

COMMUNICATION ENGINEERING-EC8395

UNIT I

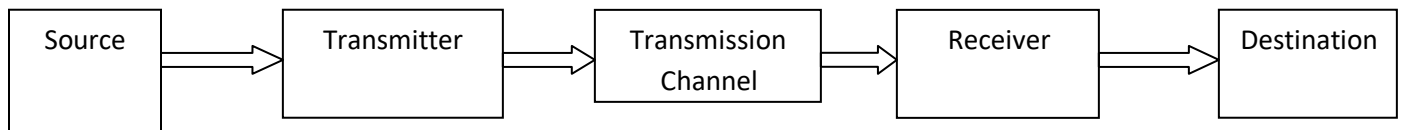
ANALOG COMMUNICATION

Communication is the process of conveying or transferring of information from one point to another point. Information can be image, text or any other data. Communication between any two points or places requires a medium in between them. This medium can be wired or wireless medium. The information that needs to be transmitted may not be in a form that is suitable for all medium. It needs to be processed. This processing of raw information to convert it into a form that is suitable for a medium is called as modulation.

TYPES OF COMMUNICATION

Communication can be of two types- Analog & Digital

In Analog communication the transmit information is continuous in nature, whereas in digital communication it is discrete in nature.



Basic block diagram for communication System

Information from the source should be modulated before transmission to enable proper transmission of information from transmitter to receiver. The process of modifying or changing any characteristics of any signal is called modulation. Any signal has three characteristic they are

1. Amplitude
2. Frequency
3. Phase

MODULATION:

The process of changing any one of the characteristics of carrier signal with respect to information signal is known as modulation.



Information (or) message



Carrier



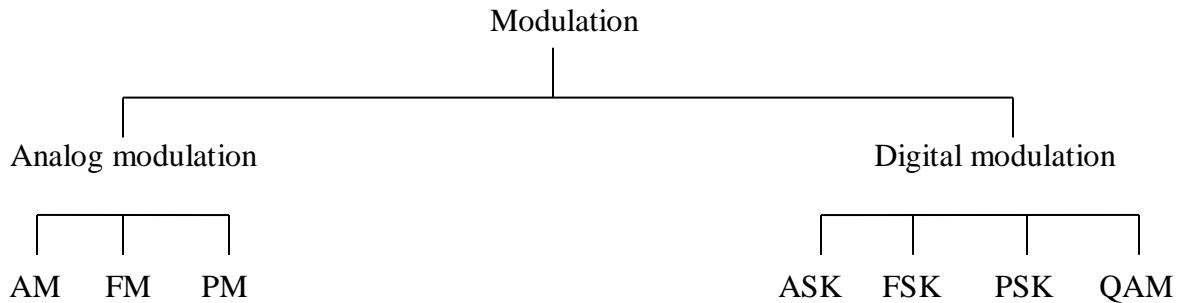
Information + Carrier



= modulated signal

TYPES OF MODULATION

Modulation is classified into two types they are, Analog modulation and Digital modulation. In analog modulation both information and carrier signal are analog in nature, whereas in digital information signal is digital but carrier signal is analog.



AM (Amplitude modulation):

It is the process of changing the amplitude of high frequency carrier signal in accordance with low frequency information signal. Here frequency and phase angle of carrier remains unchanged.

FM (Frequency modulation):

It is the process of changing the frequency of carrier signal accordance with amplitude of information signal.

PM (Phase modulation):

It is the process of changing the phase of carrier signal accordance with amplitude of information signal..

NEED FOR MODULATION

- Reduce height of antenna
- Transmit signal over a long distance
- Avoid noise and interference
- Multiplexing
- Improve the signal to noise ratio

AMPLITUDE MODULATION

It is the process of changing the amplitude of a relatively high frequency carrier signal in proportion with the instantaneous value of the modulating signal. AM is used for commercial broadcasting of audio and video signals.

Applications of AM: 1. Two-way mobile radio, Audio and video broadcast

AM VOLTAGE

The modulating signal is represented as, $e_m(t) = E_m \sin \omega_m t$

The carrier signal is represented as, $e_c(t) = E_c \sin \omega_c t$

According to the definition, the amplitude of the carrier signal is changed after modulation.

$$E_{AM} = E_c + e_m(t) = E_c + E_m \sin \omega_m t \text{ -----(1)}$$

$$= E_c [1 + (E_m/E_c) \sin \omega_m t] \text{ ----- (2)}$$

$$E_{AM} = E_c(1 + m_a \sin \omega_m t) \text{ ----- (3)}$$

Depth of Modulation/Modulation Index:

Coefficient of modulation and percent modulation:

It is defined as the ratio of maximum amplitude of the message signal to the maximum amplitude of the carrier signal.

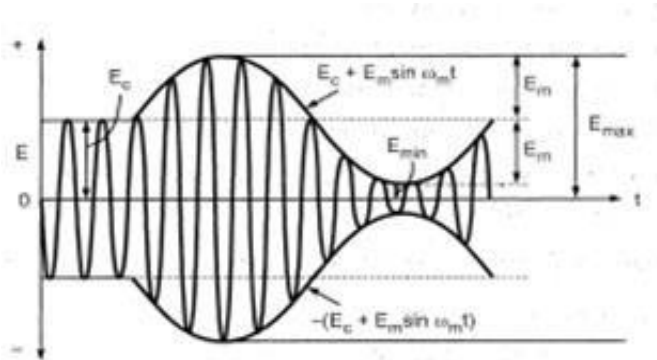
$$m_a = \frac{E_m}{E_c}$$

Percent modulation is indicated as M

$$M = \frac{E_m}{E_c} \times 100 \quad \text{or} \quad M = m_a \times 100$$

Relationship between m, E_m & E_c

From the figure.



$$E_m = \frac{1}{2} (E_{max} - E_{min})$$

$$E_c = \frac{1}{2} (E_{max} + E_{min})$$

$$M = \frac{\frac{1}{2} (E_{max} - E_{min})}{\frac{1}{2} (E_{max} + E_{min})} \times 100 = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \times 100$$

Where $m_a = E_m/E_c$ Where m_a is the modulation index (or) depth of modulation. The value E_m must be less than value of E_c to avoid distortion in the modulated signal. Hence maximum value of m_a will be equal to 1. When m_a is expressed in percentage it is called percentage modulation.

But the instantaneous amplitude of modulated signal, i.e at any time

$$e_{AM}(t) = E_{AM} \sin \omega_c t \text{ ----- (4)}$$

Substitute equation (3) in (4)

$$e_{AM}(t) = E_c (1 + m_a \sin \omega_m t) \sin \omega_c t$$

$$= E_c \sin \omega_c t + m_a E_c \sin \omega_m t \sin \omega_c t$$

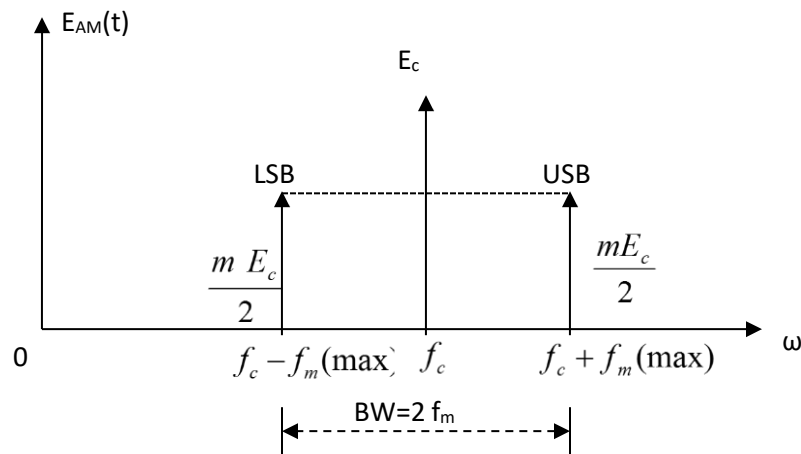
(1)
(2)

Expand the second term ($\sin \omega_m t \sin \omega_c t$) according to (SinASinB) formula, we get

$$e_{AM}(t) = E_c \sin \omega_c t + \frac{m_a E_c}{2} \cos(\omega_c - \omega_m)t - \frac{m_a E_c}{2} \cos(\omega_c + \omega_m)t \text{ ----- (5)}$$

= Carrier + USB + LSB

Frequency spectrum and Bandwidth of AM Wave



- The figure shows the frequency spectrum of Am.
- It extends from $f_c - f_m (\text{max})$ to $f_c + f_m (\text{max})$.
- The band of frequencies b/w f_c and $f_c - f_m (\text{max})$ is called lower side band [LSB] and any frequency within this band is called lower side frequency [LSF].
- The band of frequencies b/w f_c and $f_c + f_m (\text{max})$ is called upper side band [USB] and any frequency within this and is called upper side frequency [USF]

Bandwidth of AM.

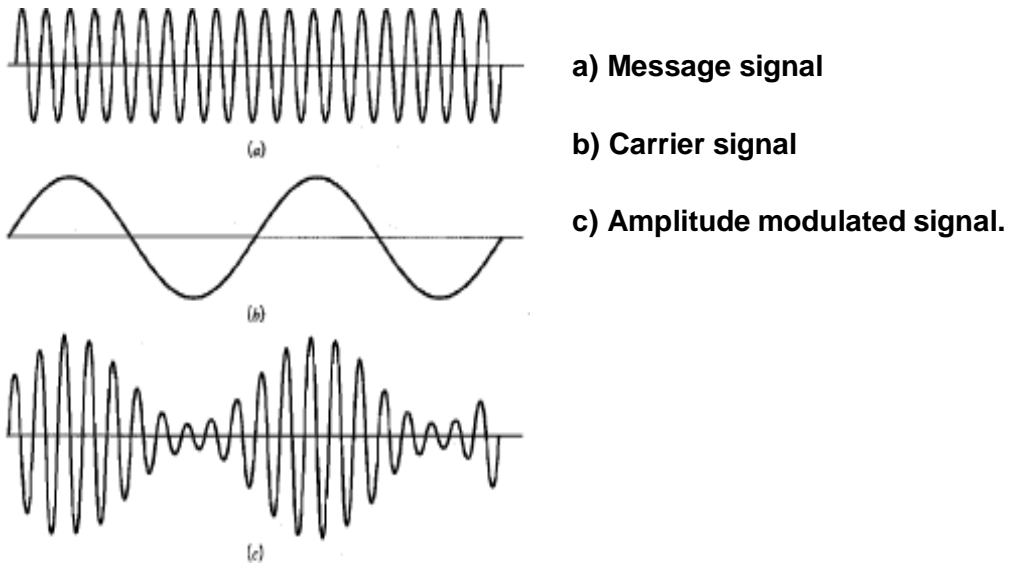
The Bandwidth of Am wave is equal to the difference b/w the highest upper side frequency and lowest lower side frequency.

$$B = f_c + f_m (\text{max}) - [f_c - f_m (\text{max})]$$

$$= f_c + f_m (\max) - f_c + f_m (\max)$$

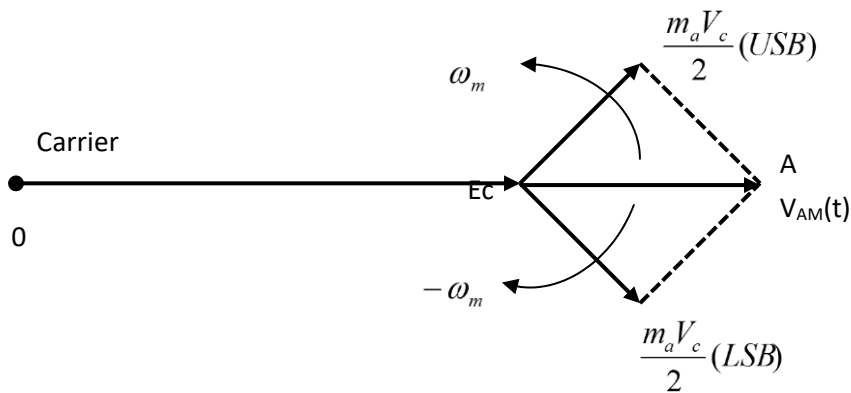
$$BW = 2f_m (\max)$$

AM Waveform



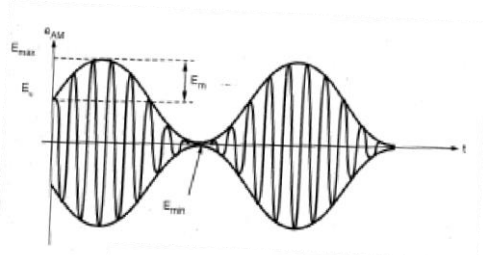
The shape of modulated waveform is known as **AM envelope**.

Phasor representation of AM



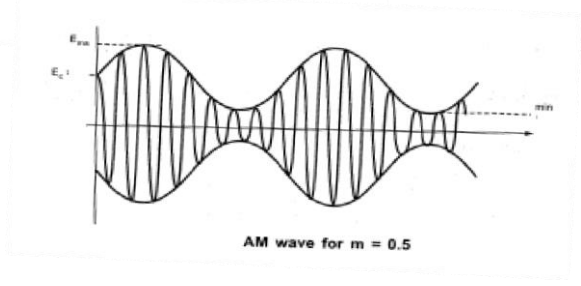
- Based on the modulation index modulation can be either,
 - (i). Critical Modulation
 - (ii). Over Modulation
 - (iii). Under Modulation
- When $E_m = E_c$ modulation goes to 100% this situation is known as critical modulation.

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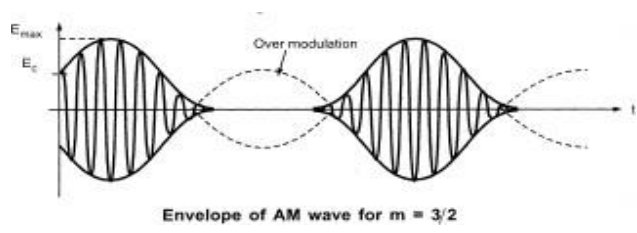


- $E_m < E_c$

leads to under modulation.



- $E_m > E_c$ leads to over modulation.



AM POWER DISTRIBUTION

- The modulated wave contains three terms such as carrier wave, LSB, USB.
- The modulated wave contains more power than the unmodulated carrier.

Total Power in modulated wave will be,

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

i.e. total power P_t of AM wave is the sum of carrier power and side band power.

P_c - Carrier power, P_{USB} - Upper Side Band power, P_{LSB} - Lower Side Band power

The carrier power is

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

The lower and upper sideband powers are same which is given by

$$P_{USB} = P_{LSB} = \frac{(m_a E_c / 2\sqrt{2})^2}{R} = \frac{m_a^2 E_c^2}{8R}$$

In terms of carrier power

$$P_{USB} = P_{LSB} = \frac{(m_a E_c / 2\sqrt{2})^2}{R} = \frac{m_a^2 E_c^2}{8R} = \frac{m_a^2 P_c}{4}$$

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

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

$$P_t = P_c \left(1 + \frac{m_a^2}{2} \right)$$

AM CURRENT DISTRIBUTION

The equation of P_t given by

$$\frac{P_t}{P_c} = \left(1 + \frac{m_a^2}{2} \right)$$

$$P_t = I_t^2 R$$

$$P_c = I_c^2 R$$

$$I_t^2 = I_c^2 \left(1 + \frac{m_a^2}{2} \right)$$

$$I_t = I_c \sqrt{1 + \frac{m_a^2}{2}}$$

Where I_t = Total(or)modulated current, I_c = Carrier current

Efficiency:

$$\% \eta = \frac{\text{Power in side band}}{\text{Total Power}} * 100$$

$$= \frac{P_{LSB} + P_{LSB}}{P_{Total}} * 100$$

$$= \frac{m_a^2}{2 + m_a^2} * 100$$

If $m_a = 1$, Then $\% \eta = 33.33 \%$

In this only one third of total power is carried by the sidebands and the rest two third is wasted.

Modulation by a complex information signal:

- If the modulating signal contains two frequencies say f_{m1} & f_{m2} , the modulated wave will contain the carrier and two sets of side frequencies. Spaced symmetrically about the carrier.

$$V_{am}(t) = \sin 2\pi f_c t + \frac{1}{2} \sin 2\pi (f_c - f_{m1}) t - \frac{1}{2} \sin 2\pi (f_c + f_{m1}) t + \frac{1}{2} \sin 2\pi (f_c - f_{m2}) t - \frac{1}{2} \sin 2\pi (f_c + f_{m2}) t$$

- The coefficient of modulation or modulation index is given by $m_t = \frac{\sqrt{m_1^2 + m_2^2}}{\dots}$
- In general for n different signals $m_t = \sqrt{m_1^2 + m_2^2 + \dots + m_n^2}$
- $P_{usb} = P_{lsb} = P_c m_t^2 / 4$

$$P_t = P_c (1 + m_t^2 / 2)$$

Advantages, Disadvantages and Applications of AM (DSBFC)

Advantages

1. Simple and inexpensive receivers. Easy to detect with simple equipment even if the signal is not very strong
2. Narrow bandwidth than FM
3. Wider coverage
4. Well-established, mature art used for broadcasting almost exclusively

Disadvantages

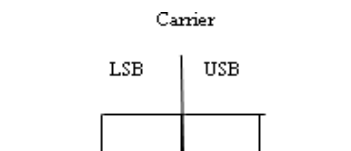
1. Received signal affected by electrical storms and other radio frequency interference
2. Receivers able to reproduce frequencies up to 5 MHz or less
3. Inefficient use of transmitter power

Applications

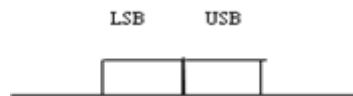
1. Low quality form of modulation that is used for commercial broadcast of both audio and video signals
2. Two way mobile radio communications such as citizen band (CB) radio
3. Aircraft communication in the VHF frequency range

TYPES OF AM MODULATION

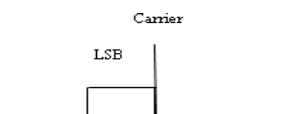
1. Double sideband with full carrier



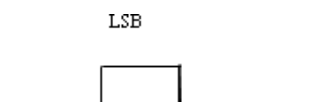
2. Double side without carrier



3. Single sideband with carrier



4. Single sideband without carrier



5. Vestigial sideband



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AM modulating Circuits

- Based on the location in the transmitter AM modulating circuits are classified as
 - a. Low level AM modulator
 - b. High level AM modulator

Difference b/w low level and High level AM mod.

Low level AM modulator	High level AM modulator
Modulation takes place prior to the final stage of the transmitter	Modulation takes place in the final element of final stage.
Less modulating signal power is required	More modulating signal power is required.

GENERATION OF AM-DSBFC (AM MODULATORS)

The generation method of AM waves are broadly divided in to two types

- Linear modulator(or)large signal modulator(or)high level modulation
- Non Linear modulator(or)small signal modulator(or)low level modulation

LINEAR MODULATOR:

In this type of modulators the devices are operated in linear region of its transfer characteristics. **Linear modulators are also divided in to two types,**

- Transistor modulator
- Switching modulator.

