LECTURE NOTES

Communication Engineering

B.Tech,6th Semester,EEE

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COURSE CONTENT

Communication Engineering

B.Tech,6th Semester,EEE

- ***Module I:*** Introduction: Elements of an Electrical Communication System, CommunicationChannels and their Characteristics, Mathematical Models for Communication ChannelsFrequency domain analysis of signals and systems: Fourier series,Fourier Transforms, Power and Energy, Sampling and Band limited signals, Band passsignals.

  {PageNo. 1}
- **Module II:** Analog signal transmission and reception: Introduction to modulation, Amplitude Modulation (AM), Angle Modulation, Radio and Television broadcasting.
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  {Page No.42}
- *Module III:* Pulse modulation systems: Pulse amplitude modulation, Pulse Time Modulation Pulse code modulation: PCM system, Intersymbol interference, Eye patterns, Equalization, Companding, Time Division Multiplexing of PCM signals, Line codes, Bandwidth of PCM system, Noise in PCM systems.

  {PageNo. 68}
- *Module IV*: Delta Modulation (DM), Limitations of DM, Adaptive Delta Modulation, Noise in Delta Modulation, Comparison between PCM and DM, Delta or Differential PCM (DPCM), S-Ary System.

  {Page ***No. 96}***

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Books:

Books:

[1] John G.Proakis,M. Salehi, Communication Systems Engineering, 2nd ed. New Delhi, India. PHI Learning Private Limited, 2009.

[2] R.P Singh and S.D Sapre, Communication Systems Analog & Digital, 2nd ed. New Delhi, India. Tata McGraw Hill Education Private Limited, 2009.

DigitalLearningResources:

Course Name:	Analog Communication
Course Link:	https://nptel.ac.in/courses/117/105/117105143/
Course Instructor:	Prof. Goutam Das, IIT Kharagpur

EC 6651 - Communication Engineering

INTRODUCTION:

Communication is the Process of establishing a connection between two point for information exchange

Telecommunication:

→ Long distance Communication.

Communication Components

A basic Communication Components are

* Transmitter
* channel
* Receiver

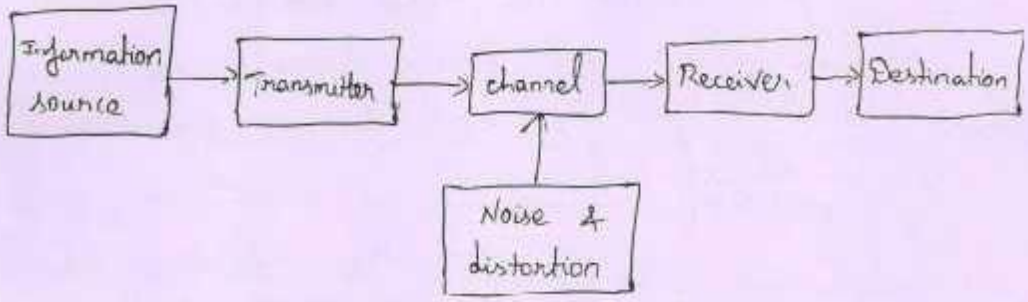


Fig: Block diagram of general communication system

Information source:

In this, the signal can be either analog or digital.

Analog signal Means continuous waveform, (or) Continuous Varying signal with respect to time.

Eg: human Voice, Music etc.

Transmitter:

It is a collection of electronic Components and

Circuits designed to convert information to a signal suitable for transmission through the channel.

It also increases the power level of the signal

channel:

It means medium by which electrical signals are sent from one place to another.

Depending on this channel, two types of communication system will exist

wire communication

In this, the medium is simple wires, cables & optical fibers.

→ only short distance communication.

wireless communication:

In this, the medium is air.

→ signals are transmitted through freespace by EM waves called Radio waves.

→ Radio waves are radiated from the transmitter in open space through the device called antenna. Eg: Radio, TV Broadcasting, Satellite communication etc.

→ Long distance communication.

Noise:

→ undesirable electric signals interfere with the information. At that time, it is not possible to get the original message.

Receiver:

It is used to receive the message signal from channel

Destination:

It is a final stage which is used to convert the electrical signal into its original form.

Without Modulation, there are some disadvantages

* Large antenna heights
* Short range of communication
* Signals get mixed up.
* Multiplexing is not possible.

Modulation:

modulation is defined as the process by which some parameter of the carrier signal (high frequency signal) is varied in accordance with the instantaneous value of modulating signal.

why we go for Modulation:

In wireless communication, signals from various sources are transmitted through free space. This causes interference among various signals & no useful information is received by the receiver. The problem of interference is solved by translating the message signal to different radio frequency spectrum. This is done in the transmitter by a process called modulation.

