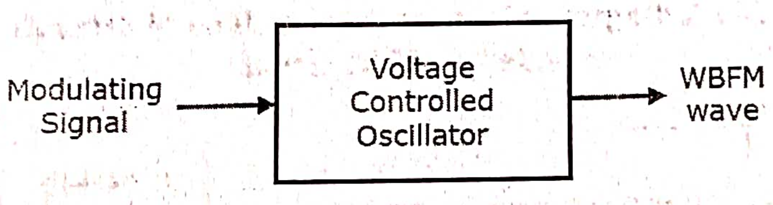
Generation of WBFM

The following two methods generate WBFM waves.

- Direct method
- Indirect method

Direct Method

This method is called the Direct Method because we are generating a wide band FM wave directly. In this method, Voltage Controlled Oscillator (VCO) is used to generate WBFM. VCO produces an output signal, whose frequency is proportional to the input signal voltage. This is similar to the definition of FM wave. The block diagram of the generation of WBFM wave is shown in the following figure.



Here, the modulating signal m(t) is applied as an input of Voltage Controlled Oscillator (VCO). VCO produces an output, which is nothing but the WBFM.

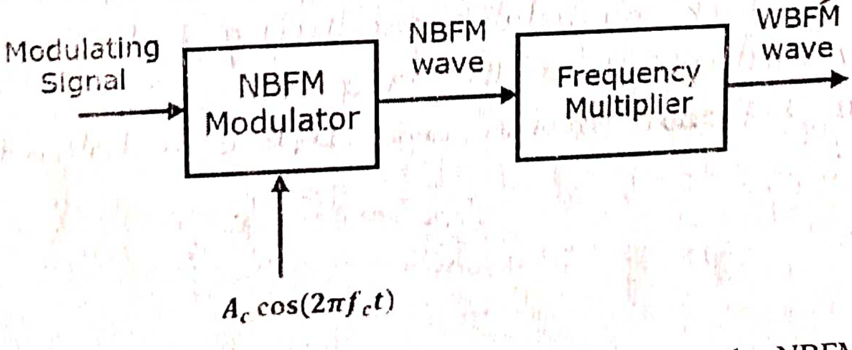
$$f_i \alpha m(t)$$

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

Where, f_i is the instantaneous frequency of WBFM waves.

Indirect Method

This method is called the Indirect Method because we are generating a wide band FM wave indirectly. This means, first we will generate NBFM waves and then with the help of frequency multipliers we will get WBFM waves. The block diagram of generation of WBFM waves is shown in the following figure.



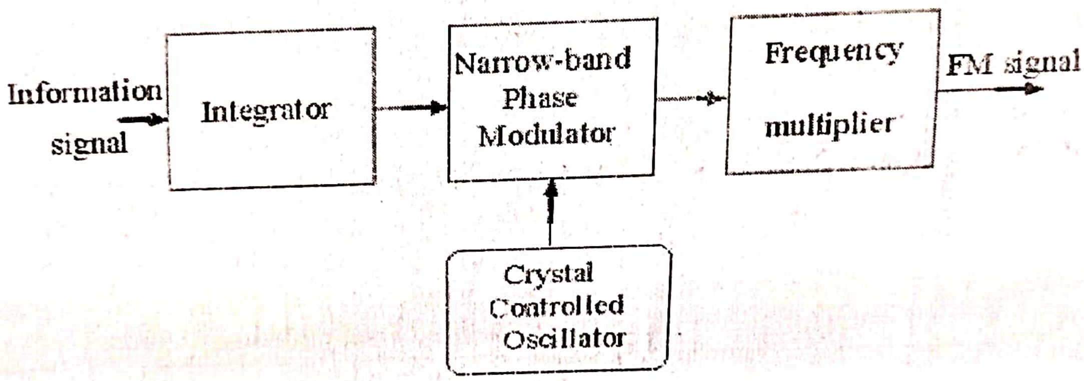
This block diagram contains mainly two stages. In the first stage, the NBFM wave will be generated using the NBFM modulator. The modulation index of the NBFM wave is less than one. Hence, in order to get the required modulation index (greater than one) of the FM wave, choose the frequency multiplier value properly.