NON LINEAR MODULATORS:

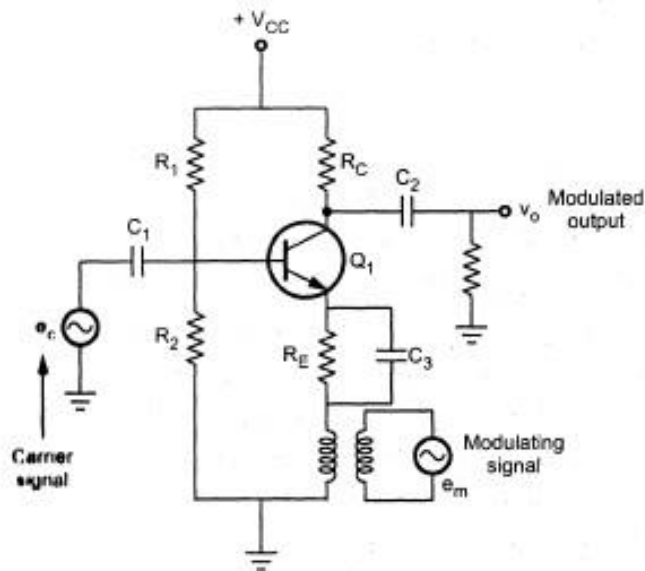
These modulators are operated in nonlinear region. These are used in low level modulation.

The types of non linear modulators are,

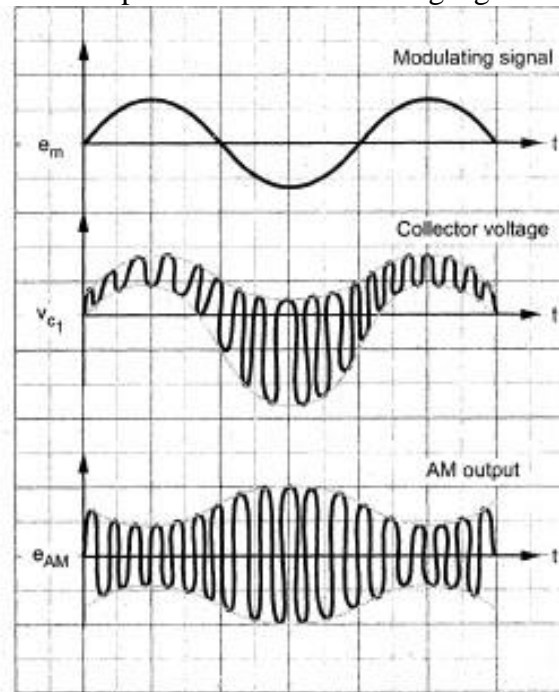
- Square law modulator,
- Product modulator,
- Balanced modulator.

LOW LEVEL AM MODULATOR

- Class A amplifier can perform amplitude modulation.
- Amplifier must have 2 inputs one for the carrier signal & second for modulating signal.
- With no modulating signal present, the circuit operates as a linear class A amplifier, and the output is simply the carrier amplified by the quiescent voltage gain .
- The carrier is applied the base and the modulating signal to the emitter. Hence it is also called as **Emitter Modulation**.
- The modulating signal varies the gain of the amplifier at a sinusoidal rate equal to the frequency of the modulating signal.
- The depth of modulation achieved is proportional to the amplitude of the modulating signal.



(a) Circuit diagram of low level AM modulator



(b) Waveforms

- The voltage gain for an emitter modulator is expressed as,

$$A_v = A_q (1 + m \sin 2\pi f_m t)$$

A_v → Amplifier voltage gain with modulation.

A_q → Amplifier quiescent (without modulation) voltage gain.

$\sin 2\pi f_m t$ varies from +1 to -1

Hence, $A_v = A_q (1 \pm m)$

$$A_{v \max} = 2A_q, \quad \text{when } m = +1$$

$$A_{v \min} = 0, \quad \text{when } m = -1$$

- The modulating signal drives the circuit into both saturation and cutoff, thus producing the nonlinear amplification necessary for modulation to occur. The collector waveform includes the carrier and the upper

and lower side frequencies as well as a component at the modulating signal frequency from the waveform, thus producing a symmetrical AM envelop at V_{out} .

Advantages of Low level modulation:

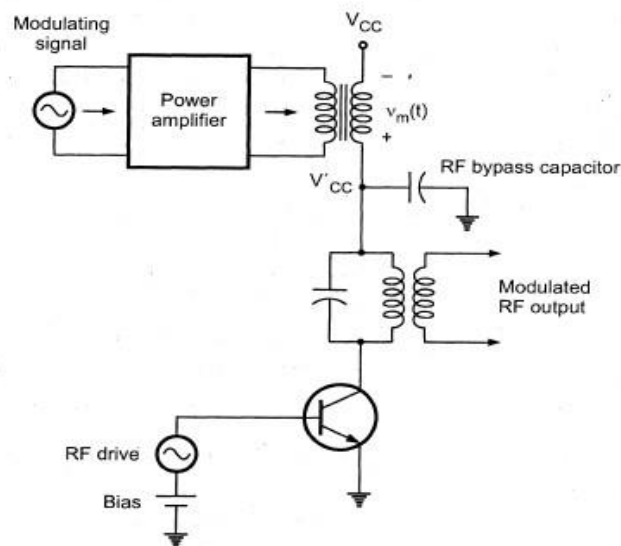
1. Less modulating signal power is required to obtain high percentage modulation.
2. Modulating circuit is designed for low power.

Disadvantage of Low level modulation

Amplifiers following modulator stage must be linear. At high operating powers linear amplifiers are very inefficient.

HIGH POWER AM MODULATOR / MEDIUM POWER AM MODULATOR

- The class C amplifier is used. It operates nonlinear and is capable of nonlinear mixing (modulation).
- This is known as collector modulator because modulating signal is applied to the collector.
- When the amplitude of the carrier exceeds the barrier potential (0.7V) Q1 turns on collector current flows.



- When carrier voltage drops below 0.7V Q1 turns off and collector current ceases.
- The corresponding current and voltage waveforms are shown.
- When the modulating signal is applied it adds up with the E_c and gets submitted from E_c producing an Am o/p.

Advantages of high level modulators:

- There is no constraint of linear operation on amplifiers preceding modulator stage.
- Power efficiency is good

Disadvantages of high level modulators:

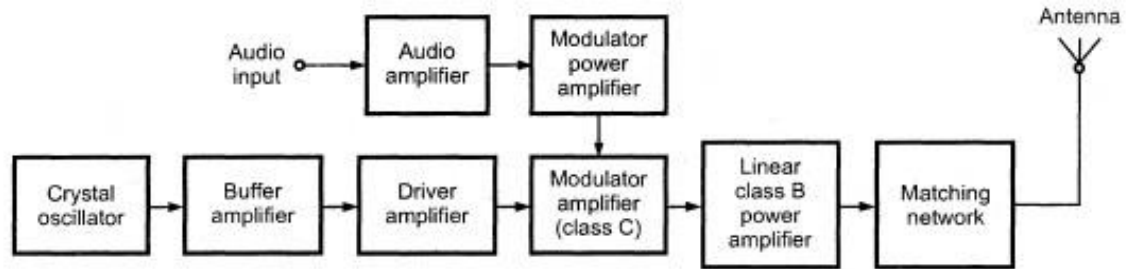
- High modulating power is required.
- Final modulating signal amplifier has to supply all the sideband power.

AM TRANSMITTERS

Low Level AM Transmitter

- The block diagram of a typical AM transmitter is shown in which carrier source is a crystal oscillator. The crystal oscillator is stabilized in order to maintain the carrier frequency deviation within a prescribed limit.

- The crystal oscillator is followed by a tuned buffer amplifier (class B) and drive amplifier.

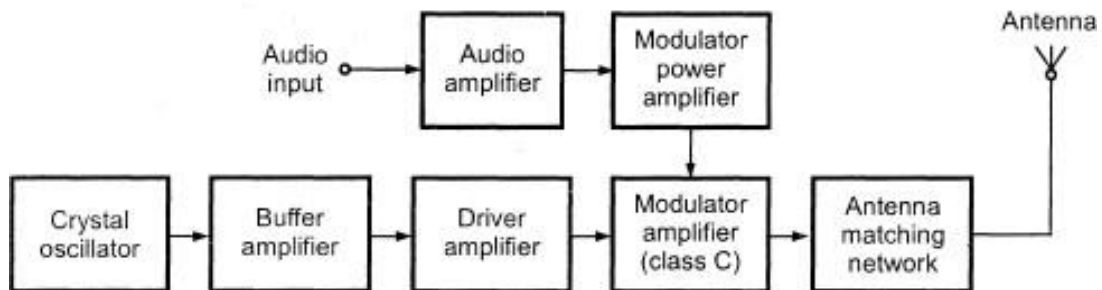


Low level AM Transmitter

- The modulator circuit used is generally a class C power amplifier that is a collector modulator.
- The audio signal is amplified by a chain of low level audio amplifiers and a power amplifier. This amplifier is controlling the power being delivered to the final RF amplifier. Class B push pull amplifier is usually used for this purpose.
- The amplified modulating signal is applied to the modulator along with the carrier. AM wave is got at the output of the modulator.
- This AM signal is then amplified using a chain of linear amplifiers to raise its power level. Class B amplifiers are used for this purpose. The linear power amplifier is used to avoid the distortion in the AM wave.
- The amplitude modulated signal is then transmitted using transmitting antenna. The matching network matches the output impedance of the final amplifier to the transmission line and antenna.

Application of Low Level AM Transmitter: It is used in low capacity system such as wireless intercoms, Remote control units, pagers, shot range talkie.

High Level AM Transmitter



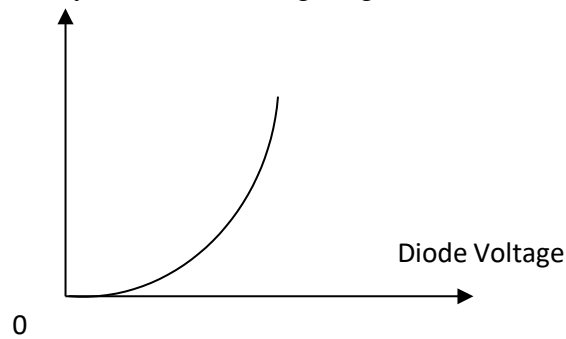
High level AM Transmitter

- Here modulating signal power should be higher than the low level.
- The amplification takes place prior to modulation.

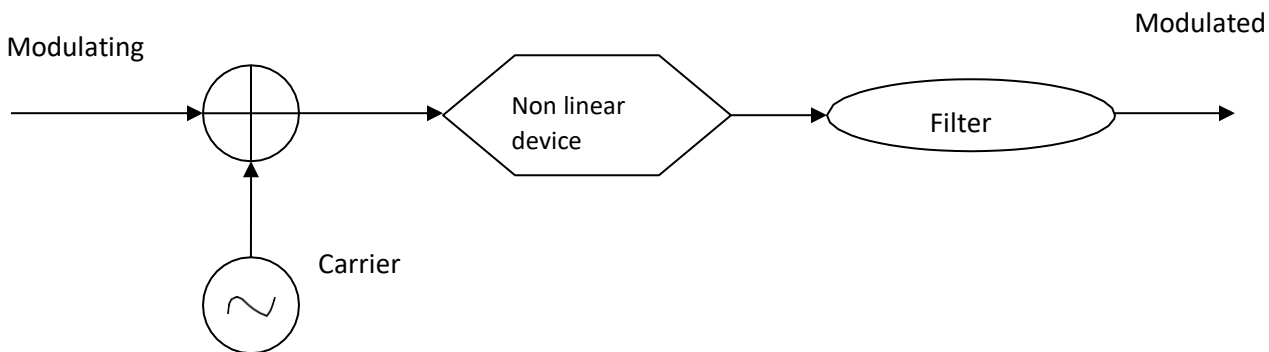
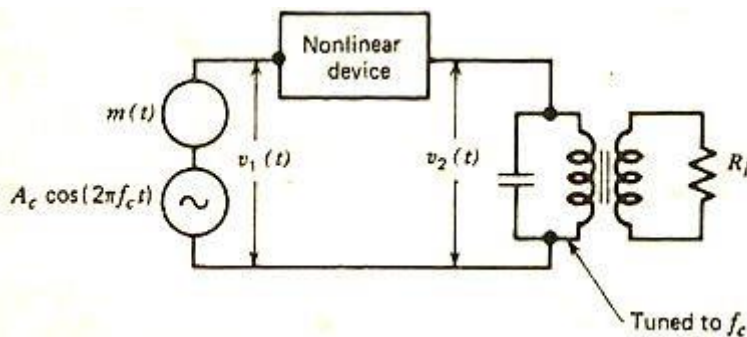
Application of High Level Transmitter: Used for long distance communications.

SQUARE LAW MODULATOR

- The non linear portion of V-I characteristics of diode is used as a element for non-linear modulators.
- This is suited at low voltage levels because of the fact that current-voltage characteristics of a diode is highly non-linear particularly in the low voltage region as shown in figure.



- A square law modulator has three features shown in figure.
- Summer - To sum carrier and modulating signal
- A non linear element
- Band pass filter for extracting desired modulating products.



Principle of operation:

- From the figure the non linear device diode is used to produce low level amplitude modulation.
- Here the carrier and modulating signals are applied across the diode.
- A dc battery E_{cc} is connected across the diode to get a fixed operating point on the V-I characteristics of the diode.
- This amplitude modulation that is low level can be explained by considering the fact when two different frequencies are passed through the non linear device.
- So when we apply carrier and modulating frequencies different frequency terms appear at the output of diode.
- These different frequency terms are applied across the tuned circuit which is tuned to carrier frequency and has a narrow bandwidth just to pass two sidebands along with the carrier and reject other frequencies.

- So the output of the tuned circuit will be carrier and two sidebands that is amplitude modulated wave is produced.

Mathematical analysis:

Let the modulating voltage will be

$$e_m(t) = E_m \sin \omega_m t \text{-----(1)}$$

Let the carrier voltage will be

$$e_c(t) = E_c \sin \omega_c t \text{-----(2)}$$

So the input voltage applied to the diode will be

$$\begin{aligned} e_1(t) &= e_m + e_c \\ &= E_m \sin \omega_m t + E_c \sin \omega_c t \text{----- (3)} \end{aligned}$$

We know that the current and voltage relationship of a linear circuit is,

$$i = av$$

where i=current through linear device

v=voltage through the linear device

a=proportionality constant

- The current and voltage relationship of a nonlinear circuit may be expressed as,

$$i = a V_1 + b V_1^2 + c V_1^3 + \text{-----}$$

- This means that due to non-linearity in the V-I characteristics of a non-linear circuits, the current becomes proportional not only to voltage but also to the square, cube and higher powers of voltage. So

$$i = a_1 V_1 + a_2 V_1^2 + a_3 V_1^3 + \text{-----(4)}$$

Where a_1, a_2, a_3 are proportionality constants and V_1 is the input voltage applied to the diode or FET.

- Sub eqn (3) in (4) then

$$\begin{aligned} i &= a_1(E_m \sin \omega_m t + E_c \sin \omega_c t) + a_2(E_m \sin \omega_m t + E_c \sin \omega_c t)^2 + \text{-----} \\ &= a_1 E_m \sin \omega_m t + a_1 E_c \sin \omega_c t + a_2 E_m^2 \sin^2 \omega_m t + a_2 E_c^2 \sin^2 \omega_c t + \\ &\quad 2a_2 E_m E_c \sin \omega_m t \sin \omega_c t + \text{---} \end{aligned}$$

Neglecting second and higher order terms, we get

$$i(t) = a_1 E_m \sin \omega_m t + a_1 E_c \sin \omega_c t + a_2 E_m E_c \sin \omega_m t \sin \omega_c t + \text{---}$$

$$= a_1 E_m \sin \omega_m t + a_1 E_c \sin \omega_c t + a_2 E_m E_c [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$$

- The tuned circuit is tuned to the carrier frequency and it allows only $\omega_c, \omega_c + \omega_m, \omega_c - \omega_m$ terms and eliminates all other terms. hence we obtain

$$i(t) = a_1 E_c \sin \omega_c t + a_2 E_m E_c [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t]$$

$i(t) = a_1 E_c \sin \omega_c t + a_2 E_m E_c \cos(\omega_c - \omega_m)t - a_2 E_m E_c \cos(\omega_c + \omega_m)t \text{----- (5)}$		
(carrier)	(LSB)	(USB)

➤ The

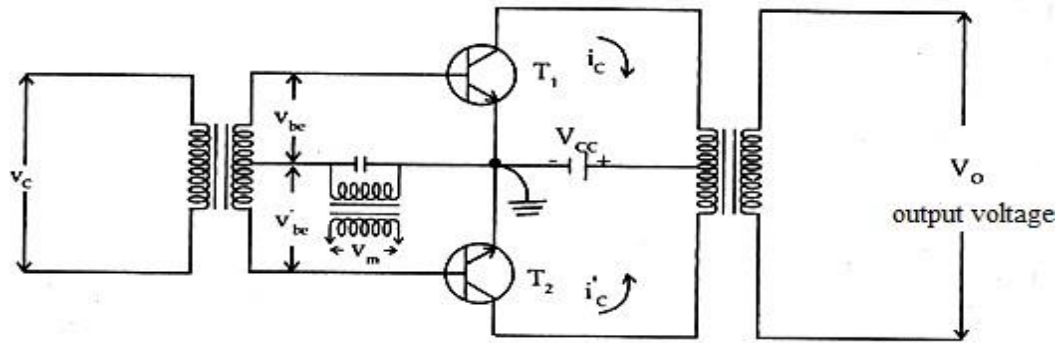
main drawback of using diode modulator is it does not provide amplification and a single diode is unable to balance out the frequency completely. These limitations can be eliminated by using amplifying devices like transistor, FET in a balanced mode.

- We can also use the square law modulator with FET instead of diode.

- From the final equation we know that it consists only the carrier and USB and LSB frequency components and all the components are removed.

BALANCE MODULATOR METHOD

It is assumed that the two transistors are identical and the circuit is symmetrical. The operation is confined in the nonlinear region of the active devices employed in this circuit. The carrier voltage across the upper and lower part of the secondary windings of the center tap transformers are equal in magnitude and opposite in phase.



BALANCED MODULATOR

- In this the carrier voltage across the two windings of a centre tap transformers are equal and opposite in phase $V_{be} = -V'_{be}$

- Input voltage to the transistor T1 is given by,
 $V_{be} = e_c(t) + e_m(t)$

$$V_{be} = E_c \sin \omega_c t + E_m \sin \omega_m t \text{----- (1)}$$

- Similarly Input voltage to the transistor T2,

$$V'_{be} = -e_c(t) + e_m(t)$$

$$V'_{be} = -E_c \sin \omega_c t + E_m \sin \omega_m t \text{----- (2)}$$

By using the non-linearity property the collector current can be written as per square law equation

$$i_c = a_1 V_{be} + a_2 V_{be}^2 + \dots \text{----- (3)}$$

$$i'_c = a_1 V'_{be} + a_2 V'_{be}^2 + \dots \text{----- (4)}$$

On substituting eqn 1 and 2 in 3 and 4 we get,

$$i_c = a_1 [E_c \sin \omega_c t + E_m \sin \omega_m t] + a_2 [E_c \sin \omega_c t + E_m \sin \omega_m t]^2$$

$$i_c = a_1 [E_c \sin \omega_c t + E_m \sin \omega_m t] + a_2 E_c^2 \sin^2 \omega_c t + a_2 E_m^2 \sin^2 \omega_m t + 2a_2 E_m E_c \sin \omega_m t \sin \omega_c t \text{---- (5)}$$

$$i'_c = a_1 [-E_c \sin \omega_c t + E_m \sin \omega_m t] + a_2 [-E_c \sin \omega_c t + E_m \sin \omega_m t]^2$$

$$i'_c = a_1 [-E_c \sin \omega_c t + E_m \sin \omega_m t] + a_2 E_c^2 \sin^2 \omega_c t + a_2 E_m^2 \sin^2 \omega_m t - 2a_2 E_m E_c \sin \omega_m t \sin \omega_c t \text{--- (6)}$$

$$\text{The output AM Voltage } V_0 \text{ is given by } V_0 = K [i_c - i'_c] \text{----- (7)}$$

since i_c, i'_c flows in the opposite direction and 'K' is a constant depending on impedance or other circuit parameters.