Need of Modulation (or) Advantages of Modulation

* Reduction in antenna height
* Increases the range of communication.
* Avoids mixing of signals.
* Multiplexing is possible.

Frequency:

→ Number of cycles of a waveform per second. Unit is Hertz.

Wavelength:

Distance between two points of similar cycles of a periodic wave.

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \, m/s}{f}$$

Bandwidth:

Frequency range through which information being transmitted.

Frequency designation	Frequency range
Low frequency	30 - 300 KHz
medium "	300 KHz - 3 MHz
High "	3 - 30 MHz
Very high "	30 - 300 MHz
Ultra high "	300 MHz - 3 GHz
Super high "	3 - 30 GHz
Extremely high "	30 - 300 GHz

③

UNIT- I

ANALOG COMMUNICATION

AM (DSB-FC)

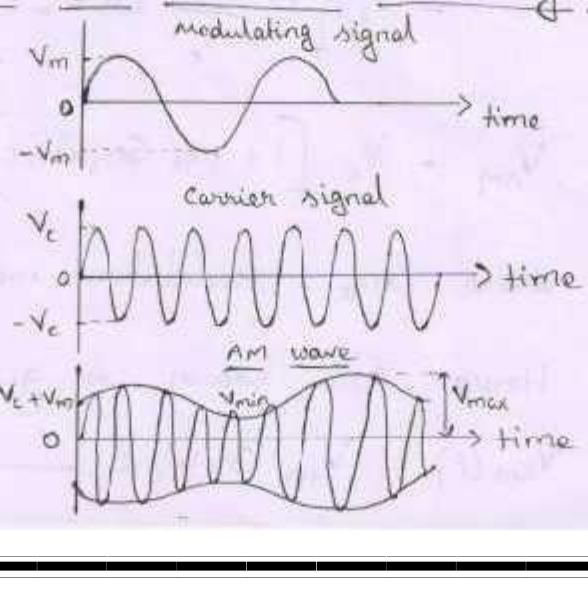
→ Frequency spectrum & Bandwidth
→ Vector representation (phasor)
→ Power relation
→ Generation of AM waves.

AM:

Definition:

Amplitude modulation is defined as the Process by which amplitude of the carrier signal is varied in accordance with the instantaneous value of the modulating signal, but frequency & phase remains constant

AM waveform for sinusoidal modulating signal



Mathematical representation of an AM wave

Let, the Modulating signal,

$$V_m(t) = V_m \cos \omega_m t \quad \text{——} \ (1)$$

Carrier signal,

$$V_c(t) = V_c \cos \omega_c t \quad \text{——} \ (2)$$

where $V_m \rightarrow$ amplitude of modulating signal

$V_c \rightarrow$ amplitude of carrier signal

After modulation, peak amplitude of modulated wave is expressed as,

$$V_{AM} = V_c + V_m(t) \quad \text{——} \ (3)$$

Substitute (1) in (3)

$$V_{AM} = V_c + V_m \cos \omega_m t$$

$$= V_c \left[1 + \frac{V_m}{V_c} \cos \omega_m t \right]$$

$$V_{AM} = V_c \left[1 + m_a \cos \omega_m t \right] \quad \text{——} \ (4)$$

where m_a = Modulation index = $\frac{V_m}{V_c}$

Hence AM wave is given by

$$V_{AM}(t) = V_{AM} \cos \omega_c t \longrightarrow (5)$$

Substitute (4) in (5)

$$V_{AM}(t) = V_c\left[1 + m_a \cos\omega_m t\right] \cos\omega_c t$$

$$\boxed{V_{AM}(t) = V_c\left[1 + m_a \cos\omega_m t\right] \cos\omega_c t} \longrightarrow (6)$$

This equation gives the mathematical representation of AM wave

AM Frequency spectrum and Bandwidth

Frequency spectrum:

Although the modulated signal contains two frequencies f_c & f_m, the modulation process generates new frequencies that are sum & difference of f_c & f_m.

The spectrum is found by expanding the equation of modulated wave as follows.

The AM wave is given by

$$V_{AM}(t) = V_c\left[1 + m_a \cos\omega_m t\right] \cos\omega_c t$$

$$= V_c \cos\omega_c t + m_a V_c \cos\omega_m t \cos\omega_c t$$

w.k.t $\cos\omega_m t \cos\omega_c t = \frac{\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t}{2}$

$$V_{Am}(t) = V_c \cos\omega_c t + \frac{m_a V_c}{2}\left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\right]$$

$$\boxed{V_{Am}(t) = \underbrace{V_c \cos\omega_c t}_{\text{Carrier}} + \underbrace{\frac{m_a V_c}{2}\cos(\omega_c - \omega_m)t}_{\text{Lower Side band (LSB)}} + \underbrace{\frac{m_a V_c}{2}\cos(\omega_c + \omega_m)t}_{\text{Upper Sideband (USB)}}}$$