Frequency multiplier is a non-linear device, which produces an output signal whose frequency is 'n' times the input signal frequency. Where, 'n' is the multiplication factor.

If an NBFM wave whose modulation index β is less than 1 is applied as the input of frequency multiplier, then the frequency multiplier produces an output signal, whose modulation index is 'n' times β and the frequency also 'n' times the frequency of WBFM wave. Sometimes, we may require multiple stages of frequency multiplier and mixers in order to increase the frequency deviation and modulation index of FM waves.

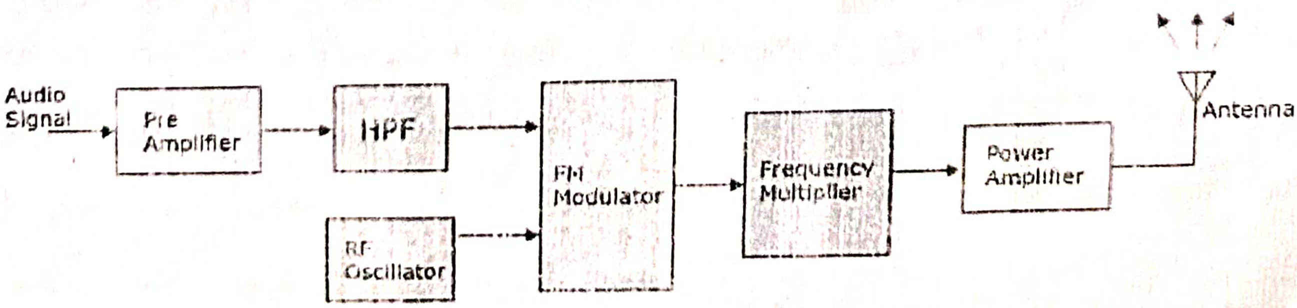
Another Block diagram

Block diagram of the indirect method of generating a wide-band FM-signal



FM Transmitter

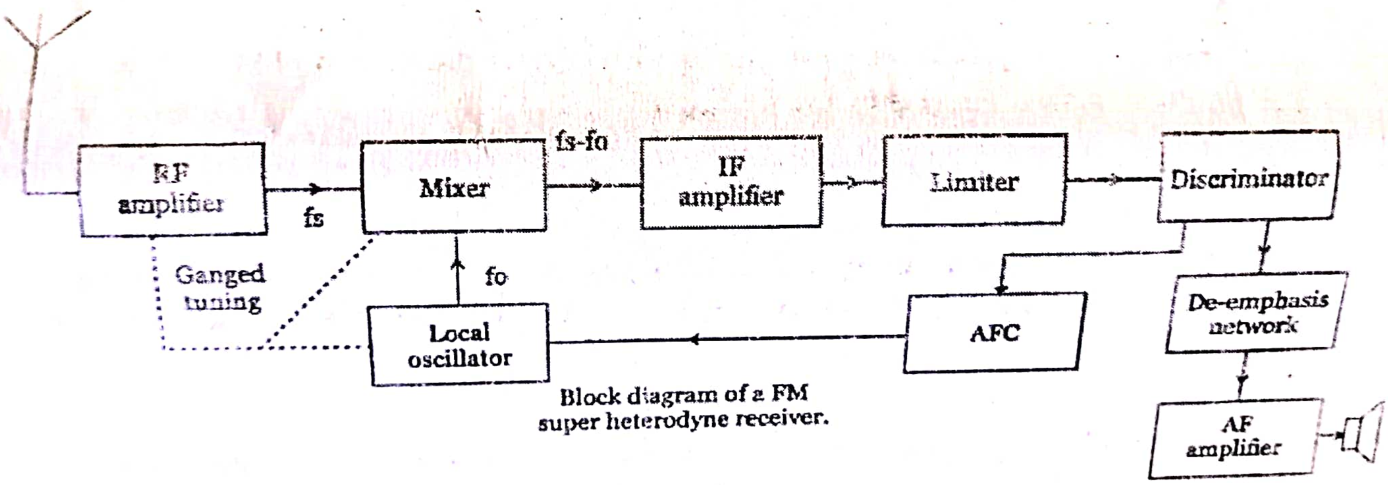
FM transmitter is the whole unit, which takes the audio signal as an input and delivers FM wave to the antenna as an output to be transmitted. The block diagram of FM transmitter is shown in the following figure.