On substituting equation 5 and 6 in 7 we get,

$$V_o = K [i_c - i'_c]$$

$$E_o = K [2 a_1 E_c \sin\omega_c t + 4a_2 E_m E_c \sin\omega_m t \sin\omega_c t]$$

$$= 2KEc a_1 \sin\omega_c t \left[1 + \frac{2 a_2 E_m \sin\omega_m t}{a_1} \right]$$

$$= 2KEc a_1 \sin\omega_c t \left[1 + m_a \sin\omega_m t \right]$$

where $m_a = \frac{2 a_2 E_m}{a_1}$ is the modulation index

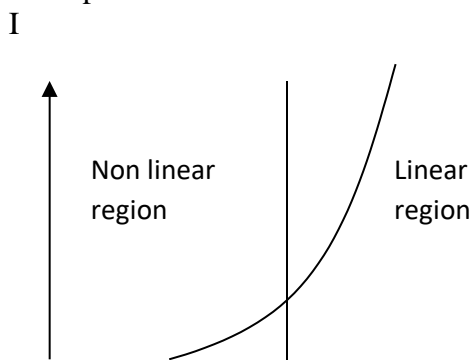
This equation represents the output modulated voltage which contains carrier and side band terms but no modulating terms. Thus this circuit is used as AM modulator. The advantage of this circuit is that the undesired harmonics are automatically balanced out and hence there is no need for separate filter.

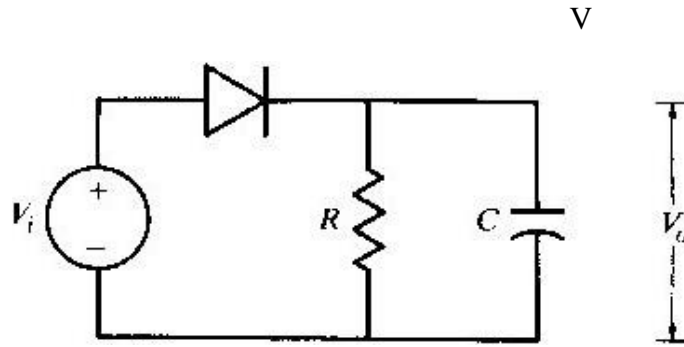
DEMODULATION/DETECTION OF AM-DSBFC (AM DEMODULATORS)

- Demodulation or detection is nothing but the process of extracting a modulating or information signal from modulated signal. Otherwise in other words, demodulation or detection is the process by which the message is recovered from the modulated signal at receiver.
- The devices used for demodulation or detection are called as demodulators or detector
- For amplitude modulation, the detectors or demodulators are categorized are
 - Square law detectors or nonlinear detectors**
 - Linear detectors**
- The low level modulated signals are using non linear detectors to recover the original message signal

SQUARE LAW DETECTOR

- The square law detector circuit is used for detecting low level modulated signal.
- Here the diode is used in V – I characteristics of the device i.e. non linear characteristics of the diode.
- The square law detector is similar to the square law modulator. The only difference lies in the filter circuit.
- In square law modulator we are using band pass filters, in square law detector; a low pass filter is used. The operation is limited to the non-linear region of the diode characteristics, so the lower half portion of the modulated waveform is compressed.
- This produces the envelope distortion, so the average value of the diode – current is no longer constant and varies with time. The average diode current consists of steady DC component and time varying modulation frequency. Due to nonlinear region the lower half of its current wave form is compressed. This may cause envelope distortion due to this diode current will not be constant, and varies with time.





SQUARE LAW DETECTOR

The distorted output diode current is expressed by the non-linear V-I relationship (i.e. square law) is,

$$i_0 = a_1 e_{AM} + a_2 e_{AM}^2 \quad (1)$$

where $e_{AM} = i/p$ modulated signal.

➤ The equation of AM wave is

$$e_{AM} = E_c (1 + m_a \sin \omega_m t) \sin \omega_c t \quad (2)$$

On substituting equation 2 in 1 we get

$$i_0 = a_1 E_c (1 + m_a \sin \omega_m t) \sin \omega_c t + a_2 [E_c (1 + m_a \sin \omega_m t) \sin \omega_c t]^2$$

$$i_0 = a_1 E_c \sin \omega_c t + a_1 m_a E_c \sin \omega_c t \sin \omega_m t + a_2 E_c^2 \sin^2 \omega_c t (1 + m_a \sin \omega_m t)^2$$

$$= a_1 E_c \sin \omega_c t + a_1 m_a E_c \sin \omega_c t \sin \omega_m t + a_2 E_c^2 \sin^2 \omega_c t (1 + m_a^2 \sin^2 \omega_m t + 2 m_a \sin \omega_m t)$$

$$= a_1 E_c \sin \omega_c t + a_1 m_a E_c \sin \omega_c t \sin \omega_m t + a_2 E_c^2 (1 + m_a^2 \sin^2 \omega_m t + 2 m_a \sin \omega_m t) \frac{1 - \cos 2\omega_c t}{2}$$

$$= a_1 E_c \sin \omega_c t + a_1 m_a E_c \sin \omega_c t \sin \omega_m t + \frac{a_2 E_c^2}{2} - \frac{a_2 E_c^2 \cos 2\omega_c t}{2} + \frac{a_2 E_c^2 m_a^2 \sin^2 \omega_m t}{2} +$$

$$- \frac{a_2 E_c^2 m_a^2 \sin^2 \omega_m t \cos 2\omega_c t}{2} + a_2 E_c^2 m_a \sin \omega_m t - a_2 E_c^2 m_a \sin \omega_m t \cos 2\omega_c t$$

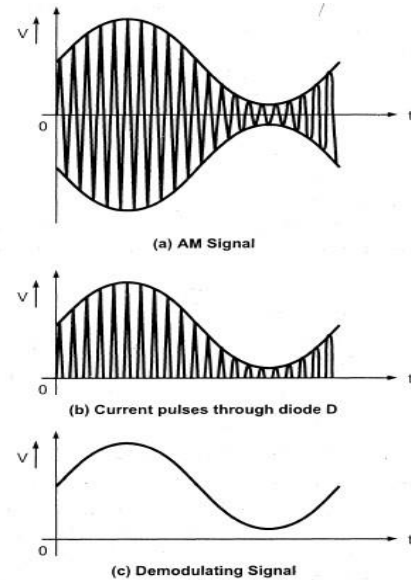
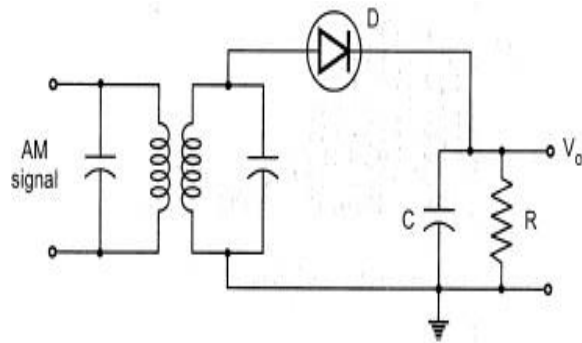
The carrier term is filtered by using a low pass filter and high frequency term are also reduced then,

$$i_0 = a_2 E_c^2 m_a \sin \omega_m t$$

So the final output contains a signal with modulating frequency. Hence original signal is recovered.

ENVELOPE DETECTOR

- A detector circuit whose output follows the envelope of the modulated signal which is used to reproduce the modulating or message signal is called as “Envelope Detector”.
- This is most popular commercial receiver circuits since it is very simple and not expensive, and also it gives satisfactory performance. An envelope detector of the series type is shown in Figure which consists of a diode and a resistor capacitor filter a time constant network.



Principle Of Operation:

- Modulated signal is applied to the series combination of diode and the load impedance consisting of a resistor R and C.
- Operation takes place over the linear region of VI characteristics of Diode.
- For positive cycle of carrier signal the diode D conducts thereby the capacitor charges to the peak voltage with the time constant $\tau = RC$ of the carrier signal through the resistor R.
- As the input falls below the peak value, the diode reaches cut-off. The diode acts as open switch and hence the capacitor gets discharge path through R.
- During negative half cycle the diode is reverse biased and the carrier voltage is disconnected from the RC circuit. So the capacitor discharges continuously until next positive cycle appears.
- From the peak of one positive cycle to the next the capacitor discharges slowly and this process continues. Thus the voltage across 'C' is same as the envelope of the modulated carrier but spikes are introduced. So the output voltage across capacitor is a spiky modulating or base band signal. So the envelope is detected at the output of capacitor. Thus from the average value the original signal is recovered by extracting the envelope.
- The spikes can be reduced to a negligible amount by keeping the time constant RC large so that the capacitor C discharges negligible amount.

CHOICE OF TIME CONSTANT RC

- Large (or) small value of time constant makes problem. So time constant is important consideration.
- **If time constant RC is quite low: Discharge curve during non conductive period is almost vertical, so fluctuations may occur in output voltage. This results in Diagonal clipping**
- **If RC is very large: Discharge curve is almost horizontal, so several peaks will be missed in the rectified output voltage. This results in negative peak clipping.**

Distortion in diode detector:

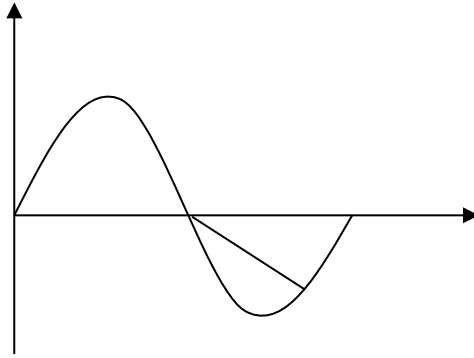
There are two clippings i.e. distortions available

Negative peak clipping

Diagonal clipping.

Diagonal clipping:

It results when time constant of detector is not selected properly. If the modulating voltage is faster than the rate of voltage fall across RC combination resulting in distorted output. This type of distortion is called diagonal clipping which results in distorted output.



- To avoid the diagonal clipping proper value of RC needs to be selected. The voltage across RC combination during the non-conducting period of diode is V_c at an instant t which is given by

$$V_c(t) = V_0 e^{-\frac{t}{RC}}$$

The rate of slope in capacitor due to period discharging is calculated by differentiating $V_c(t)$ So

$$\frac{dV_c(t)}{dt} = \frac{d}{dt} \left[V_0 e^{-\frac{t}{RC}} \right] = -\frac{V_0}{RC} e^{-\frac{t}{RC}} = -\frac{V_c(t)}{RC} \dots\dots\dots(1)$$

The decrease in capacitor voltage must follow the modulation envelope if distortion is to be avoided. The envelope of the modulated voltage is given by

$$e_{AM} = E_c (1 + m_a \cos \omega_m t)$$

The slope of the envelope is given by

$$\begin{aligned} \frac{de_{AM}}{dt} &= \frac{d}{dt} [E_c (1 + m_a \cos \omega_m t)] \\ &= -m_a E_c \omega_m \sin \omega_m t \end{aligned} \dots\dots\dots(2)$$

To avoid the clipping the slope of capacitor voltage V_c should be algebraically equal or less than the slope of envelope voltage, so

$$\begin{aligned} -\frac{V_c(t)}{RC} &\leq -E_c m_a \omega_m \sin \omega_m t \\ \frac{V_c(t)}{RC} &\geq E_c m_a \omega_m \sin \omega_m t \\ \frac{E_c (1 + m_a \cos \omega_m t)}{RC} &\geq E_c m_a \omega_m \sin \omega_m t \end{aligned}$$

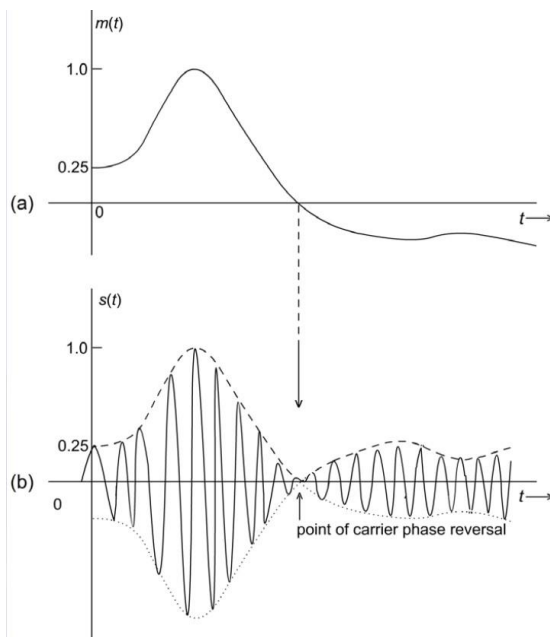
Mathematically the above equation is written as

$$\frac{1}{RC} \geq \frac{m_a \omega_m \sin \omega_m t}{(1 + m_a \cos \omega_m t)} \dots\dots\dots(3)$$

To find the maximum amount of RC differentiate the equation 3 and equate it to zero

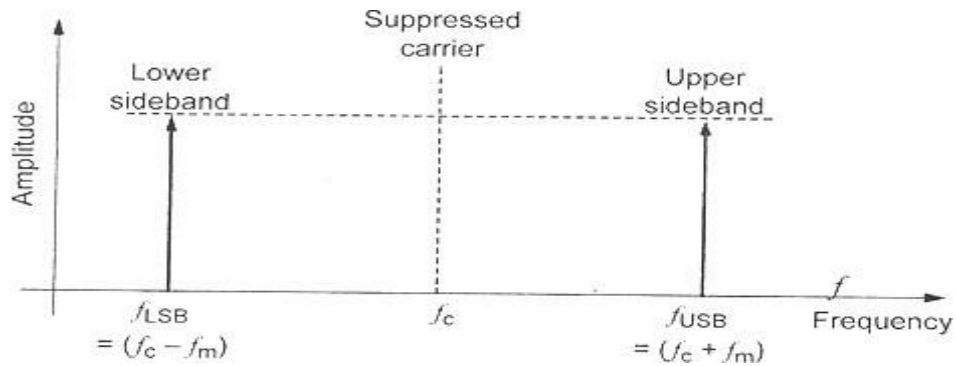
$$\begin{aligned} \frac{d}{dt} \left(\frac{m_a \omega_m \sin \omega_m t}{(1 + m_a \cos \omega_m t)} \right) &= 0 \\ m_a \omega_m \frac{(1 + m_a \cos \omega_m t) \cos \omega_m t \omega_m - \sin \omega_m t (m_a (-\sin \omega_m t) \omega_m)}{(1 + m_a \cos \omega_m t)^2} &= 0 \end{aligned}$$

$$\omega_m \cos \omega_m t + (m_a \cos^2 \omega_m t) \omega_m + (m_a \sin^2 \omega_m t) \omega_m = 0$$



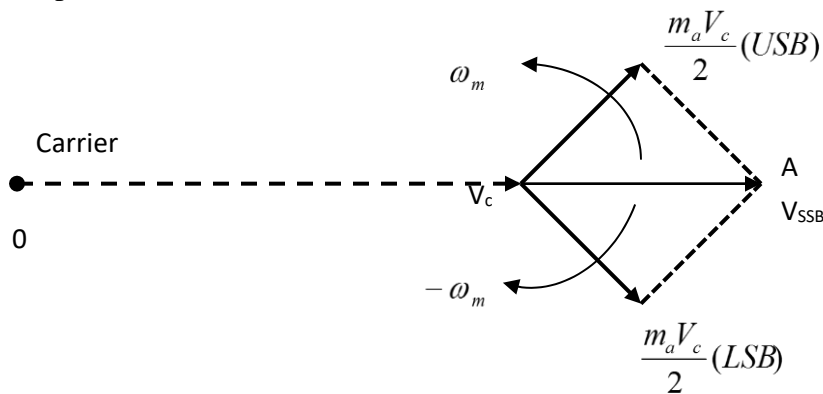
(a) Baseband signal (b) DSB-SC

Frequency spectrum of DSB-SC AM



It shows that carrier term ω_c is suppressed. It contains only two sideband terms having frequency $(\omega_c - \omega_m)$ and $(\omega_c + \omega_m)$. Hence this scheme is called as DSB-SC AM.

Phasor representation of DSB-SC AM:



POWER CALCULATION:

The total power transmitted in AM is

$$P_t = P_{\text{carrier}} + P_{\text{LSB}} + P_{\text{USB}}$$

If the carrier is suppressed, then the total power transmitted is

$$P_t' = P_{\text{LSB}} + P_{\text{USB}}$$

We know that, $P_{\text{LSB}} = P_{\text{USB}} = \frac{m_a^2 E_c^2}{8R}$

$$\begin{aligned} P_t' &= \frac{m_a^2 E_c^2}{8R} + \frac{m_a^2 E_c^2}{8R} \\ &= \frac{m_a^2 E_c^2}{4R} = \frac{m_a^2 P_c}{2} \end{aligned}$$

Therefore the power saving with respect to AM is

$$\begin{aligned} \text{Power Saving} &= \frac{P_t - P_t'}{P_t} \times 100 \\ &= \frac{[1 + m_a^2/2] P_c - [m_a^2/2] P_c}{[1 + m_a^2/2] P_c} \\ &= \frac{P_c}{[1 + m_a^2/2] P_c} \end{aligned}$$

$$\% \text{ Power Saving} = \frac{2}{2 + m_a^2} \times 100$$

If $m_a = 1$, then power saving $(2/3) \times 100 = 66.7\%$
i.e 66.7% of power is saved by using DSB-SC-AM.

Advantages

DSB-SC is more efficient in transmitted power as compared to DSB-FC.
DSB-FC has better signal to noise ratio as compared to SSB transmission.

Disadvantages

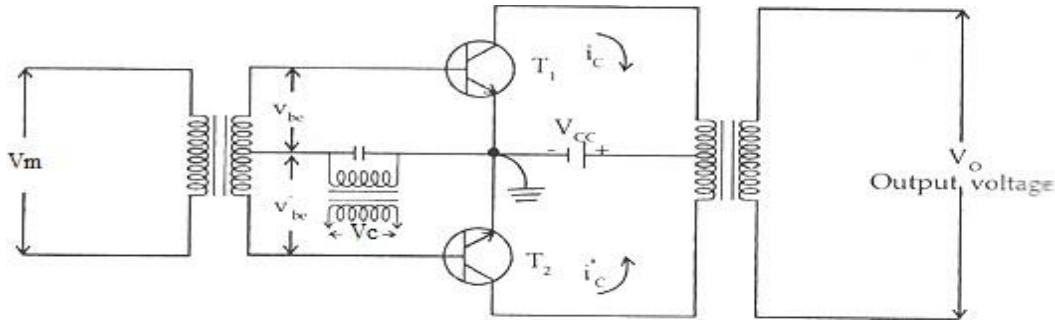
Bandwidth remains same as DSB-FC even though the carrier is suppressed.