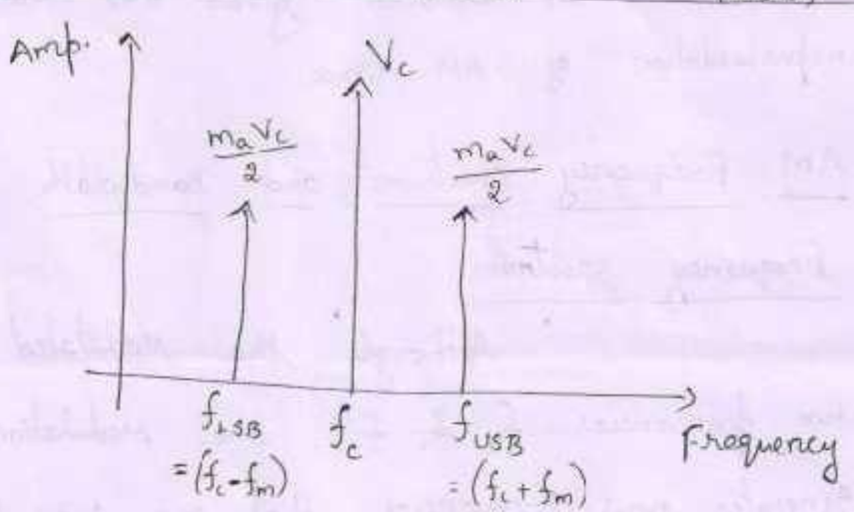


Fig. Frequency Domain representation of AM wave

Bandwidth of AM

$$B = f_{USB} - f_{LSB}$$

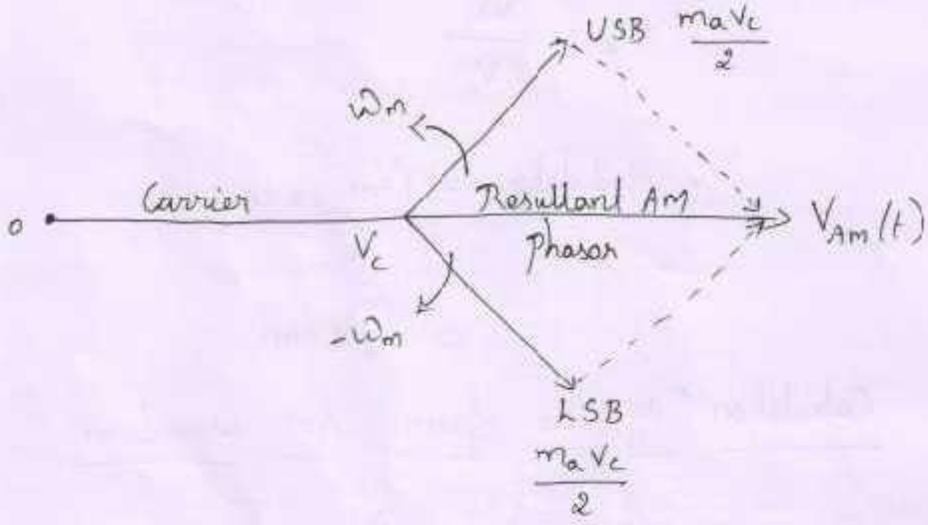
$$= f_c + f_m - f_c + f_m$$

$$\boxed{B = 2f_m} \ Hz$$

$B \rightarrow$ Bandwidth

$f_m \rightarrow$ Highest modulating frequency in Hz.

Phasor (vector) representation of AM wave with Carrier



→ phasor for the USB rotates in anticlockwise direction at an angular frequency of ω_m and phasor for the LSB rotates in clockwise at an same angular frequency $-\omega_m$.

→ upper side frequency ω_m rotates faster than the Carrier ω_c i.e $\omega_m > \omega_c$ and the Lower side frequency rotates slower than the carrier i.e $\omega_m < \omega_c$.

→ The resulting amplitude of the modulated wave at any instant is the vector sum of the two sideband phasors.

→ V_c is carrier wave phasor taken as reference phasor & the resulting phasor is $V_{Am}(t)$.

Modulation index & Percentage modulation

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

$$\% \text{ Modulation} = \frac{V_m}{V_c} \times 100$$

$$= m_a \times 100$$

Calculation of m_a from AM waveform

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

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

$$\boxed{m_a = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}}$$

$$\boxed{\% M_a = \frac{V_{max} - V_{min}}{V_{max} + V_{min}} \times 100}$$

Degree of Modulation:

- Under Modulation $m_a < 1$ when $V_m < V_c$
- Critical modulation $m_a = 1$ when $V_m = V_c$
- Over modulation $m_a > 1$ when $V_m > V_c$

AM Power relation:

→ Power is the rate at which work is done (or) power is the rate of energy transfer. unit of power is watt. $P = VI = V^2/R = I^2R$

An AM wave Consists of Carrier and two sidebands.