The working of FM transmitters can be explained as follows.

- The audio signal from the output of the microphone is sent to the pre-amplifier, which boosts the level of the modulating signal.
- This signal is then passed to high pass filter, which acts as a pre-emphasis network to filter out the noise and improve the signal to noise ratio.
- This signal is further passed to the FM modulator circuit.
- The oscillator circuit generates a high frequency carrier, which is sent to the modulator along with the modulating signal.
- Several stages of frequency multiplier are used to increase the operating frequency. Even then, the power of the signal is not enough to transmit. Hence, a RF power amplifier is used at the end to increase the power of the modulated signal. This FM modulated output is finally passed to the antenna to be transmitted.

FM Receiver



Block diagram of a FM super heterodyne receiver.

The above figure is the block diagram of FM Superheterodyne Receiver. The components are;

RF amplifier: The RF amplifier increases the signal strength before the signal is fed to mixer when turned to the desired frequency. The RF amplifier is designed to handle large bandwidth of 150 kHz.

Mixer: the incoming RF signal of frequency fm is applied to a mixer which also receives the output from the local oscillator. A new frequency called intermediate frequency IF is produced whose value is the difference of local oscillator signal f and signal frequency f.

Local oscillator: the receiver converts incoming carrier frequency to the IF by using local oscillator frequency higher than incoming tuned frequency. Colpitts oscillator is used as the local oscillator.

IF amplifier : IF signal is amplified by one or more number of amplifiers, which raises the strength of IF signal. It has a multistage class A amplifier providing better selectivity and gain.

Limiter : It removes all the amplitude variation in FM signals caused by noise. Differential amplifiers are preferred for limiters.

Discriminator : It recovers the modulating signal from the IF signal. It converts frequency variation into corresponding voltage variation and produces the modulating signal.

De-emphasis network : It reduces the relative amplitude of high frequency signals that are boosted in the transmitter and brings them back to their original level.

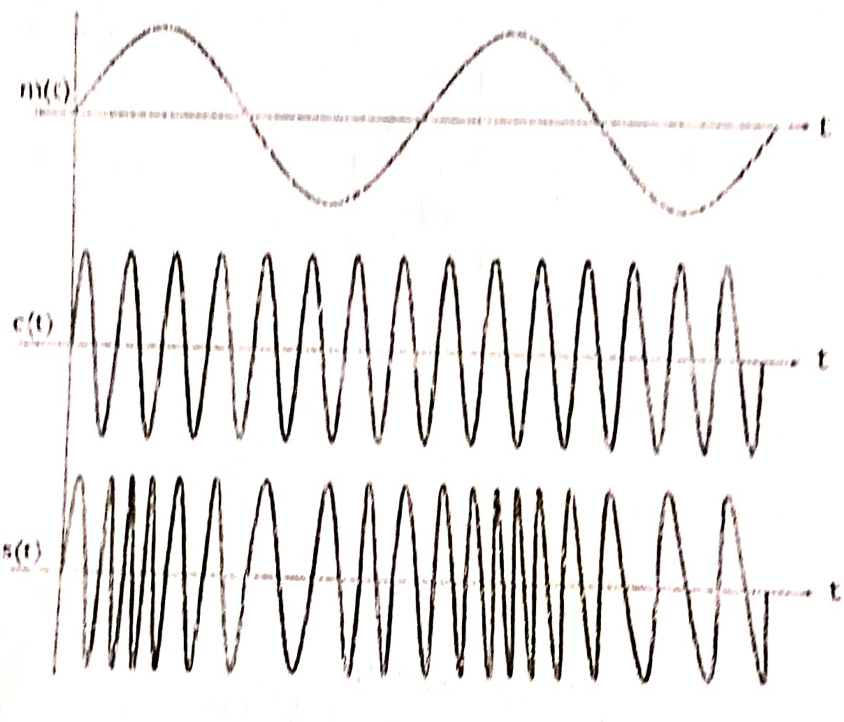
AF amplifier : It amplifies the modulating signal recovered by the FM detector. The speaker converts the electrical signal into sound signal.