GENERATION OF AM-DSBSC

1. Balanced Modulator Method
2. Ring Modulator Method

BALANCE MODULATOR METHOD

- The same circuit can be used to generate AM with carrier. The main difference between AM with carrier generation and DSB-SC –AM is the feeding points of the carrier and modulating signals are interchanged.
- The transistor is operated in a balanced mode thus heavy filtering is not required to remove the unwanted harmonics.
- It is assumed that the two transistors are identical and the circuit is symmetrical. The operation is confined in the nonlinear region of the active devices employed in this circuit. The carrier voltages across the upper and lower part of the secondary windings of the center tap transformers are equal in magnitude and opposite in phase.



BALANCED MODULATOR

Principle of operation:

- The modulating signal is applied as the input to the transistor T₁ and T₂ and the carrier signal is applied to the common input of the push pull amplifier configuration. Because of centre tap transformers are equal and opposite in phase $V_m = -V_m$

- Input to the transistor T₁ is given by,

$$V_{be} = e_m(t) + e_c(t)$$

$$V_{be} = E_m \sin \omega_m t + E_c \sin \omega_c t \text{ ----- (1)}$$

- Similarly Input to the transistor T₂,

$$V'_{be} = -e_m(t) + e_c(t)$$

$$V'_{be} = -E_m \sin \omega_m t + E_c \sin \omega_c t \text{ ----- (2)}$$

By using the non-linearity property the collector current can be written as per square law equation

$$i_c = a_1 V_{be} + a_2 V_{be}^2 + \dots \text{ ----- (3)}$$

$$i'_c = a_1 V'_{be} + a_2 V'_{be}{}^2 + \dots \text{ ----- (4)}$$

On substituting eqn 3 and 4 in 1 and 2 we get

$$i_c = a_1 [E_m \sin \omega_m t + E_c \sin \omega_c t] + a_2 [E_m \sin \omega_m t + E_c \sin \omega_c t]^2$$

$$i_c = a_1 [E_m \sin \omega_m t + E_c \sin \omega_c t] + a_2 E_m^2 \sin^2 \omega_m t + a_2 E_c^2 \sin^2 \omega_c t + 2a_2 E_m E_c \sin \omega_m t \sin \omega_c t \text{ ----- (5)}$$

Similarly

$$i_c = a_1 [-E_m \sin \omega_m t + E_c \sin \omega_c t] + a_2 [-E_m \sin \omega_m t + E_c \sin \omega_c t]^2$$

$$i_c = a_1 [-E_m \sin \omega_m t + E_c \sin \omega_c t] + a_2 E_m^2 \sin^2 \omega_m t + a_2 E_c^2 \cos^2 \omega_c t - 2a_2 E_m E_c \sin \omega_m t \sin \omega_c t \text{ ----- (6)}$$

$$\text{The output AM voltage } V_0 \text{ is given by } V_0 = K [i_c - i'_c] \text{ ----- (7)}$$

Because i_c , i'_c flows in the opposite direction and 'K' is a constant depending on impedance or other circuit parameters.

On substituting equation 5 and 6 in 7 we get,

$$V_o = K[i_c - i'_c]$$

$$V_o = K [2a_1 E_m \sin\omega_{mt} + 4a_2 E_m E_c \sin\omega_{mt} \sin\omega_{ct}]$$

The output contains the original modulating signal and the two sidebands. The modulating signal has been suppressed by tuning the tank circuit to the center frequency $\pm\omega_c$

$$\begin{aligned} V_o &= 4Ka_2 E_m E_c \sin\omega_{mt} \sin\omega_{ct} \\ &= 2Ka_2 E_m E_c [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t] \end{aligned}$$

- So only the side bands are present in the o/p. Hence the DSB-SC-AM generated.
- The main advantage of this modulator is saving power and efficiency because of the suppressing of the carrier.

RING MODULATOR METHOD

- The balanced Ring modulator circuit is widely used in carrier telephony suppresses both unwanted modulating and carrier signal in its output.
- Ring modulator is a type of product modulator which is used to generate DSB-SC Signal.
- The band pass filter is not used at the output hence the harmonic frequencies are automatically controlled.
- In a ring modulator circuit four diodes are connected in the form of ring in which all the four diodes are connected in the same manner and are controlled by a square wave carrier signal $e_c(t)$.
- The carrier signal acts as a switching signal to alternate the polarity of the modulating signal at the carrier frequency.
- When no modulating signal is present diode D_1 and D_2 or D_3 and D_4 will conduct depending upon polarity of the carrier.

POSITIVE HALF CYCLE OF CARRIER:

- Diodes D_1 and D_3 are forward biased. At this time D_2 and D_4 are reverse biased and act like open circuits. The current divides equally in the upper and lower portion of the primary winding T2.
- The current in the upper part of the winding produces a magnetic field that is equal and opposite to the magnetic field produced by the current in the lower half of the secondary.
- Therefore the magnetic fields cancel each other out and no output is induced in the secondary. Thus the carrier is effectively suppressed.

NEGATIVE HALF CYCLE OF CARRIER:

- When the polarity of the carrier reverses. Diodes D_1 and D_2 are reverse biased and the diodes D_3 and D_4 will conduct. Again the current flows in the secondary winding of T1 and the primary winding of T2.
- The equal and opposite magnetic fields produced in T2 cancel each other and thus result in zero carrier output. The carrier is effectively balanced out.

PRINCIPLE OF OPERATION

- When both the carrier and the modulating signals are present, during positive half cycle of the carrier diodes D_1 and D_2 conduct, while diodes D_3 and D_4 does not conduct.
- During negative half cycle of the carrier voltage diodes D_3 and D_4 conduct and D_1 and D_2 does not conduct.
- When polarity of the modulating signal changes the result is a 180 phase reversal. At the time D_3 and D_4 are in forward bias.

Let us consider the modulating voltage,

$$e_m(t) = E_m \sin \omega_m t \text{-----(1)}$$

$$e_c(t) = E_c \sin \omega_c t \text{-----(2)}$$

The output voltage is $V_0(t) = e_m(t) \cdot e_c(t)$

$$= E_m \cdot E_c \sin \omega_m t \sin \omega_c t$$

$$V_0(t) = \frac{E_m \cdot E_c}{2} [\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t] \text{-----(3)}$$

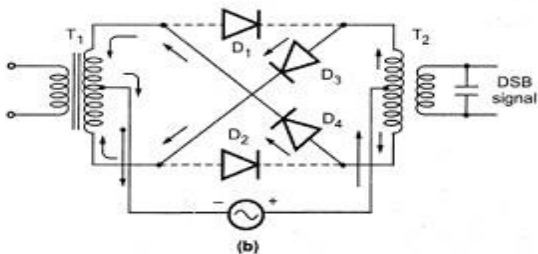
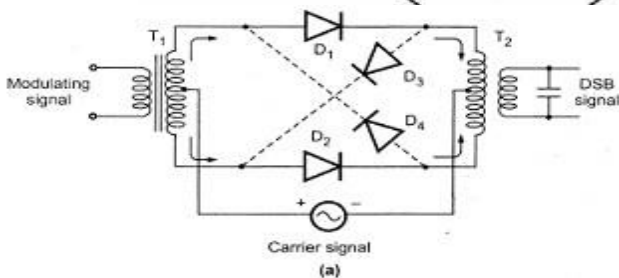
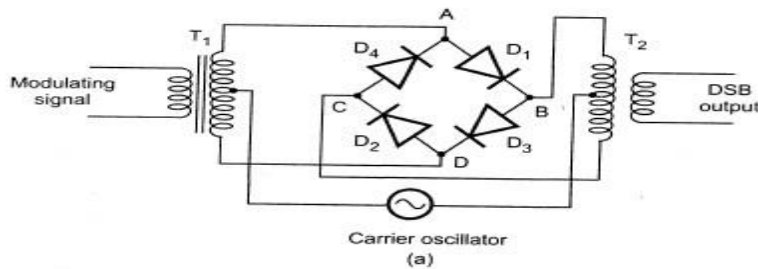
LSB

USB

The equation 3 shows that the o/p is free from the carrier and other higher order terms and it contains upper and lower sidebands only. The ring modulator circuit is also known as double balanced modulator because it is balanced with respect to both the baseband signal and the square wave carrier. The main advantage is the o/p is stable and long life, no external source to activate the diodes.

Circuit diagram:

Waveform:



(a) Equivalent circuit of balanced modulator showing positive half cycle of carrier

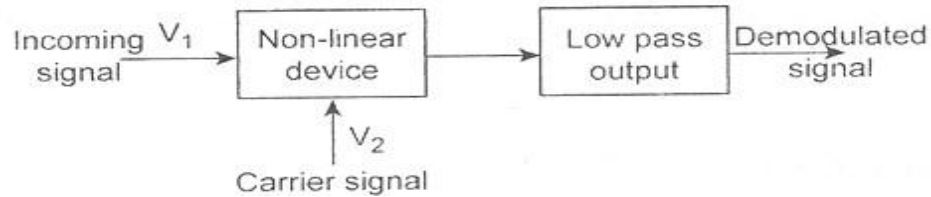
(b) Equivalent circuit of balanced modulator showing negative half cycle of carrier

DEMODULATION/DETECTION OF AM-DSBSC

- SYNCHRONOUS OR COHERENT DETECTOR
- COSTAS PLL DETECTOR

SYNCHRONOUS OR COHERENT DETECTOR

- The coherent detector uses exact carrier synchronization for retrieving the message signal from modulated signal. These types of detectors are mainly used for detecting DSB&SSB signals.
- It consists of a product modulator with a low pass filter.
- For detecting signal local oscillator at the receiver end is required. The frequency and phase of the locally generated carrier and transmitter carrier must be synchronized that is exactly coherent.
- All types of linear modulation can be detected by using synchronous detector. It consists of a product modulator with LPF.



- The incoming signal is first multiplied with locally generated carrier and then passed through low pass filter. The filter bandwidth is same as the message bandwidth ω_m
- The local oscillator should be exactly synchronized with carrier signal in both phase and velocity.
- **Considering the case of DSB-SC signal, the signal I/p is**

$$e_1(t) = E_m \cdot E_c \sin \omega_m t \sin \omega_c t$$

$$e_2(t) = E \sin \omega_c t$$

The output of the non linear device which acts as a multiplying device is given by

$$e(t) = e_1(t) \cdot e_2(t) = E_m \cdot E_c \cdot E \sin \omega_m t \sin^2 \omega_c t$$

$$e(t) = E_m \cdot E_c \cdot E \sin \omega_m t \frac{1 - \cos 2\omega_c t}{2}$$

After passing through the LPF the second order harmonic term is eliminated.

$$e(t) = \frac{E_m \cdot E_c \cdot E \sin \omega_m t}{2}$$

Assume the local oscillator carrier to have a phase difference with the transmitted carrier. The carrier is represented by

$$e_2(t) = E \sin(\omega_c t + \phi)$$

The output of the non linear device is given by

$$e(t) = e_1(t) \cdot e_2(t) = E_m \cdot E_c \cdot E \sin \omega_m t \sin \omega_c t \sin(\omega_c t + \phi)$$

$$= E_m \cdot E_c \cdot E \sin \omega_m t \sin \omega_c t [\sin \omega_c t \cos \phi + \cos \omega_c t \sin \phi]$$

$$= E_m \cdot E_c \cdot E \sin \omega_m t \sin^2 \omega_c t \cos \phi + E_m \cdot E_c \cdot E \sin \omega_m t \sin \omega_c t \cos \omega_c t \sin \phi$$

$$= E_m \cdot E_c \cdot E \sin \omega_m t \cos \phi \left[\frac{1 - \cos 2\omega_c t}{2} \right] + E_m \cdot E_c \cdot E \sin \omega_m t \sin \omega_c t \cos \omega_c t \sin \phi$$

$$= \frac{E_m \cdot E_c \cdot E \sin \omega_m t \cos \phi}{2} - \frac{E_m \cdot E_c \cdot E \sin \omega_m t \cos \phi \cos 2\omega_c t}{2} + E_m \cdot E_c \cdot E \sin \omega_m t \sin \omega_c t \cos \omega_c t \sin \phi$$

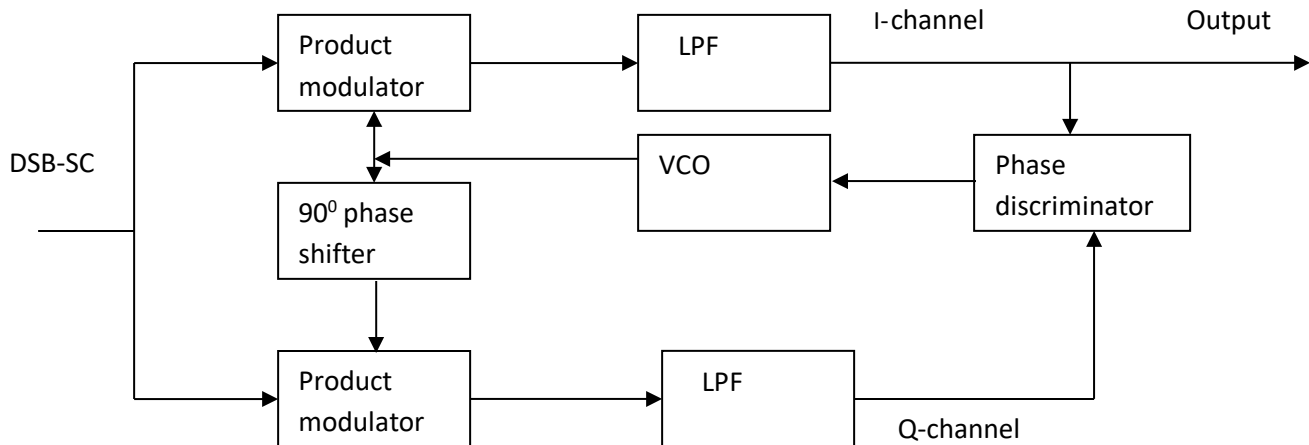
After passing through the LPF the second order harmonic term is eliminated.

$$e(t) = \frac{E_m \cdot E_c \cdot E \sin \omega_m t \cos \phi}{2}$$

If $\varphi = 90$ then $e(t)$ is minimum $e(t) = 0$

The demodulated signal $V_o(t)$ is therefore proportional to the message signal when the phase error, $\varphi = 0$ and it is minimum (zero) when $\varphi = \pm \frac{\pi}{2}$. Thus the phase error φ in the local oscillator causes the detector output to be attenuated by a factor equal to $\cos\varphi$. As long as the phase error is constant, the detector provides an undistorted version of the original baseband signal.

COSTAS PLL DETECTOR



- Costas receiver is one of the method for obtaining a practical synchronous receiver suitable for demodulating DSB-SC waves. It consists of two coherent detectors supplied with the same input signal.
- One detector is supplied with the DSB-SC AM and locally generated carrier which is in phase with the transmitted carrier. This detector is known as **“In-phase coherent detector or I channel”**.
- The other detector is supplied with the DSB-SC AM and locally generated carrier which is quadrature phase with the transmitted carrier. This detector is known as **“Quadrature coherent detector or Q channel”**.
- These two detectors are coupled together to form a negative feedback system designed in such a way as to maintain the local oscillator synchronous with the carrier wave.

Operation of the circuit:

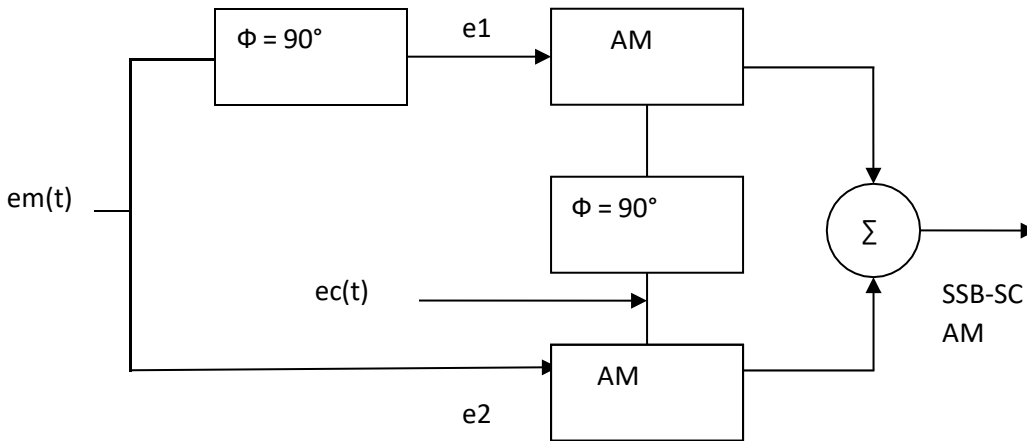
- In this case I channel output contains the desired demodulated signal where as Q channel output is zero due to the quadrature null effect of Q channel.
- Suppose there is some phase shift φ radians between local oscillator carrier and the transmitting carrier then I channel output will remain essentially unchanged. But Q channel output contains some signal which is proportional to $\sin \varphi$
- This Q channel output will have same polarity as the I channel output for one direction of local oscillator whereas the polarity will be opposite to the I channel for the other direction of phase shift.
- Thus the I and Q channel outputs are combined in phase discriminator
- The phase discriminator provides a d.c. control signal which may be used to correct local oscillator phase error.
- The local oscillator is a voltage controlled oscillator. Its frequency can be adjusted by an error control d.c signal.
- The costas receiver ceases phase control when there is no modulation and that phase lock has to be re-established with reappearance of modulation.

SINGLE SIDEBAND SUPPRESSED CARRIER

In AM with carrier both the transmitting power and bandwidth is wasted. Hence the DSB-SC AM scheme has been introduced in which power is saved by suppressing the carrier component but the bandwidth remains same.

- Increase in the saving of power is possible by eliminating one sideband in addition to the carrier component because the USB and LSB are uniquely related by symmetry about the carrier frequency. So either one sideband is enough for transmitting as well as recovering the useful message. The block diagram of SSB-SC AM is shown in figure.
- As for as transmission information is concerned only one side band is necessary. So if the carrier and one of the two sidebands are suppressed at the transmitter, no information is lost.
- This type of modulation is called as single side band suppressed carrier-AM and the SSB system reduces the band width by half.

Block diagram of SSB-SC AM is shown in figure.



- The single side band suppressed carrier can be obtained as follows,
- In order to suppress one of the sideband, the input signal fed to the modulator1 is 90° out of phase with that of the signal fed to the modulator'2'.

$$\text{Let } e_1(t) = E_m \cos \omega_m t \cdot E_c \cos \omega_c t$$

$$e_2(t) = E_m \sin \omega_m t \cdot E_c \sin \omega_c t$$

$$\text{Therefore, } e(t)_{SSB} = e_1(t) + e_2(t)$$

$$= E_m E_c [\cos \omega_m t \cdot \cos \omega_c t + \sin \omega_m t \cdot \sin \omega_c t]$$

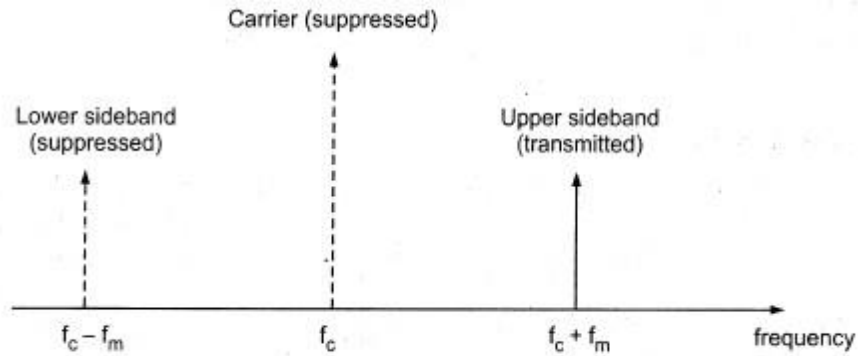
$$e(t)_{SSB} = E_m E_c \cos (\omega_c - \omega_m) t.$$

We know that for DSB-SC AM

$$e_{DSB-SC}(t) = \frac{E_m E_c}{2} [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

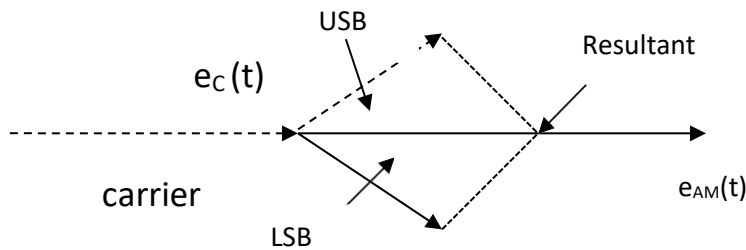
When comparing equations of $e(t)_{SSB-SC}$ and $e_{DSB-SC}(t)$, one of the sideband is suppressed. Hence this scheme is known as SSB-SC AM.