The amplitude of the sidebands depends on the modulation index 'm_a'. Therefore, the total power of the modulated wave will also depend on the modulation index.

The total power of the modulated wave is expressed as,

$$P_t = \text{Carrier Power} + \text{Power in LSB} + \text{Power in USB}$$

$$= P_{carr} + P_{LSB} + P_{USB}$$

$$= \frac{V_{carr}^2}{R} + \frac{V_{LSB}^2}{R} + \frac{V_{USB}^2}{R} \quad (\text{rms})$$

$$= \frac{(V_c^2 + V_L^2 + V_U^2)}{R} \Rightarrow \text{rms value}$$

where all these three Voltages are in rms Values & R is the resistance, in which the Power is dissipated.

(i) Carrier Power (P_c)

It is equal to the rms carrier voltage squared divided by the resistance

$$P_c = \frac{V_{carr}^2}{R}$$

where, $V_{carr} = 0.707 V_c$

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

$$= \frac{\left(\frac{V_c}{\sqrt{2}}\right)^2}{R} = \frac{V_c^2}{2R}$$

$$\boxed{P_c = \frac{V_c^2}{2R}}$$

where $V_c \rightarrow$ Peak carrier voltage (V)

$R \rightarrow$ load resistance (Ω).

(ii) Power in side bands

$$P_{LSB} = P_{USB} = \frac{(0.707 V_{SB})^2}{R}$$

where V_{SB} is the peak voltage of USB & LSB.

(7)

$$V_{SB} = \frac{m_a V_c}{2}$$ substitute in above equation

$$P_{LSB} = P_{USB} = \frac{\left(0.707 \frac{m_a V_c}{2}\right)^2}{R}$$

$$\boxed{P_{LSB} = P_{USB} = \frac{m_a^2 V_c^2}{8R} = \frac{m_a^2}{4} \cdot P_c}$$

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

$$= \frac{V_c^2}{2R} + \frac{m_a^2 V_c^2}{8R} + \frac{m_a^2 V_c^2}{8R}$$

$$= \frac{V_c^2}{2R}\left[1 + \frac{m_a^2}{4} + \frac{m_a^2}{4}\right]$$

$$\boxed{P_t = P_c\left[1 + \frac{m_a^2}{2}\right]}$$

Modulation index interms of Power

$$\frac{P_t}{P_c} = 1 + \frac{m_a^2}{2}$$

$$\frac{m_a^2}{2} = \frac{P_t}{P_c} - 1$$

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

$$m_a = \sqrt{2\left(\frac{P_t}{P_c} - 1\right)}$$

Current Calculations:

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

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

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

Modulation index interms of Current

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

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

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

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

Transmission Efficiency

$$\eta = \frac{\text{Power in SB}}{P_t}$$

$$= \frac{\frac{m_a^2 V_c^2}{8R} + \frac{m_a^2 V_c^2}{8R}}{\frac{V_c^2}{2R}\left[1 + \frac{m_a^2}{2}\right]}$$

$$= \frac{\frac{V_c^2}{2R}\left[\frac{m_a^2}{4} + \frac{m_a^2}{4}\right]}{\frac{V_c^2}{2R}\left[1 + \frac{m_a^2}{2}\right]}$$

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

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

If $m_a = 1$, then 100% Modulation takes place

$$\% \eta = \frac{1}{3} \times 100$$

$$= 33.3\%$$

Only 33.3% of energy is used & remaining Power is wasted by the Carrier signal along with sidebands.

Advantages:

* Simple modulators & demodulators
* Low cost
* AM can travel a long distance
* It covers larger area than FM.

Disadvantages:

* Power wastage takes place.
* Wastage in bandwidth.
* Poor performance in Presence of noise.

Application:

* Radio broadcasting
* Picture transmission in TV system.

9

Generation of AM waves

- Using Non-Linear Property
  - (i) Square Law Modulator
  - (ii) Balanced Modulator
- Using Linear property
  - (i) Switching Modulator

In general non linear modulators are low level, linear modulators are high level.

(i) Square Law Modulator:

The square law Modulator Circuit consists of the following.