Phase Modulation

In frequency modulation, the frequency of the carrier varies. But in Phase Modulation (PM), the phase of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal.

The amplitude and the frequency of the carrier signal remains constant whereas the phase of the carrier changes. This can be better understood by observing the following figures.

In PM, the instantaneous value of the phase angle is equal to the phase angle of the unmodulated carrier $(\omega_c t + \theta_0)$ plus a time varying component which is propotional to modulating signal $x(t)$.



The message signal is given by m(t). The carrier signal is given by c(t). And the phase modulated signal is given by s(t).

The phase of the modulated wave has got infinite points where the phase shift in a wave can take place. The instantaneous amplitude of the modulating signal changes the phase of the carrier. When the amplitude is positive, the phase changes in one direction and if the amplitude is negative, the phase changes in the opposite direction.

Mathematical Representation

The unmodulated carrier signal is expressed as $c(t) = (A \cos \omega_c t + \theta_0)$

$c(t) = A \cos \phi$ where $\phi = \omega_c t + \theta_0$

Neglecting θ_0, we get total phase angle of unmodulated carrier is, $\phi = \omega_c t$

Now according to PM, the phase angle 'ϕ' is varied linearly with a baseband or modulating s/g $x(t)$.

Let the instantaneous value of phase angle be denoted by ϕ_i.

$\therefore \phi_i = \omega_c t + k_p x(t)$

where, k_p = proportionality constant & is called phase sensitivity of the modulator. unit → radians/volt

Since the expression for carrier wave is,

$c(t) = A \cos \phi$

The expression for PM wave will be,

$$s(t) = A\cos\phi_i$$

By Substituting the value of ϕ_i in $s(t)$,

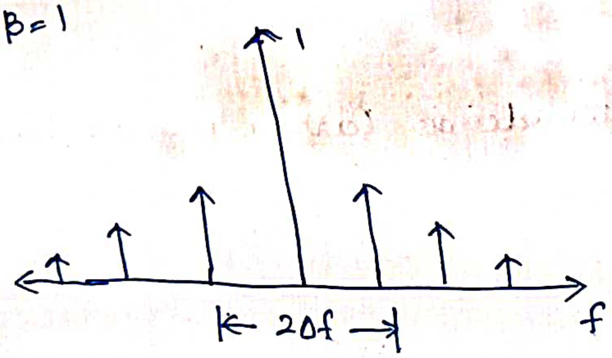
$$s(t) = A\cos\left[\omega_c t + k_p\, x(t)\right]$$ — Eqn. of PM Wave.

Frequency spectrum of FM Signal

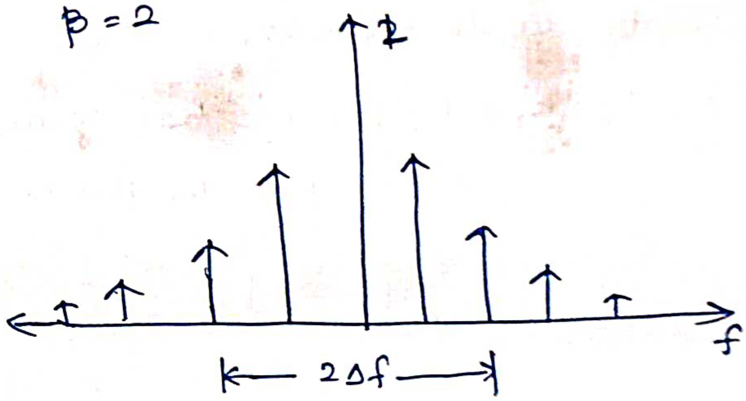
Case -1

When the frequency of modulating s/g is fixed, but its amplitude is varied, produces a variation in frequency deviation Δf.