Frequency Spectrum Of SSB-SC-AM:



- The Frequency spectrum shows that only one side band signal is present, the carrier and the other sideband signal are suppressed. Thus the bandwidth required reduces from $2 \omega_m$ to ω_m i.e., bandwidth requirement is reduced to half compared to AM & DSB-SC signals.

Phasor representation of SSB-SC-AM:



Power calculation:

$$\text{Power in sidebands } P_t'' = P_{LSB} = P_{USB} = m_a^2 V_c^2 / 8R = m_a^2 P_C / 4$$

Power saving with respect to AM with carrier

$$\text{Power saving} = \frac{P_t - P_t''}{P_t} \times 100$$

where P_t = Total power transmitted.

$$\text{Power saving} = \frac{[1 + m_a^2 / 2] P_C - [m_a^2 / 4] P_C}{[1 + m_a^2 / 2] P_C} = \frac{P_C + [m_a^2 / 2] P_C - [m_a^2 / 4] P_C}{[1 + m_a^2 / 2] P_C}$$

$$\begin{aligned} & \frac{m^2}{1 + \frac{m^2}{4}} \times 100 \\ & \frac{m^2}{1 + \frac{m^2}{2}} \\ & = \frac{4 + m_a^2}{2 + m_a^2} \times 100 \\ & = \frac{4 + m_a^2}{4 + 2m_a^2} \times 100 \end{aligned}$$

If $m_a=1$ then % power saving = $(5/6) \times 100 = 83.3\%$

So we can save 83.3% of power with respect to AM with carrier.

We can also find the power in SSB-SC-AM with respect to AM with DSB-SC system,

$$\begin{aligned} \text{powersaving} &= \frac{P_t' - P_t''}{P_t'} \times 100 \\ &= \frac{m^2 P_c - m^2 P_c}{m^2 P_c} \times 100 \\ &= \frac{\frac{a^2}{2} c - \frac{a^2}{4} c}{\frac{a^2}{2} c} \times 100 \end{aligned}$$

If $m_a=1$ then %power saving=50%.therefore 50%power is saved with respect to DSB-SC System.

Applications of SSB

1. Used to save applications where such a power saving is warranted, i.e., in mobile system, in which weight and power consumption must naturally be kept low.
2. Single sideband modulation is at a premium. Point-to-Point communication, land, air, maritime mobile communication, TV, Telemetry, Military and Radio navigation are the greatest use of SSB in one form or another.

SSB Advantages

- **Power conservation:** Much less total transmitted power required to produce the same quality signal.
- **Bandwidth conservation:** Half of the bandwidth of conventional AM bandwidth.
- **Selective Fading:** Not present in SSBSC.
- **Noise Reduction:** Since SSB uses half the bandwidth, the thermal noise power is reduced to half. Hence immunity to selective fading is improved.

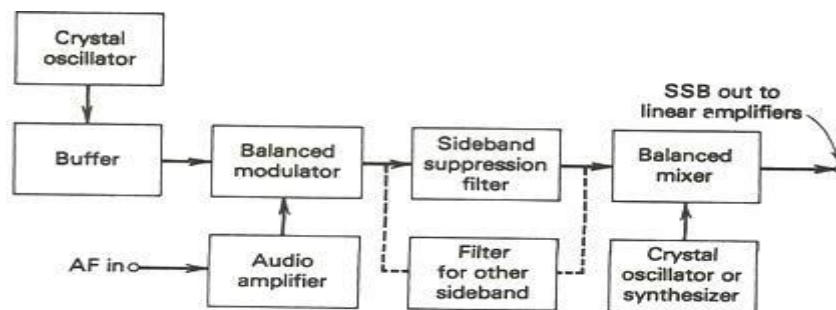
SSB Disadvantages

- **Complex Receivers:** Required carrier recovery and synchronization circuit adds cost, complexity and size.
- **Tuning Difficulties:** Complex and Expensive Tuning Circuits.

GENERATION OF SSB

1. Filter Method
2. Phase Shift Method
3. Modified Phase Shift Method or Weaver Method

FILTER METHOD



In this method of SSB generation, after the BM, the unwanted sideband is removed (actually heavily attenuated) by a filter and hence this name. The filter may be LC, ceramic or mechanical depending upon

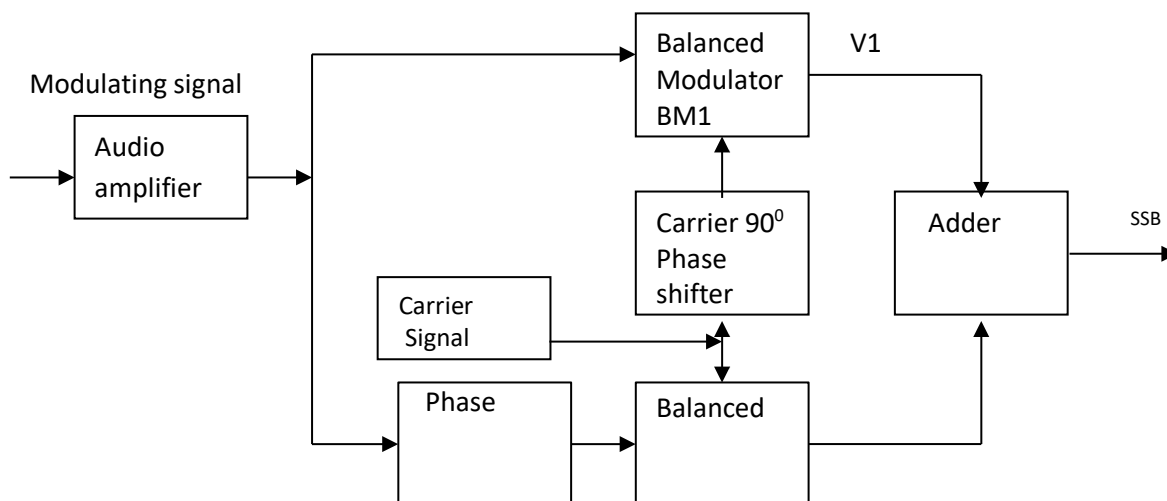
the carrier frequency and other requirements. Such a filter must have a flat bandpass and extremely high attenuation outside the passband.

In radio communication system, the frequency range used for voice is 300 Hz to about 2800 Hz in most cases. If it is required to suppress the lower sideband and if the transmitting frequency is f_c , then the lowest frequency that this filter must pass without attenuation is f_c+300 Hz whereas the highest frequency that must be fully attenuated is f_c-300 Hz. So we need a filter whose transition band is very low. This situation becomes worse if lower modulating frequencies are employed, such as the 50 Hz minimum in AM broadcasting. In order to obtain a filter response curve with skirts as steep the 'Q' of the tuned circuits must be very high.

The initial modulation takes place in the balanced modulator at a low frequency (such as 100 kHz) because of the difficulty of making adequate filters at higher frequencies. The filter is a BPF with a sharp cutoff frequency at either side of the bandpass to obtain satisfactory adjacent sideband rejection. The filtered signal is up-converted in a mixer to the final transmitter frequency and then amplified before being coupled to the antenna. The integrated ceramic filters are used as sideband filters. The drawback of filter method is that it requires sharp filtering, which requires filters with high Q. Primary modulation cannot be done at the transmitting frequency which is another drawback of the filter method.

PHASE SHIFT METHOD

- This method avoids the prime disadvantage of filtering method. That is requirement of a sideband filter with a narrow transition band and it cannot be used for very low and very high frequencies.
- This method does not have any sideband filters and the primary modulation can be done at the transmitting frequency. The unwanted sideband can be removed by generating the components of sideband out of phase.
- If the undesired sideband is LSB then the two LSB are generated such that they are 180 out of phase with each other. So that USB add with each other and LSB cancel each other. When two undesired sideband components are added they cancel each other with only the presence of desired signal.
- Two balanced modulators and two phase shifters are used. One of the modulator BBM1 receives the carrier voltage shifted by 90° and the modulating voltage, whereas another balanced modulator BBM2 receives the modulating voltage shifted by 90° and the carrier voltage.
- The carrier signal is cancelled out by both the balanced modulator and then unwanted sidebands cancel at the output of the summing amplifiers and hence produces SSB signal.



PHASE SHIFT METHOD

Mathematical analysis:

For modulator1 (BM1)

$$e_c(t) = E_c \sin(\omega_c t + 90^\circ) = E_c \cos \omega_c t$$

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

For modulator2(BM2)

$$e_c(t) = E_c \sin \omega_c t$$

$$e_m(t) = E_m \sin(\omega_m t + 90^\circ) = E_m \cos \omega_m t$$

Output for modulator(BM1) is V_1

$$V_1 = E_c \cos \omega_c t E_m \sin \omega_m t \text{ ----- (1)}$$

Output for modulator(BM2) is V_2

$$V_2 = E_c \sin \omega_c t E_m \cos \omega_m t \text{ ----- (2)}$$

The output of adder is

$$V_0 = V_1 + V_2$$

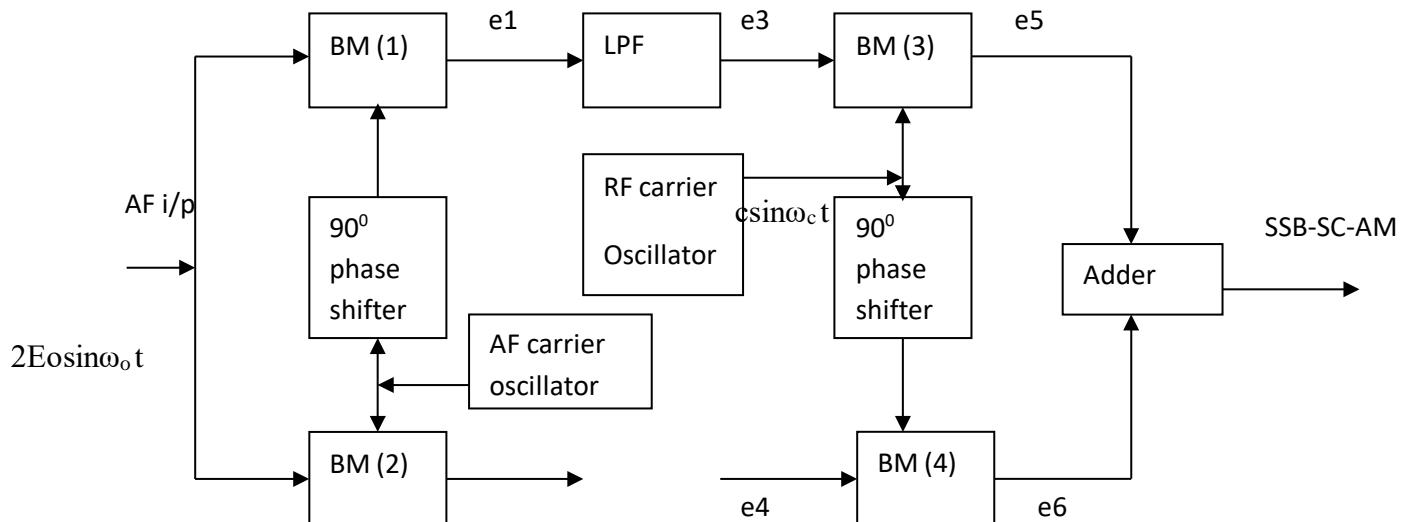
$$V_0 = E_c E_m \cos \omega_c t \sin \omega_m t + E_c E_m \sin \omega_c t \cos \omega_m t$$

$$= E_c E_m \sin(\omega_c + \omega_m)t \text{ ----- (3)}$$

Thus one of the side band is cancelled where as the other is reinforced. This method avoids the use of filters.

MODIFIED PHASE SHIFT METHOD (OR) WEAVER'S METHOD

- The modified phase shift method overcomes the limitation of phase shift method. That is AF phase shift network is required to operate over a large range of audio frequencies but also retains the advantage like its ability to generate SSB at any frequency and use of low audio frequency.
- This method provides both RF and AF oscillator phase shift and also used in low frequency and so it can be used for both audio and radio frequencies.



WEAVER'S METHOD

- Modulators 1 and 2 both have the unshifted modulating signal as inputs. BM1 takes low frequency subcarrier with a 90 phase shift from the AF oscillator. BM2 receives the subcarrier signal directly from the oscillator.
- This method tries to avoid the phase shift of audio frequencies and combine the audio frequency carrier with AF which lies in the middle of audio frequency.
- The low pass filter at the output of BM1 and BM2 with cut off frequency ensures the input to the balance modulator BM3 and BM4. The output of BM3 and BM4 gives the desired sideband suppression.

MATHEMATICAL ANALYSIS

The modulating signal is $e_m = E_m \sin \omega_m t$ ----- (1)

The A.F carrier(sub carrier signal) $e_o(t) = 2E_0 \sin \omega_0 t$ ----- (2)

The R.F carrier $e_c(t) = 2E_c \sin \omega_c t$ ----- (3)

The input for Balanced modulator 1(BM1) is

$$\begin{aligned} e_m(t) &= E_m \sin \omega_m t \\ e_o(t) &= 2E_0 \sin (\omega_0 t + 90^\circ) \end{aligned}$$

The output for Balanced modulator 1(BM1) is

$$\begin{aligned} e_1 &= E_m \sin \omega_m t \cdot 2E_0 \sin (\omega_0 t + 90^\circ) \\ &= E_m E_0 [\cos(\omega_0 t + 90^\circ - \omega_m t) - \cos(\omega_0 t + 90^\circ + \omega_m t)] \text{----- (4)} \end{aligned}$$

The input for Balanced modulator 2(BM2) is

$$\begin{aligned} e_m(t) &= E_m \sin \omega_m t \\ e_o(t) &= 2E_0 \sin \omega_0 t \end{aligned}$$

The output for Balanced modulator 2(BM2) is

$$\begin{aligned} e_2 &= E_m \sin \omega_m t \cdot 2E_0 \sin \omega_0 t \\ &= E_m E_0 [\cos(\omega_0 t - \omega_m t) - \cos(\omega_0 t + \omega_m t)] \text{----- (5)} \end{aligned}$$

The LPF1, 2 eliminates the upper sidebands of the modulator. Hence USB is suppressed

$$\text{The Output of LPF1 is } e_3 = E_m E_0 [\cos(\omega_0 t + 90^\circ - \omega_m t)] \text{----- (6)}$$

$$\text{The Output of LPF2 is } e_4 = E_m E_0 \cos(\omega_0 t - \omega_m t) \text{----- (7)}$$

The output of LPF1, 2 are given to BM3, BM4.

The input for Balanced modulator 3(BM3) is

$$\begin{aligned} e_3 &= E_m E_0 [\cos(\omega_0 t + 90^\circ - \omega_m t)] \\ e_c(t) &= 2E_c \sin \omega_c t \end{aligned}$$

The output for Balanced modulator 3(BM3) is

$$e_5 = 2E_m E_0 E_c \cos(\omega_0 t + 90^\circ - \omega_m t) \sin \omega_c t$$

Assume $E_m = E_0 = E_c = 1$, then

$$e_5 = 2 \cos(\omega_0 t + 90^\circ - \omega_m t) \sin \omega_c t$$

$$= \sin[(\omega_c + \omega_o - \omega_m)t + 90^\circ] + \sin[(\omega_c - \omega_o + \omega_m)t - 90^\circ] \text{----- (8)}$$

The input for Balanced modulator 4(BM4) is

$$e_4 = E_m E_0 \cos(\omega_o t - \omega_m t)$$

$$e_c(t) = 2E_c \sin(\omega_c t + 90^\circ)$$

The output for Balanced modulator 4(BM4) is

$$e_6 = E_m E_0 \cos(\omega_o t - \omega_m t) 2E_c \sin(\omega_c t + 90^\circ)$$

Assume $E_m = E_0 = E_c = 1$, then

$$e_6 = 2 \cos(\omega_o t - \omega_m t) \sin(\omega_c t + 90^\circ)$$

$$= \sin[(\omega_c + \omega_o - \omega_m)t + 90^\circ] + \sin[(\omega_c - \omega_o + \omega_m)t + 90^\circ] \text{----- (9)}$$

The output of adder is $e_{SSB-SC}(t) = e_5 + e_6$

$$= \sin[(\omega_c + \omega_o - \omega_m)t + 90^\circ] + \sin[(\omega_c - \omega_o + \omega_m)t - 90^\circ] +$$

$$\sin[(\omega_c + \omega_o - \omega_m)t + 90^\circ] + \sin[(\omega_c - \omega_o + \omega_m)t + 90^\circ]$$

$$= 2 \sin[(\omega_o + \omega_c - \omega_m)t + 90^\circ]$$

The other two terms cancel with each other because it is out of phase.

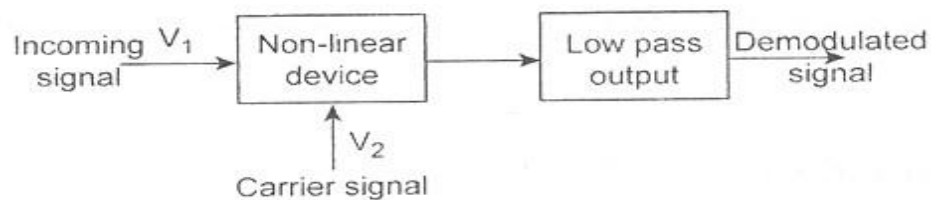
$$e_{SSB-SC}(t) = 2\cos[(\omega_o + \omega_c - \omega_m)t]$$

The final RF output frequency is $\omega_o + \omega_c - \omega_m$ which is essentially the lower side band of RF carrier $\omega_o + \omega_c$.

DEMODULATION/DETECTION OF AM-SSBSC

SYNCHRONOUS OR COHERENT DETECTOR

- The coherent detector uses exact carrier synchronization for retrieving the message signal from modulated signal. These types of detectors are mainly used for detecting DSB&SSB signals.
- It consists of a product modulator with a low pass filter.
- For detecting signal local oscillator at the receiver end is required. The frequency and phase of the locally generated carrier and transmitter carrier must be synchronized that is exactly coherent.
- All types of linear modulation can be detected by using synchronous detector. It consists of a product modulator with LPF.