(i) A non-linear device
(ii) A band pass filter
(iii) A carrier source & Modulating signal

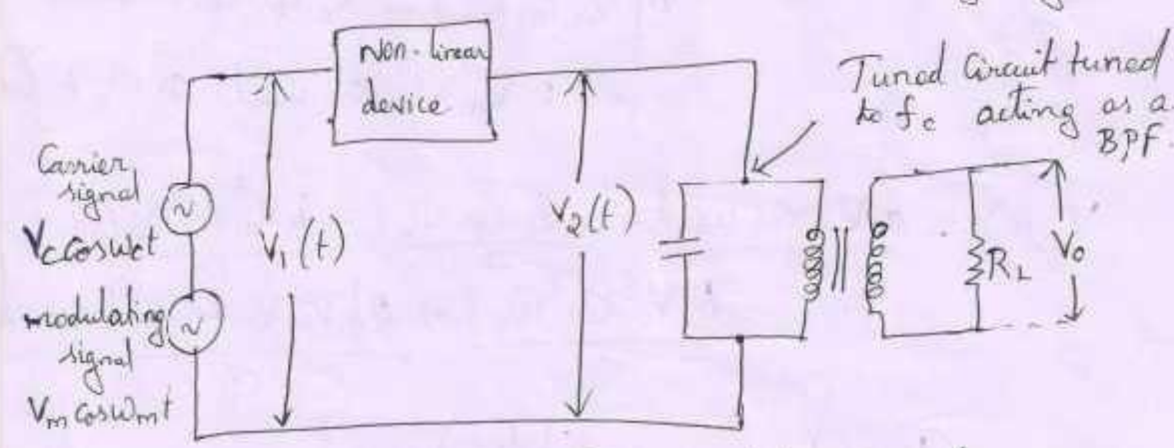


Fig: Square law Modulator Circuit

The modulating & carrier signal are Connected in series with each other, their sum $v_1(t)$ is applied at the input of the non-linear devices, such as diode, transistor etc.

$$V_1(t) = V_m \cos\omega_m t + V_c \cos\omega_c t \quad \text{——} \ (1)$$

* The input output relation for non-linear device is as follows:

$$V_2(t) = a V_1(t) + b V_1^2(t) \quad \text{——} \ (2)$$

where a & b are constants

Sub (1) in (2)

$$V_2(t) = a\left[V_m \cos\omega_m t + V_c \cos\omega_c t\right] + b\left[V_m \cos\omega_m t + V_c \cos\omega_c t\right]^2$$

$$= a V_m \cos\omega_m t + a V_c \cos\omega_c t + b\left[V_m^2 \cos^2\omega_m t + V_c^2 \cos^2\omega_c t + 2 V_m V_c \cos\omega_m t \cos\omega_c t\right]$$

$$V_2(t) = \underbrace{a V_m \cos\omega_m t}_{(1)} + \underbrace{a V_c \cos\omega_c t}_{(2)} + \underbrace{b V_m^2 \cos^2\omega_m t}_{(3)} + \underbrace{b V_c^2 \cos^2\omega_c t}_{(4)} + \underbrace{2b V_m V_c \cos\omega_m t \cos\omega_c t}_{(5)}$$

Term 1 — modulating signal

Term 2 — Carrier signal

Term 3 — Squared Modulating signal

Term 4 — squared carrier signal

fifth term — AM wave with only sidebands.

* The LC tuned Circuit acts as a band pass filter. This Circuit is tuned to frequency f_c & its bandwidth is equal to $2f_m$.

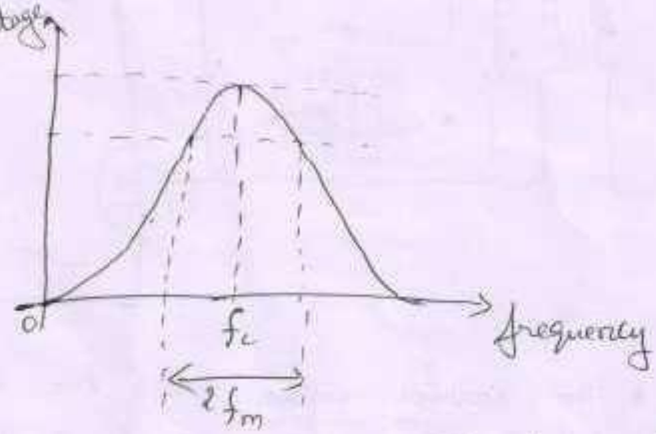


Fig: Response of the band pass filter.