$\beta = 1$



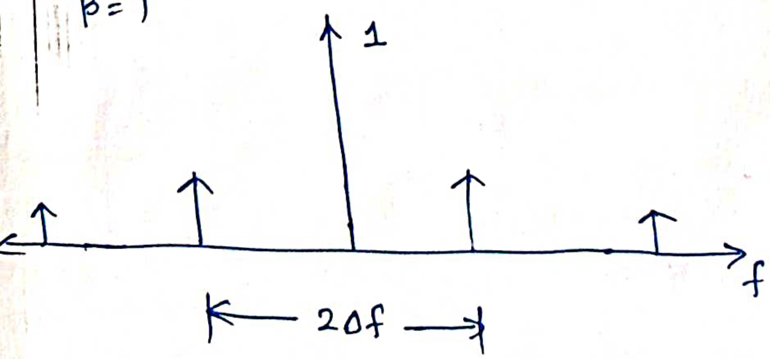
$\beta = 2$



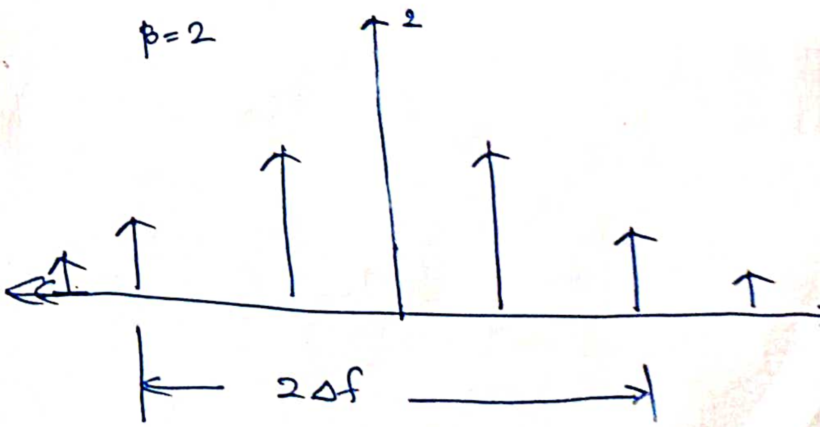
Case-2

When the amplitude of the modulating s/g is fixed, ie, Δf is maintained constant & f_m is varied.

$\beta = 1$



$\beta = 2$



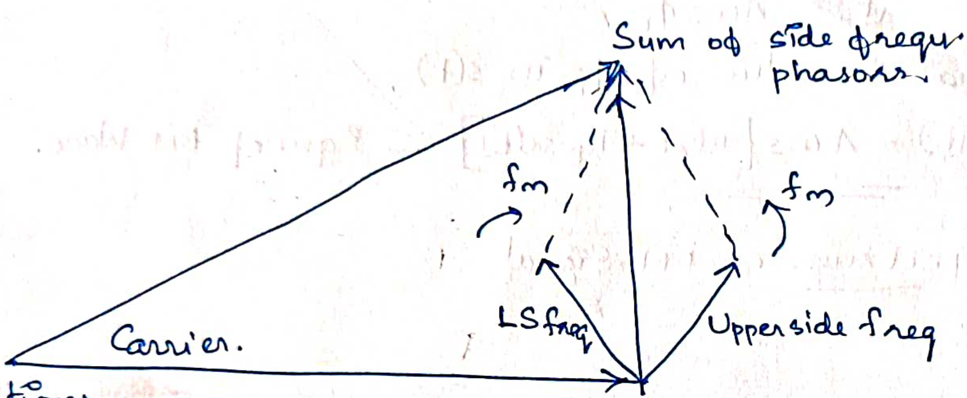
When Δf is fixed and β is increased, spectral lines are increased and they're crowding into fixed frequency interval. So when β approaches ∞, B.W of FM Waves approaches the limiting value of $2\Delta f$.

Bandwidth of FM

→ Stated by using Carson's Rule.

ie, $B.W = 2\Delta f + 2f_m = 2\Delta f\left(1 + \frac{1}{\beta}\right)$

phasor diagram representation of FM



Observations.

⇒ Carrier phasor as reference.

→ Resultant of two side frequency phasors is always at ⊥r to carrier power.

→ Resultant phasor has same amplitude as Carrier phasor, but with out of phase.