- The incoming signal is first multiplied with locally generated carrier and then passed through low pass filter. The filter bandwidth is same as the message bandwidth ω_m
- The local oscillator should be exactly synchronized with carrier signal in both phase and velocity.
- **Considering the case of SSB-SC signal, the signal I/p is**

$$e_1(t) = \frac{E_m E_c \cos(\omega_c - \omega_m)t}{2}$$

The output of the non linear device which acts as a multiplying device is given by

$$e(t) = e_1(t) \cdot e_2(t) = \frac{E_m \cdot E_c \cdot E}{2} \cos(\omega_c - \omega_m)t \sin \omega_c t$$

$$e(t) = \frac{E_m \cdot E_c \cdot E}{2} \left[\sin \omega_m t + \frac{\sin(2\omega_c - \omega_m)t}{2} \right]$$

The first term of the output is the modulating frequency signal that is passed on to the output. The second component is a RF component and is attenuated by the filter. Thus the synchronous detector is capable of demodulating SSB-SC signal

$$e(t) = \frac{E_m \cdot E_c \cdot E \sin \omega_m t}{4}$$

The synchronous detector is effective only when locally generated carrier is properly synchronize with the transmitter power. Assume the local oscillator carrier to have a phase difference with the transmitted carrier. The carrier is represented by

$$e_2(t) = E \sin(\omega_c t + \phi)$$

The output of the non linear device is given by

$$\begin{aligned} e(t) &= e_1(t) \cdot e_2(t) = \frac{E_m \cdot E_c}{2} \cos(\omega_c - \omega_m)t \cdot E \sin(\omega_c t + \phi) \\ &= \frac{E_m \cdot E_c \cdot E}{2} \cos(\omega_c - \omega_m)t \sin(\omega_c t + \phi) \\ &= \frac{E_m \cdot E_c \cdot E}{2} (\cos \omega_c t \cos \omega_m t + \sin \omega_m t \sin \omega_c t) (\sin \omega_c t \cos \phi + \cos \omega_c t \sin \phi) \\ &= \frac{E_m \cdot E_c \cdot E}{2} [\cos \omega_c t \cos \omega_m t \sin \omega_c t \cos \phi + \sin \omega_m t \sin^2 \omega_c t \cos \phi + \\ &\quad \cos^2 \omega_c t \cos \omega_m t \sin \phi + \cos \omega_c t \sin \omega_c t \cos \omega_m t \sin \phi] \\ &= \frac{E_m \cdot E_c \cdot E}{2} [\cos \omega_c t \cos \omega_m t \sin \omega_c t \cos \phi + \sin \omega_m t \cos \phi \frac{1 - \cos 2\omega_c t}{2} \\ &\quad \cos^2 \omega_c t \cos \omega_m t \sin \phi + \cos \omega_c t \sin \omega_c t \cos \omega_m t \sin \phi] \end{aligned}$$

After passing through the LPF the second order harmonic term is eliminated.

$$e(t) = \frac{E_m \cdot E_c \cdot E \sin \omega_m t \cos \phi}{4}$$

If $\phi = 0$ then $e(t)$ is maximum $e(t) = \frac{E_m \cdot E_c \cdot E \sin \omega_m t}{4}$

If $\phi = 90$ then $e(t)$ is minimum $e(t) = 0$

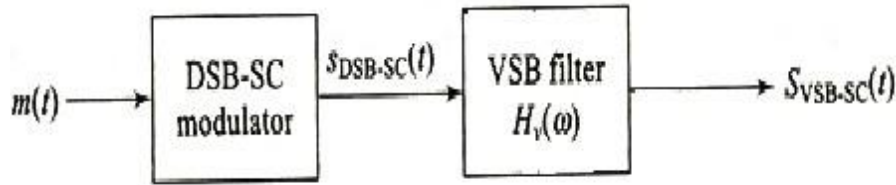
Thus there is a phase delay due to improper synchronization.

VESTIGIAL SIDE BAND MODULATION

Definition : One of the sideband is partially suppressed and vestige (portion) of the other sideband is transmitted, This vestige (portion) compensates the suppression of the sideband. It is called vestigial sideband transmission.

Generation and demodulation of VSB:

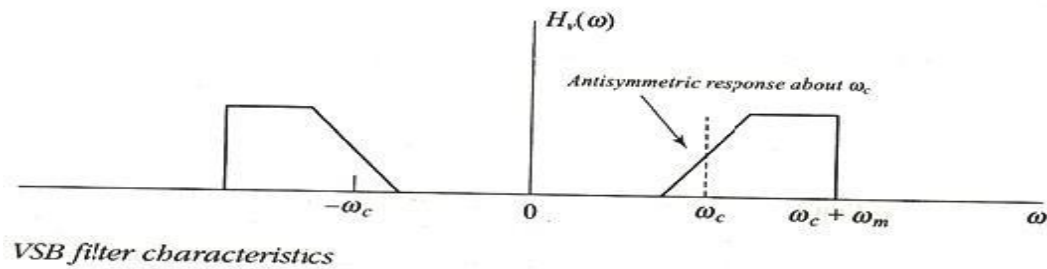
A VSB signal is obtained as shown figure below by suppressing one of the sidebands of a DSBSC using a VSB filter.



VSB filter is a BPF having an asymmetric frequency response in the transition band, positioned in such a way that the carrier frequency corresponds to the middle of the transition band. From the figure,

$$S_{DSB-SC}(t) = A_c m(t) \cos(\omega_c t)$$

The transfer function of the VSB filter is $H_v(\omega)$.



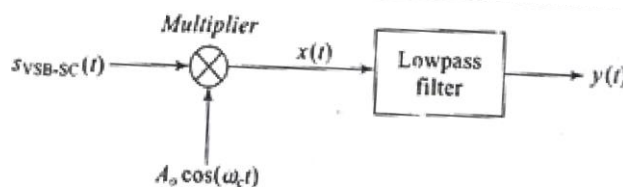
The inverse FT of $H_v(\omega)$ gives the unit impulse, $h_v(t)$. We can express the VSB filter output as:

$$S_{VSB-SC}(t) = S_{DSB-SC}(t) * h_v(t) = A_c m(t) \cos(\omega_c t) * h_v(t) \text{----- (1)}$$

Taking FT on both sides,

$$S_{VSB-SC}(\omega) = \left\{ \frac{A_c}{2} [M(\omega - \omega_c) + M(\omega + \omega_c)] \times H_v(\omega) \right\} \text{----- (2)}$$

The coherent detector is a sort of universal detector of AM signals in the sense that DSBSC, conventional AM and SSBSC can all be detected successfully by using it. It would be natural to expect that coherent detection to work for the VSB-SC signal too.



The output of the multiplier in the VSB demodulator in the figure is given by:

$$x(t) = S_{VSB-SC}(t) \times A_0 \cos(\omega_c t) \text{----- (3)}$$

It is assumed perfect synchrony between the transmitter and demodulator carriers.

Taking FT on both sides of equation (3), we obtain,

$$X(\omega) = \frac{A_0}{2} [S_{VSB-SC}(\omega - \omega_c) + S_{VSB-SC}(\omega + \omega_c)] \text{----- (4)}$$

Using (2) in (4),

$$X(\omega) = \left(\frac{A_0 A_c}{4}\right) \{ [M(\omega) + M(\omega - 2\omega_c)] H_v(\omega - \omega_c) + [M(\omega + 2\omega_c) + M(\omega)] H_v(\omega + \omega_c) \} \quad \text{.....(5)}$$

The signal $x(t)$ is passed through an ideal filter (LPF) to obtain $y(t)$. If the VSB modulation is successful, then $y(t)$ should be proportional to the message signal, $m(t)$.

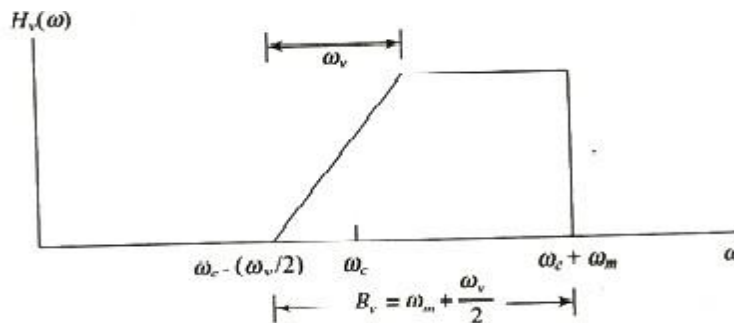
It is observed from (5) that $M(\omega - 2\omega_c)$ and $M(\omega + 2\omega_c)$ are high pass terms, since they represent $M(\omega)$ translated by $\pm 2\omega_c$. These terms are blocked by the LPF which yields an output signal $y(t)$ with the FT $Y(\omega)$ given by

$$Y(\omega) = \left(\frac{A_0 A_c}{4}\right) M(\omega) [H_v(\omega - \omega_c) + H_v(\omega + \omega_c)] \quad \text{.....(6)}$$

VSBSC modulation and demodulation is considered to be successful if $Y(\omega) = kM(\omega)$, where k is proportionality constant. Hence, for perfect demodulation, the required condition is:

$$[H_v(\omega - \omega_c) + H_v(\omega + \omega_c)] = \text{constant for } |\omega| \leq \omega_m.$$

This is called *vestigial symmetry condition*.



Transmission bandwidth of a VSB-SC signal

It is seen that the VSB bandwidth exceeds the corresponding SSB bandwidth ω_m by $\omega_v/2$. Thus, the filter transition bandwidth ω_v is an important parameter which decides the VSB bandwidth. It is observed in filter design that spectral components that lie in the transition region suffer distortion causing phase shifts.

Magnitude Response of VSB Filter

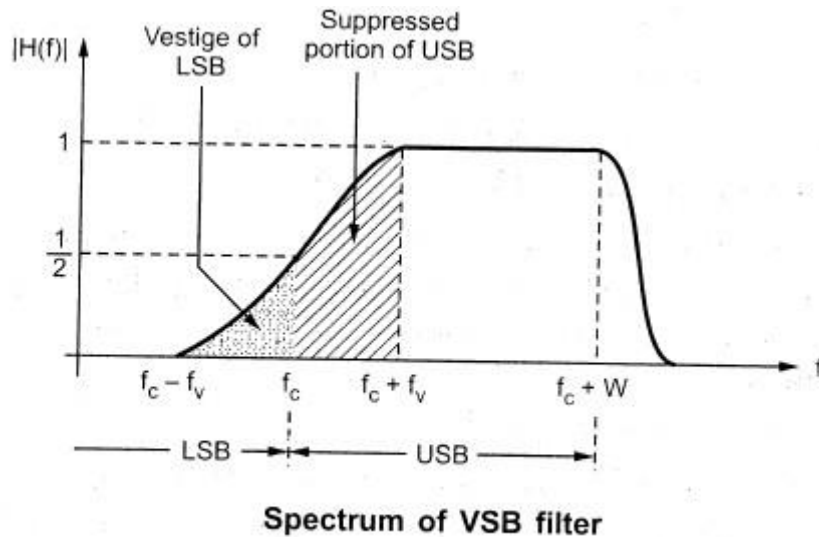
Fig. shows the magnitude response of VSB filter.

- Here observe that f_c to $f_c + W$ is USB. It's portion from f_c to $f_c + f_v$ is suppressed partially. f_c to $f_c - W$ is LSB. It's portion from $f_c - f_v$ to f_c is transmitted as vestige.
- Observe that $H(f_c) = 1/2$. And the frequency response $f_c - f_v \leq H(f) \leq f_c + f_v$ exhibits odd symmetry. The sum of any two frequency components in the range is

$$f_c - f_v \leq f \leq f_c + f_v$$

equal to unity. i.e $H(f - f_c) + H(f + f_c) = 1$

Phase response is linear



Advantages:

1. Low frequencies, near f_c are, transmitted without any attenuation.
2. Bandwidth is reduced compared to DSB.

Applications:

VSB is mainly used for TV transmission, since low frequencies near f_c represent significant picture details. They are unaffected due to VSB.

UNIT -2

Angle Modulation

Definition

We know that amplitude, frequency or phase of the carrier can be varied by the modulating signal. Amplitude is varied 'in AM. When frequency or phase of the carrier is varied by the modulating signal, then it is called angle modulation, There are two types of angle modulation.

1. Frequency Modulation :

When frequency of the carrier varies as per amplitude variations of modulating signal, then it is called Frequency Modulation (FM). Amplitude of the modulated carrier remains constant.

2. Phase Modulation :

When phase of the carrier varies as per amplitude variations of modulating signal, then it is called Phase Modulation (PM). Amplitude of the modulated carrier remains constant,

Frequency Modulation:

The frequency of the high frequency carrier signal is varied in accordance with the modulating signal.

$$V_m = E_m \sin 2\pi f_m t$$

$$V_c = E_c \sin 2\pi f_c t$$

$$V_{fm} = E_c \sin (2\pi f_c t + m_f \sin 2\pi f_m t)$$

$$V_{fm} = E_c \sin (\omega_c t + m_f \sin \omega_m t)$$

$m_f \rightarrow$ modulating index of f_m

Relationship/Difference between FM and PM:

- The basic difference between FM and PM lies in which property of the carrier is directly varied by modulating signal. Note that when frequency of the carrier varies, phase of the carrier also varies and viceversa.
- But if frequency is varied directly, then it is called FM.,
- And if phase is varied directly, then it is called PM.

The instantaneous phase deviation is denoted by $\theta(t)$. It is the instantaneous change in phase of the carrier with respect to reference phase. The instantaneous phase of the carrier is precise phase of the carrier at a given instant. It is mathematically expressed as,

Instantaneous phase =

$$\omega_c t + \theta(t) \dots\dots\dots(1)$$

Here $\theta(t)$ is the instantaneous phase deviation and ω_c is the carrier frequency. Now the instantaneous frequency deviation is defined as

$$= \frac{d}{dt} \theta(t) = \theta'(t) \text{ Hz} \dots\dots\dots(2)$$

Definition for instantaneous frequency deviation: It is the instantaneous change in carrier frequency. It is equal to the rate at which instantaneous phase deviation takes place.

Definition of instantaneous frequency: It is the frequency of the carrier at a given instant of time. It is given as

$$\begin{aligned} \text{Instantaneous frequency} &= \omega_i(t) = \frac{d}{dt} [\omega_c t + \theta(t)] \\ &= \omega_c + \theta'(t) \text{ rad/sec} \end{aligned} \dots\dots\dots(3)$$

Instantaneous phase deviation $\theta(t)$ is proportional to modulating signal voltage

$$\theta(t) = k e_m(t) \text{ rad} \dots\dots\dots(4)$$

Where K is the deviation sensitivity of phase

Similarly the instantaneous frequency deviation is proportional to modulating signal voltage.

$$\theta'(t) = k_1 e_m(t) \text{ rad/sec} \dots\dots\dots(5)$$

Where k_1 is the deviation sensitivity of frequency.

From equation (2), We have

$$\begin{aligned} \theta(t) &= \int \theta'(t) dt \\ &= \int k_1 e_m(t) dt \end{aligned} \dots\dots\dots(6)$$

Let the modulating signal be given as

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

Using the equation in equation (6)

$$\begin{aligned} \theta(t) &= k_1 \int E_m \cos \omega_m t dt \\ &= k_1 \frac{E_m}{\omega_m} \sin \omega_m t \end{aligned} \dots\dots\dots(7)$$

The angle modulated wave is mathematically expressed as

$$e(t) = E_c \sin [\omega_c t + \theta(t)] \dots\dots\dots(8)$$

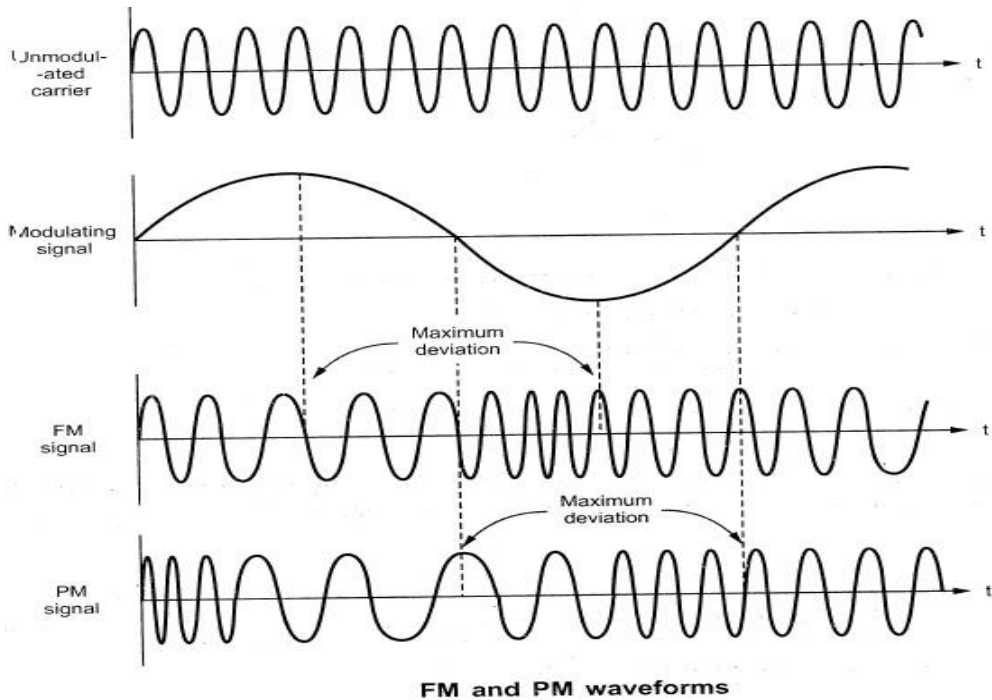
Using the

FM equation :
$$e(t) = E_c \sin \left[\omega_c t + \frac{k_1 E_m}{\omega_m} \sin \omega_m t \right] \dots(9)$$

Similarly using the value of $\theta(t)$ from equation (5) in equation (8) we get

PM equation :
$$e(t) = E_c \sin [\omega_c t + k E_m \cos \omega_m t] \dots\dots\dots(10)$$

FM and PM waveforms:



From

the above waveform we can

note the following

- For FM signal maximum frequency deviation takes Place when Modulating signal is at positive .and negative peaks.
- For PM signal the maximum frequency. deviation takes place near zero crossings of the modulating signal.
- Both FM and PM waveforms are identical except the phase shift.

Definition of Modulation index of PM and FM

The modulation index of PM is given as

$$M = K E_m$$

For FM It is the ratio of maximum frequency deviation (δ) to the modulating frequency (f_m).

$$m_f = \frac{\text{Maximum frequency deviation}}{\text{Modulating frequency}} = \frac{\delta}{f_m}$$

- The maximum frequency deviation is the shift from centre frequency f_c when the amplitude of message is maximum.

$$\Delta f = K_1 E_m \text{ (Hz)}$$

K_1 = Deviation sensitivity.

The Bandwidth of FM:

- By Carson's rule the Bandwidth needed by fm is given as,

$$B\omega = 2(\delta + f_{m\max})$$

δ → Maximum frequency Deviation

$f_{m\max}$ is Maximum modulating frequency.