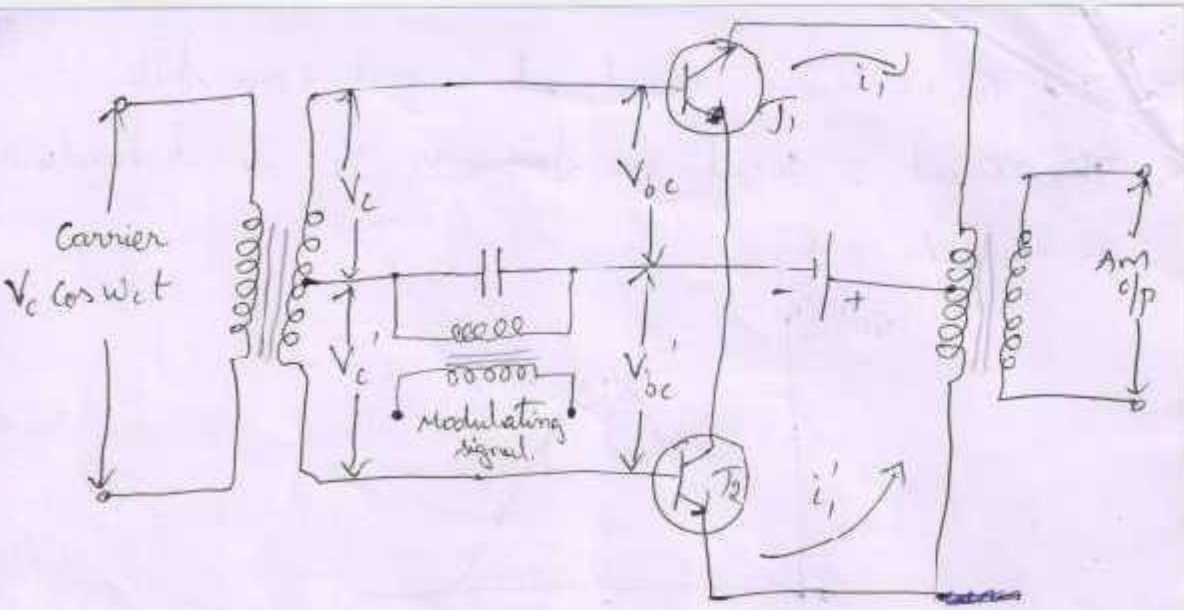
* When the BPF is tuned to the Carrier frequency, it allows only ω_c, $(\omega_c - \omega_m)$ & $(\omega_c + \omega_m)$. Neglecting second & higher order terms,

$$V_2(t) = a V_c \cos \omega_c t + b V_m V_c \left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\right]$$

Balanced Modulator:

Here two non-linear devices are connected in the balanced mode.

It is assumed that the two transistors are identical & the Circuit is symmetrical



* The carrier voltage across the two windings of a Centre-tap transformer are equal, & opposite in phase, i.e $V_c = -V_c'$

* The input voltage to transistor T_1 is given by.

$$V_{bc} = V_c + V_m$$

$$= V_c \cos \omega_c t + V_m \cos \omega_m t \quad \text{—} (1)$$

since, both V_c & V_m are in phase.

III^{ly}, the i/p vtg to transistor T_2 is given by

$$V_{bc}' = V_c' + V_m$$

$$= -V_c \cos \omega_c t + V_m \cos \omega_m t \quad \text{—} (2).$$

(11)

By the non-linearity relationship, the collector current can be written as.

$$i_1 = a_1 V_{be} + a_2 V_{be}^2 \quad \text{—— (3)}$$

$$i_1' = a_1 V_{be}' + a_2 V_{be}'^2 \quad \text{—— (4)}$$

Sub (1) & (2) in (3) & (4).

$$i_1 = a_1 [V_c \cos \omega_c t + V_m \cos \omega_m t] + a_2 [V_c \cos \omega_c t + V_m \cos \omega_m t]^2$$

$$= a_1 [V_c \cos \omega_c t + V_m \cos \omega_m t] + a_2 [V_c^2 \cos^2 \omega_c t + V_m^2 \cos^2 \omega_m t + 2 V_c V_m \cos \omega_c t \cos \omega_m t]$$

|||ly —— (5).

$$i_1' = a_1 [-V_c \cos \omega_c t + V_m \cos \omega_m t] + a_2 [V_c^2 \cos^2 \omega_c t + V_m^2 \cos^2 \omega_m t - 2 V_c V_m \cos \omega_c t \cos \omega_m t]$$

—— (6).

The output AM Voltage V_o is given by

$$V_o = K (i_1 - i_1') \quad \text{—— (7)}$$

This is bcz (because), currents i_1 & i_1' flow in opposite directions in a tuned circuit.

K is a constant

Sub (5) & (6) in (7).

$$V_o = K(a_1 V_c \cos w_c t + a_1 V_m \cos w_m t + a_2 V_c^2 \cos^2 w_c t + a_2 V_m^2 \cos^2 w_m t + 2 a_2 V_m V_c \cos w_c t \cos w_m t$$
$$+ a_1 V_c \cos w_c t - a_1 V_m \cos w_m t - a_2 V_c^2 \cos^2 w_c t - a_2 V_m^2 \cos^2 w_m t + 2 a_2 V_m V_c \cos w_c t \cos w_m t]$$

$$= K(2 a_1 V_c \cos w_c t + 4 a_2 V_m V_c \cos w_c t \cos w_m t)$$

$$= 2K a_1 V_c \cos w_c t + 4K a_2 V_c V_m \cos w_c t \cos w_m t \quad \text{——— (8)}.$$

- Other terms are balanced out.

$$(8) \Rightarrow V_o = 2K a_1 V_c \cos w_c t \left[1 + \frac{2 a_2 V_m}{a_1} \cos w_m t\right]$$

$$V_o = 2K a_1 V_c \left[1 + m_a \cos w_m t\right] \cos w_c t$$

where $m_a = \frac{2 a_2 V_m}{a_1}$ is the Modulation index.