Deviation Ratio :

The modulation index corresponding to maximum modulating frequency is called deviation ratio.

$$\text{Deviation Ratio} = \frac{\text{Maximum frequency deviation}}{\text{Maximum modulating frequency}}$$

Frequency Spectrum of angle modulated wave :

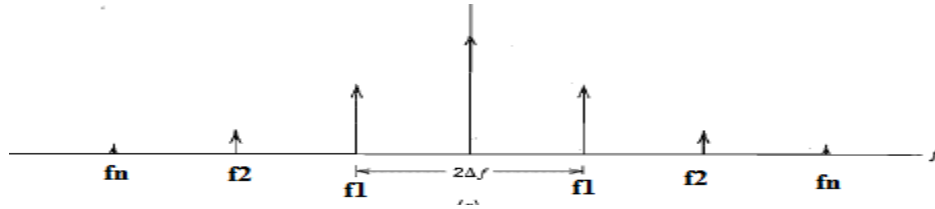
- FM and PM analysis is quite complicated. It is derived with the help of Bessel function.

$$E_{fm} = E_c \sin(\omega_c t + m_f \cos \omega_m t)$$

Using Bessel function this can be expanded as,

$$E_{fm} = A \{ J_0 m_f \sin \omega_c t + J_1 m_f [\sin(\omega_c + \omega_m)t - \sin(\omega_c - \omega_m)t] \\ + J_2 m_f [\sin(\omega_c + 2\omega_m)t - \sin(\omega_c - 2\omega_m)t] + J_3 m_f [\sin(\omega_c + 3\omega_m)t \\ - \sin(\omega_c - 3\omega_m)t] + J_4 m_f [\sin(\omega_c + 4\omega_m)t - \sin(\omega_c - 4\omega_m)t] \dots \}$$

$J_0, J_1, J_2, J_3 \dots$ Are Bessel functions. The value of this depends on modulation index m_f .



From the figure the Bandwidth of FM is given by

$$B = f_c + nf_m - f_c + nf_m$$

$$BW = 2nf_m$$

Bessel Function Table :

m	J0	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
0	1	-	-	-	-	-	-	-	-	-	-
0.25	0.98	0.12	-	-	-	-	-	-	-	-	-
0.5	0.94	0.24	0.03	-	-	-	-	-	-	-	-
1	0.77	0.44	0.11	0.02	-	-	-	-	-	-	-
1.5	0.51	0.56	0.23	0.06	0.01	-	-	-	-	-	-
2	0.22	0.58	0.35	0.13	0.03	-	-	-	-	-	-
2.5	-0.05	0.50	0.45	0.22	0.07	0.02	-	-	-	-	-
3	-0.26	0.34	0.49	0.31	0.13	0.04	0.01	-	-	-	-
4	-0.04	-0.07	0.36	0.43	0.28	0.13	0.05	0.02	-	-	-
5	0.18	-0.33	0.05	0.31	0.39	0.25	0.13	0.05	0.02	-	-

Classification of FM:

1. Narrowband FM
2. Wide band FM

Narrow band FM:

When the modulation index is less than 1, it is called narrowband FM. The FM Equation given by eq. 9 can also be expressed as,

$$e(t) = E_c \cos \left[\omega_c t + \frac{k_1 E_m}{\omega_m} \sin \omega_m t \right] \dots\dots\dots(1)$$

$$\frac{k_1 E_m}{\omega_m} = m,$$

$$e(t) = E_c \cos [2\pi f_c t + m \sin 2\pi f_m t]$$

Expanding the equation

$$e(t) = E_c \cos (2\pi f_c t) \cos [m \sin (2\pi f_m t)] - E_c \sin (2\pi f_c t) \sin [m \sin (2\pi f_m t)] \dots\dots\dots(2)$$

For narrowband FM, the modulation index, m is very small therefore following approximations can be considered.

$$\begin{aligned} \cos [m \sin (2\pi f_m t)] &\approx 1 \\ \sin [m \sin (2\pi f_m t)] &\approx m \sin (2\pi f_m t) \end{aligned}$$

Using this in equation (2)

$$e(t) = E_c \cos (2\pi f_c t) - m E_c \sin (2\pi f_c t) \sin (2\pi f_m t)$$

Expanding

$$e(t) = E_c \cos (2\pi f_c t) + \frac{1}{2} m E_c \{ \cos 2\pi(f_c + f_m)t - \cos 2\pi(f_c - f_m)t \}$$

This equation gives the spectrum of narrowband FM. Observe that there is carrier frequency f_c , upper sideband ($f_c + f_m$) and lower sideband ($f_c - f_m$).

Wide band FM

If the modulation index is higher than 10 it is called as wide band FM

$$\begin{aligned} e(t) &= E_c \cos[2\pi f_c t + m \sin 2\pi f_m t] \\ &= \text{Re} [E_c e^{j(2\pi f_c t + m \sin 2\pi f_m t)}] \\ &= \text{Re} [E_c e^{j2\pi f_c t} \cdot e^{jm \sin 2\pi f_m t}] \end{aligned}$$

Let $x(t) = E_c e^{jm \sin 2\pi f_m t}$, then the above equation becomes

$$e(t) = \text{Re} [x(t) e^{j2\pi f_c t}] \dots\dots\dots(1)$$

Here $x(t) = E_c e^{jm \sin 2\pi f_m t}$ is periodic with fundamental frequency of f_m . It can be expressed with the help of Fourier series as,

$$x(t) = \sum_{n=-\infty}^{\infty} C_n e^{j2\pi n f_m t} \dots\dots\dots(2)$$

where

$$\begin{aligned}
 C_n &= f_m \int_{-\frac{1}{2}f_m}^{\frac{1}{2}f_m} x(t) e^{-j 2\pi n f_m t} dt \\
 &= f_m \int_{-\frac{1}{2}f_m}^{\frac{1}{2}f_m} E_c e^{jm \sin 2\pi f_m t} e^{-j 2\pi n f_m t} dt \\
 &= f_m E_c \int_{-\frac{1}{2}f_m}^{\frac{1}{2}f_m} e^{j(m \sin 2\pi f_m t - 2\pi n f_m t)} dt
 \end{aligned}$$

put $y = 2\pi f_m t$ hence the limits will change from $-\pi$ to π

$$C_n = \frac{E_c}{2\pi} \int_{-\pi}^{\pi} e^{j(m \sin y - ny)} dy$$

The above integral is known as the n th order Bessel function of the first kind. It is given as

$$\begin{aligned}
 J_n(m) &= \frac{1}{2\pi} \int_{-\pi}^{\pi} e^{j(m \sin y - ny)} dy \\
 C_n &= J_n(m) E_c
 \end{aligned}$$

Using the value of C_n in equation (2)

$$x(t) = \sum_{n=-\infty}^{\infty} J_n(m) E_c e^{j 2\pi n f_m t}$$

Using the value $x(t)$ in equation (1)

$$\begin{aligned}
 e(t) &= \operatorname{Re} \left[\sum_{n=-\infty}^{\infty} J_n(m) E_c e^{j 2\pi n f_m t} \cdot e^{j 2\pi f_c t} \right] \\
 &= E_c \sum_{n=-\infty}^{\infty} \operatorname{Re} [J_n(m) e^{j 2\pi (f_c + n f_m) t}] \\
 &= E_c \sum_{n=-\infty}^{\infty} J_n(m) \cos [2\pi (f_c + n f_m) t]
 \end{aligned}
 \tag{3}$$

The Fourier transform of the above equation becomes

$$E(f) = \frac{E_c}{2} \sum_{n=-\infty}^{\infty} J_n(m) \{ \delta(f - f_c - n f_m) + \delta(f + f_c + n f_m) \}$$

This equation shows that there are infinite number of components located

$f_c \pm f_m, f_c \pm 2f_m, f_c \pm 3f_m, \dots$

Comparison between narrowband and wideband FM

Sr.no	Narrow band FM	Wide band FM
1	Modulation index is < 1	Modulation index > 10
2	$s(t) = A_c \cos(2\pi f_c t) - m A_c \sin(2\pi f_c t) \sin(2\pi f_m t)$	$s(t) = A_c \sum_{n=-\infty}^{\infty} J_n(m) \cos[2\pi(f_c + n f_m)t]$
3	Spectrum contains 2 sidebands and carrier	Spectrum contains infinite number of sidebands and carrier
4	$BW = 2f_m$	$BW = 2(\delta + f_m(\max))$
5	It is used for mobile communication	It is used for broadcasting and entertainment
6	Maximum deviation = 75 Hz	Maximum deviation = 5 Hz
7	Range of modulating frequency 30 Hz to 15 Kz	Range of modulating frequency 30 Hz to 3 Kz

Comparison between FM and PM

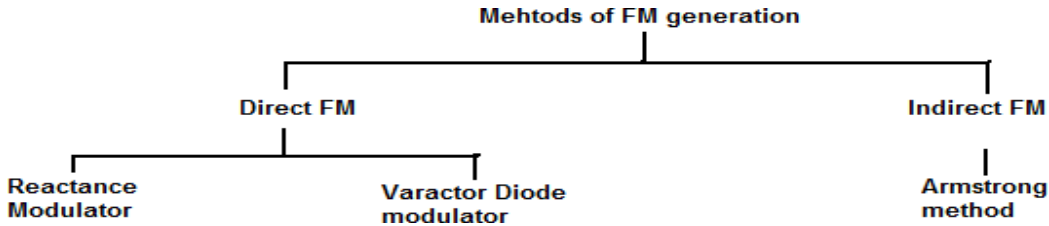
	Frequency modulation	Phase modulation
1	The maximum frequency deviation depends upon amplitude of modulating voltage and modulating frequency	The maximum phase deviation depends only upon the amplitude of modulating voltage
2	Frequency of the carrier is modulated by modulating signal	Phase of the carrier is modulated by modulating signal
3	Modulation index is increased as modulation frequency is reduced and vice versa	Modulation index remains same if modulating frequency is changed
4	Noise immunity is better than AM and PM	Noise immunity is better than AM but worse than FM

5	FM is widely used	PM is used in some mobile systems.
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Generation of FM waves:

Fm Modulators: There are 2 types of FM modulators.

1. Direct Method
2. Indirect Method



Direct FM Modulators : In this type the frequency of the carrier is varied directly by the modulating signal.

Indirect FM Modulators: In this type FM is obtained by phase modulation of the carrier.

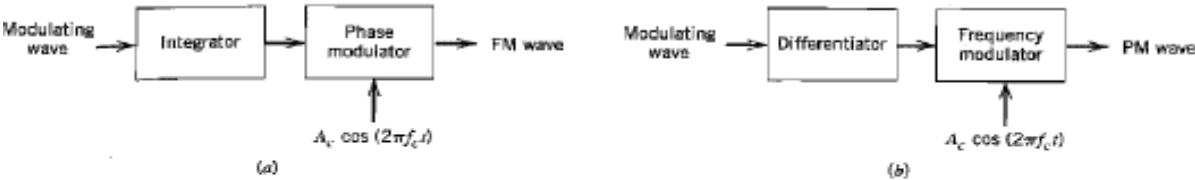
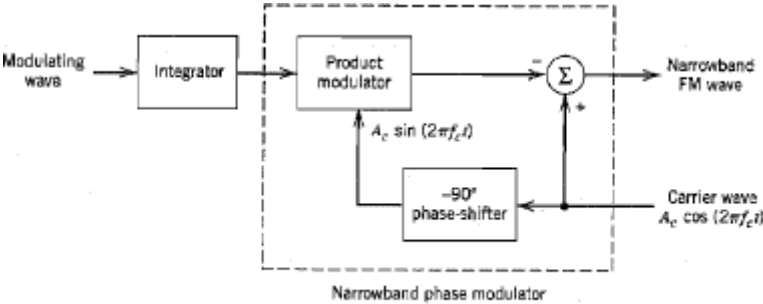


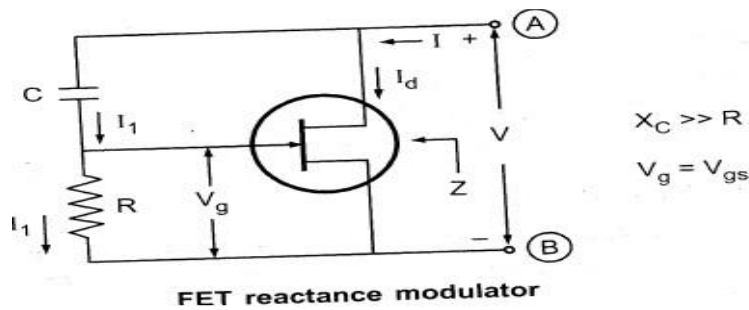
Illustration of the relationship between FM and PM
Fig (a) Generation of FM using PM
Fig (b) Generation of PM from FM

Generation of Narrow band FM:



Block diagram of a method for generating a narrowband FM signal.

Direct FM reactance modulator.



- It behaves as reactance across terminal A-B.
- The terminal A-B of the circuit may be connected across the tuned circuit of the oscillator to get fm o/p.
- The varying voltage (modulating voltage) V, across the terminals A-B changes the reactance of FET.
- This change in reactance can be inductive or capacitive.
- Neglecting the gate current, let the current through C & R be I_1 .
- At the carrier freq. the reactance of C is much larger than

$$R \text{ \& } I_1 = \frac{V}{R + 1/j\omega C}$$

$$j\omega C \gg R$$

$$I_1 = j\omega C V$$

From the Circuit,

$$V_g = I_1 R = j\omega C R V$$

$$I_d = g_m V_{gs} = g_m V_g$$

$$I_d = j\omega C R g_m V$$

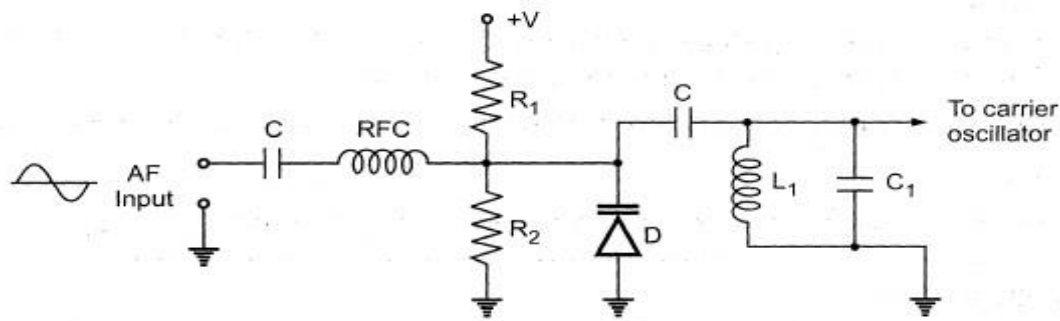
From the circuit impedance of the FET is,

$$Z = \frac{V}{I_d}$$

$$= \frac{V}{j\omega C R g_m V} = \frac{1}{j\omega (g_m C R)} = \frac{1}{j\omega (C_{eq})}$$

- The impedance of FET is capacitive.
- By carrying the modulating voltage across FET, the operating point g_m can be varied and hence C_{eq} .
- This change in the capacitance will change the frequency of the oscillator.

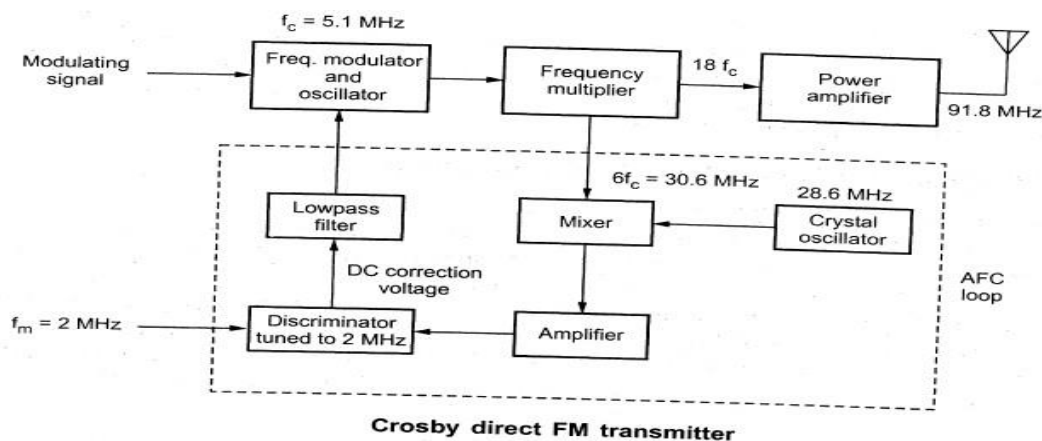
Frequency Modulation using Varactor diode.



Varactor diode for FM generation

- We know that the junction capacitance of the varactor diode changes as the reverse bias across it is varied.
- L_1 & C_1 forms the tank circuit of the carrier oscillator.
- The capacitance of the varactor diode depends on the fixed bias set by R_1 & R_2 & AF modulating signal.
- Either R_1 or R_2 is made variable.
- The radio frequency choke [RFC] has high reactance at the carrier frequency to prevent carrier signal from getting into the modulating signal.
- At +ve going modulating signal adds to the reverse bias applied to the varactor diode D, which decreases its capacitance & increases the carrier frequency.
- A -ve going modulating signal subtracts from the bias, increasing the capacitance, which decreases the carrier frequency.

Direct Fm Transmitters :



Crosby direct FM transmitter

- Fig. shows the FM Crosby transmitter with an AFC loop. (Automatic frequency correction loop).
- The Frequency modulator can be either a reactance modulator or voltage controlled oscillator.
- The carrier freq is 5.1MHz. which multiplies by 18 in three steps to produce a final frequency of 91.8 MHz.
- When the frequency modulated carrier is multiplied, its frequency & phase deviations are also multiplied.
- The rate at which the carrier is deviated is unaffected by the multiplication process. Hence the modulation index is multiplied.
- When an angle modulated carrier is heterodyned with another freq in a non linear mixer, the carrier can either be up converted or down converted.

AFC loop :

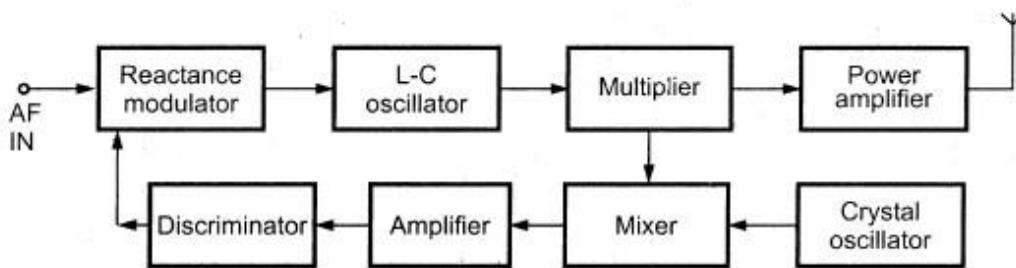
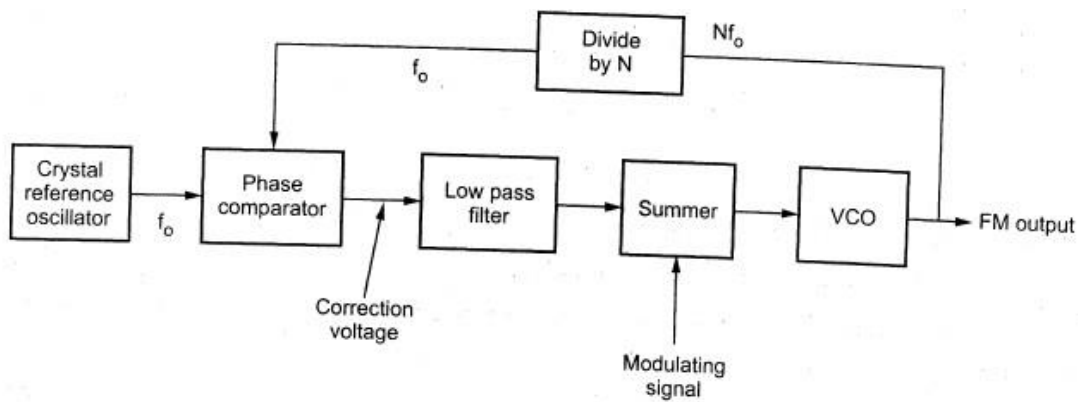


Fig. 2.3.1 Typical AFC circuit

- The purpose of the AFC loop is to achieve near crystal stability of the transmit carrier freq. without using a crystal in the carrier oscillator.
- The carrier frequency is mixed with a local oscillator freq and then down converted in freq. & fed to a frequency discriminator.
- Frequency discriminator is a device whose o/p voltage is proportional to the difference b/w i/p freq and its resonant freq.
- Discriminator responds to low freq changes in the carrier center freq because of master oscillator freq drift.
- When the discriminator responds to frequency deviation, the feedback loop would cancel the deviation and thus remove the modulation.
- The dc correction voltage is added to the modulating signal to automatically adjust the master oscillator's centre frequency to compensate for low freq drift.

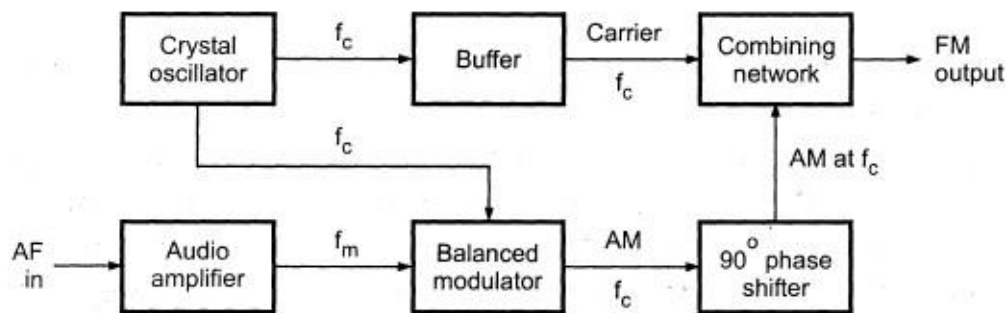
PLL Direct FM transmitter:



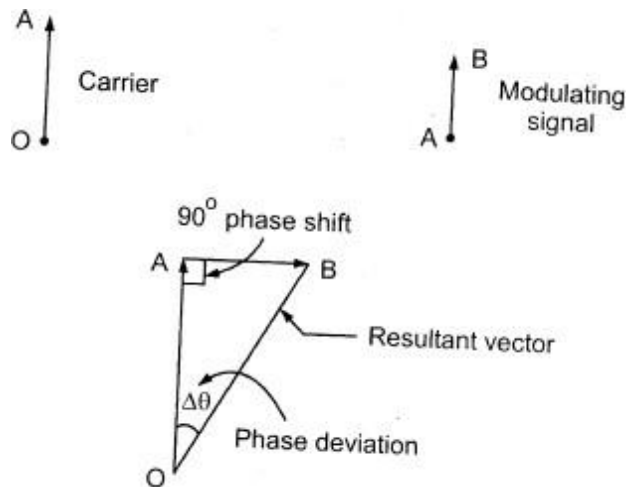
Block diagram of PLL direct FM transmitter

- Fig shows a wide band FM transmitter.
- The VCO o/p freq is divided by N & fed back to the PLL phase comparator, where it is compared to a stable reference freq.
- The phase comparator generates a correction voltage that is proportional to the difference b/w the 2 frequencies.
- The correction voltage is added to the modulating signal & applied to the VCO i/p.
- The correction voltage adjusts the VCO centre freq to its proper value.
- The LPF prevents the changes in the VCO o/p frequency due to the modulating signal from being converted to a voltage & fed back to VCO.
- The LPF also prevents the loop from locking onto a side frequency.

Indirect Fm transmitter



Block diagram of Armstrong method to generate FM



- Here the modulating signal directly deviates the phase of the carrier, which indirectly changes the frequency.
- The carrier source is a crystal oscillator hence stability can be achieved without a AFC.
- A carrier is phase shifted to 90° & fed to the Balanced modulator. Where it is mixed with the i/p modulating signal.
- The o/p of balanced modulator is DSBSC.
- The o/p of Balanced modulator is combined with original carrier in the combining N/W. to produce a low index, phase modulated waveform.
- Fig (b) shows phasor of original carrier, modulating signal and the resultant Vector.
- Fig (b) shows the phasors for the side freq. components of the suppressed carrier wave. As suppressed carrier is out of phase with V_c , the upper & Lower side bands combine to produce $V_m - 90^\circ$ with V_c .
- The phase modulated signal is obtained by vector addition of carrier and modulating signal.
- Modulating signal vector adds to the carrier OA with 90° phase Shift.
- The resultant phase modulated vector is OB with phase shift θ .
- This works only if both have the same frequency. The means carrier & modulating signal should have same frequency. Under this condition phase modulation produces FM o/p.

FM Demodulators / Detectors

FM demodulator must satisfy the following requirements

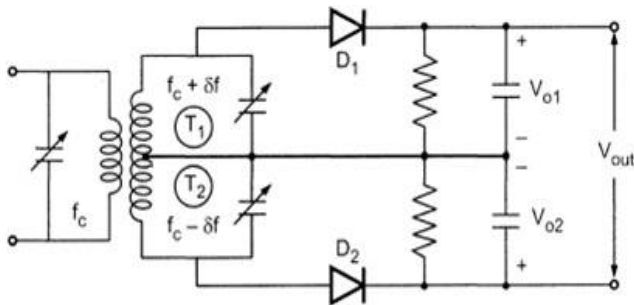
- It must convert the frequency variations into amplitude variations
- This conversion must be linear and efficient.
- The demodulator circuits must be insensitive to amplitude changes.
- It should not be too critical in its adjustment and operation.

Types of

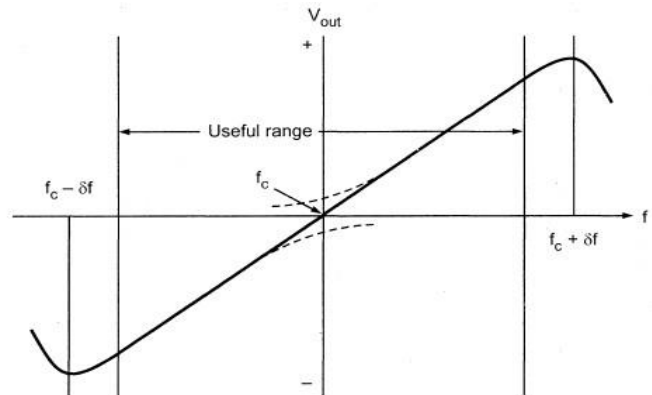
FM MODULATION:

- Round Travis Detector or Balanced discriminator.
- Foster – Seley Discriminator or Phase discriminator.
- Ratio Detector.

Slope Detector / Round Travis Detector :



Balanced slope detector

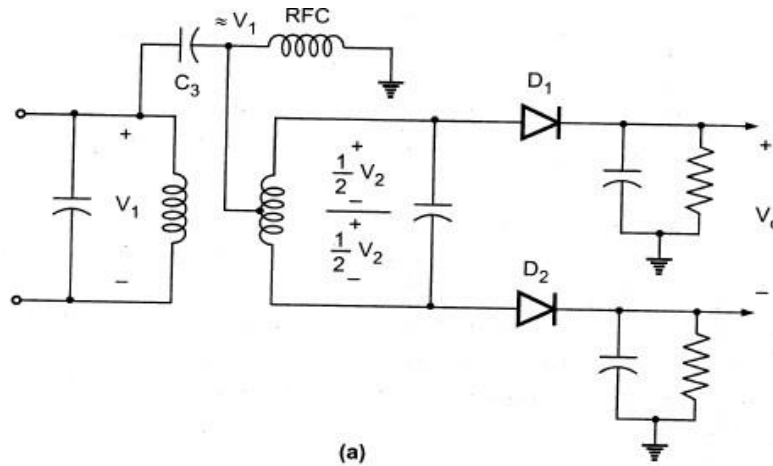


Characteristic of balanced slope detector, or 'S'-curve

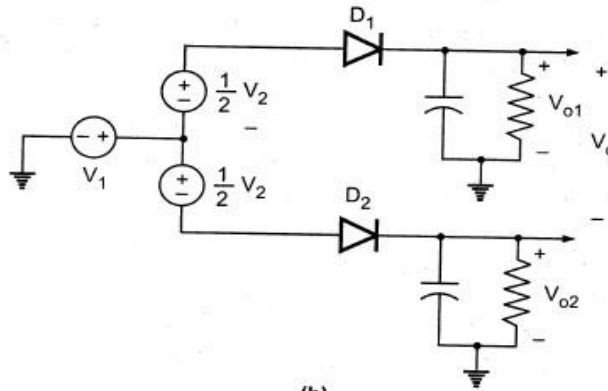
- Consists of 2 identical circuit connected back to back.
- FM signal is applied to the tuned LC circuit.
- Two tuned LC circuits are connected in series.
- The inductance of the secondary tuned LC circuit is coupled with the inductance of the primary LC circuit this forms a tuned transformer.
- Upper tuned circuit is T_1 & lower tuned circuit is T_2 .
- I/P side LC is tuned to be
 - T_1 is tuned to $f_c + \delta f$ - max freq fm.
 - T_2 is tuned to $f_c - \delta f$ - max freq fm.
- Secondary of T_1 & T_2 are connected to diodes D_1 & D_2 with RC loads.
- The total o/p is equal to difference b/w V_{o1} & V_{o2} .
- When i/p freq is f_c , both T_1 & T_2 produce the same voltage hence o/p = 0
- When i/p freq is $f_c + \delta f$, the upper circuit T_1 produces maximum voltage since it is tuned to this freq. Hence this produces maximum votalge.
 - V_{o1} is high compared to V_{o2} .
 - $V_{out} = V_{o1} - V_{o2}$ is positive for $f_c + \delta f$.

- When i/p freq is $f_c - \delta f$. T_2 produces maximum signal since it is tuned to it. But T_1 produces minimum voltage. Hence o/p Volt = $V_{o1} - V_{o2}$ is negative. Thus we get a modulating signal.

Foster - Seeley Discriminator :



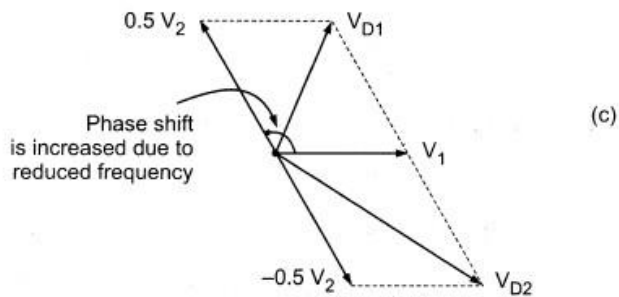
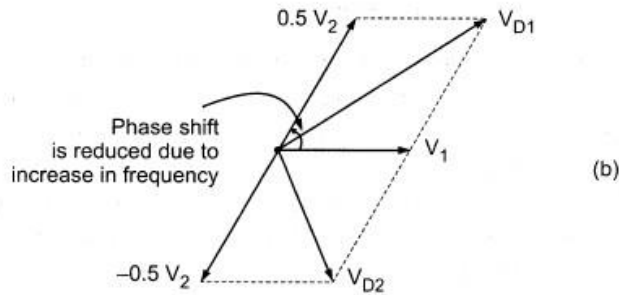
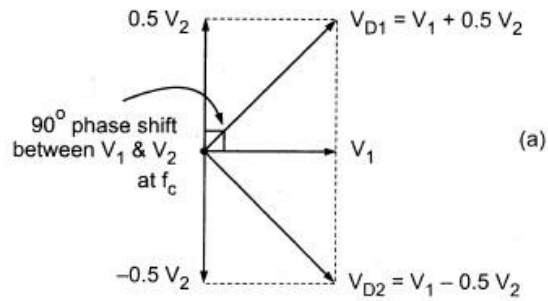
(a)



(b)

(a) Basic Foster-Seeley discriminator
(b) Voltage generator equivalent circuit

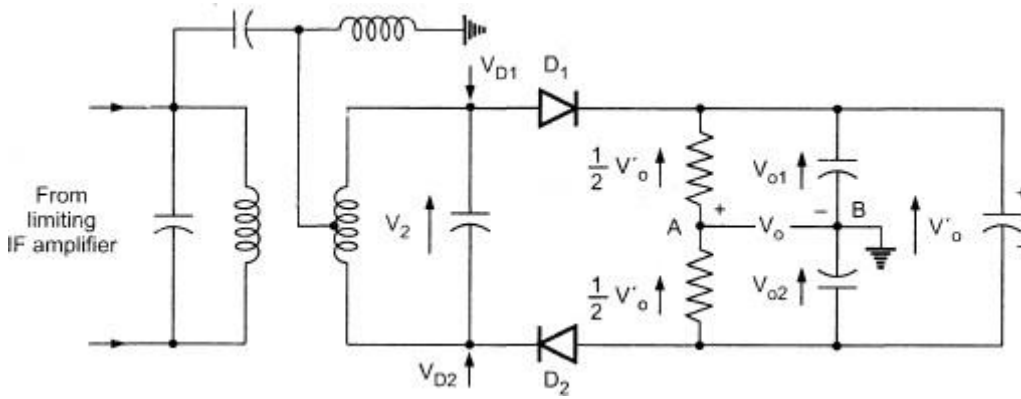
- The primary voltage is coupled through C_3 & RFC to the centre tap on the secondary.
- The capacitor C_3 passes all the frequencies of F_m . The voltage V_1 is generated across RFC.
- RFC offers high impedance to frequencies of F_m .



- (a) At center frequency, phase shift between V_1 and V_2 is 90° . Hence $|V_{D1}| = |V_{D2}|$
- (b) For the frequencies above center frequency, the phase shift between V_1 and V_2 is reduced. Hence $|V_{D1}| > |V_{D2}|$
- (c) For frequencies below center frequency, the phase shift between V_1 and V_2 is increased. This makes $|V_{D1}| < |V_{D2}|$

- The voltage V_1 thus appears across centre tap of secondary and ground also.
- The voltage of secondary is V_2 & equally divided across upper half & lower half of the secondary.
- In the figure the voltage across diode D_1 is $V_{D1} = V_1 + 0.5 V_2$ and that across D_2 is $V_{D2} = V_1 - 0.5 V_2$.
- The o/p of upper rectifier is V_{O1} and lower rectifier is V_{O2} .
- The net o/p $V_0 = V_{O1} - V_{O2} \cong V_0 = |V_{D1}| - |V_{D2}|$
- At carrier frequency $V_{D1} \times V_{D2}$ are equal hence the net o/p of the discriminator will be zero.
- When the i/p frequency increases above f_c the phase shift b/w V_1 & V_2 reduces $|V_{D1}| > |V_{D2}|$ hence $V_{O1} = |V_{D1}| - |V_{D2}|$ will be +ve.
- When the i/p frequency reduces below f_c then $|V_{D1}| < |V_{D2}|$ hence $V_{O1} = |V_{D1}| - |V_{D2}|$ will be -ve.

Ratio detector :



Ratio detector can be obtained by slight modifications in the foster-Seeley discriminator. Fig shows the circuit diagram of ratio detector. As shown in the diagram the diode D_2 is reversed, and output is taken from different points. In the above circuit the regular conversion from frequency to phase shift and phase shift to amplitude takes place as in faster-Seeley discriminator. The polarity of voltage in the lower capacitor is reversed. Hence the voltages V_{01} and V_{02} across two capacitors add. (Note that these voltages subtract in faster-seeley circuit). And we know that when V_{01} increases, V_{02} decreases and vice-versa as we have seen in faster-Seeley circuit. Since, V_o' is sum of V_{01} and V_{02} , it remains constant. From the circuit of Fig we can write two equations for the output voltage V_0 (Note that V_0 is the net output voltage and taken across points A and B). The First equation will be,

$$V_0 = \frac{1}{2} V_o' - V_{02}$$

and $V_0 = -\frac{1}{2} V_o' - V_{01}$

adding the above two equations,

$$2 V_0 = V_{01} - V_{02}$$

$$V_0 = \frac{1}{2} (V_{01} - V_{02})$$

Since $V_{01} \approx |V_{D1}|$ and $|V_{02}|$ above equation will be,

$$V_0 = \frac{1}{2} (|V_{D1}| - |V_{D2}|)$$

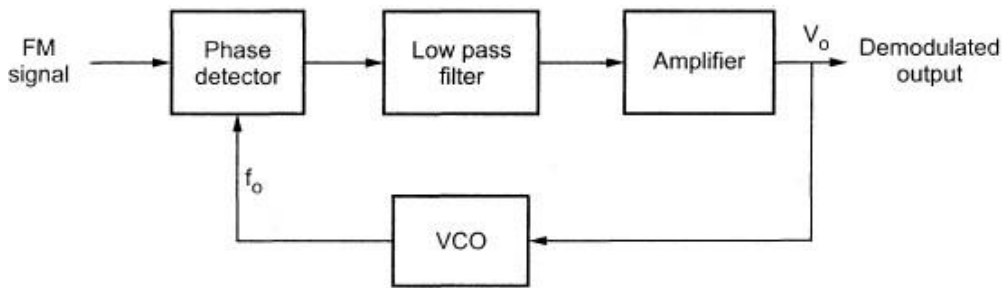
- Here V_{D1} & V_{D2} are obtained as discussed earlier in foster seeley circuit.
- From the equation we know that the output of ratio detector is half compared to that of Foster-Seeley circuit

- As frequency increases above $f_c' |V_{D1}| > |V_{D2}|$ hence o/p is +ve.
- IIIrdly as frequency decreases below $f_c = |V_{D2}| > |V_{D1}|$, hence o/p is -ve.

Advantage :

- Reduced fluctuations in the o/p voltage compared to foster seeley circuit

PLL Demodulator circuit



- Fig. shows the block diagram of PLL FM demodulator.
- The output frequency of VCO is equal to the frequency of unmodulated carrier.
- The phase detector generates the voltage which is proportional to difference between the FM signal and VCO output.
- This voltage is filtered and amplified. It is the required modulating voltage.
- Here frequency correction is not required in VCO since it is already done at transmitter

Comparison of FM and AM

	Amplitude Modulation	Frequency Modulation
1.	Amplitude of the carrier is varied according to amplitude of modulating signal.	Frequency of the carrier is varied according to amplitude of the modulating signal.
2.	Am has poor fidelity due to narrow bandwidth.	Since the bandwidth is large, fidelity is better.
3.	Most of the power is in carrier hence less efficient.	All the transmitted power is useful.
4.	Noise interference is more.	Noise interference is minimum.
5.	Adjacent Chennai Interference is present	Adjacent Chennai Interference is avoided due to guard bands.

6.	Am Broadcast operates in MF and HF range	FM Broadcast operates in VHF and UHF range.
7.	In Am only carrier and two sidebands are present	Infinite number of sidebands are present
8.	The transmission equipment is simple.	The transmission equipment is complex.
9.	Transmitted power varies according to modulation index.	Transmitted power remains constant irrespective of modulation index.
10.	Depth of modulation have limitation. It can not be increased above 1.	Depth of modulation have no limitation. It can be increased by increasing frequency deviation.