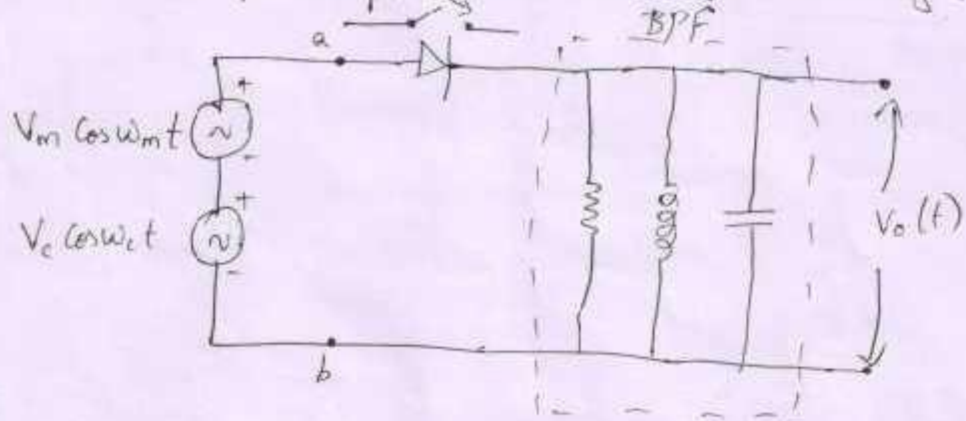
Advantage

→ In this, the undesired non linear terms are automatically balanced out, & at the o/p we get only the desired terms, so filter design is not required.

Generation of AM waves using Linear Property:

(1) Switching Modulator

* A simple diode used for switching Modulator



* The diode is forward biased for every positive half cycle of the carrier, & behaves like a short circuited switch. The signal appears at the i/p of the BPF.

* The diode is reverse biased for a negative half cycle of the carrier & behaves like a open switch. The signal does not reach the filter & no o/p is obtained. Thus signal is modulated at the rate of carrier frequency.

* The BPF passes frequency $\omega_c + \omega_m$

* The o/p voltage in absence of Modulating signal is

$$V_o(t) = V_c \cos\omega_c t$$

* The diode conducts when the Message plus Carrier sgl (Combined signal) is positive. Then the o/p voltage is given by

$$V_o(t) = V_c \cos w_c t + V_m \cos w_m t \cos w_c t$$

$$\boxed{V_o(t) = (V_c + V_m \cos w_m t) \cos w_c t}$$

DSB

(13)

To overcome the power wastage & bandwidth, we can make the three modified forms of amplitude modulation. Carrier sgl doesnot convey any useful infm.

Classification of AM

Amplitude modulation

- DSB with full Carrier AM
- Double sideband with suppressed Carrier - AM
- SSB - SC AM
- VSB - AM

Double side band - Suppressed Carrier

→ In this, the transmitted wave consists of only upper & lower sidebands.

→ Txed Power is saved here through the suppression of the carrier wave.

Txion B.W

$$\boxed{BW = 2 f_m}$$

→ twice the freq. of the modulating signal.

Expression for DSB-SC

Let, the modulating signal, $V_m(t) = V_m \cos \omega_m t$ —— (1)

The carrier sgl. $V_c(t) = V_c \cos \omega_c t$ —— (2)

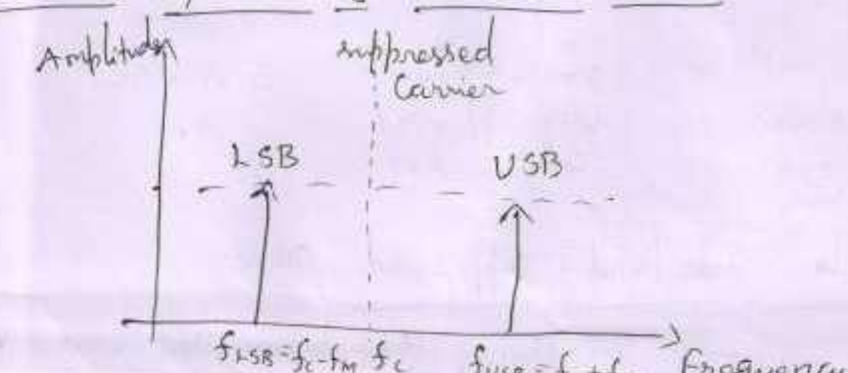
$$V(t)_{DSB\text{-}SC} = V_m(t)\, V_c(t)$$

$$= V_m V_c \cos \omega_m t \cos \omega_c t$$

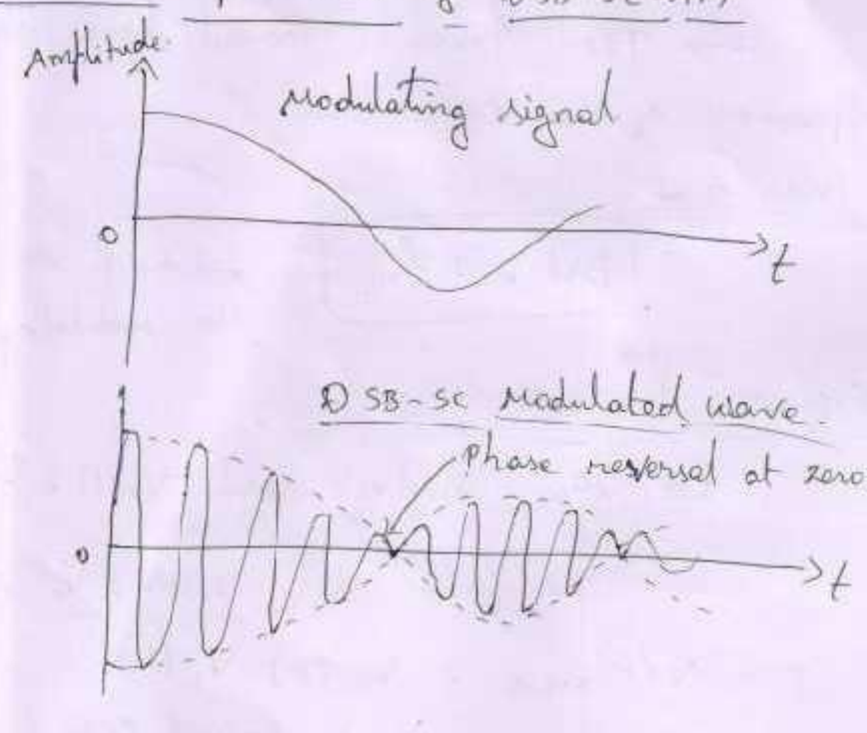
$$V(t)_{DSB-SC} = \frac{V_m V_c}{2}\left[\cos(w_c - w_m)t + \cos(w_c + w_m)t\right] \quad \text{--- (3)}$$

The above equation contains only sideband components & no carrier component.

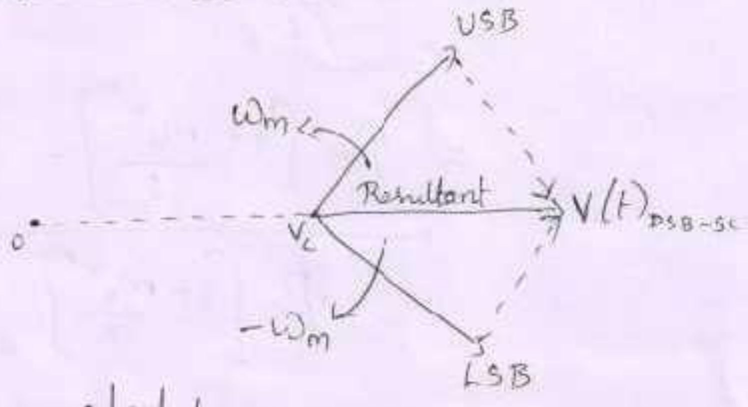
Frequency spectrum of DSB-SC AM



Graphical representation of DSB-SC-AM



Phasor diagram of DSB-SC AM



Power calculation

* The total power transmitted in AM is

$$P_t = P_c\left[1 + \frac{m_a^2}{2}\right] \quad \text{where } P_c = \frac{V_c^2}{2R}.$$

* If the carrier is suppressed, then the total power transmitted in DSB-SC is,

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

$$= \frac{m_a^2 V_c^2}{8R} + \frac{m_a^2 V_c^2}{8R}$$

$$= \frac{V_c^2}{2R}\left[\frac{m_a^2}{4} + \frac{m_a^2}{4}\right]$$

$$P_t' = P_c\left[\frac{m_a^2}{2}\right]$$

* Power savings $= \frac{P_t - P_t'}{P_t}$

$$= \frac{P_c\left[1+\frac{m_a^2}{2}\right] - \frac{m_a^2}{2}P_c}{P_c\left[1+\frac{m_a^2}{2}\right]}$$

$$= \frac{P_c\left[1+\frac{m_a^2}{2} - \frac{m_a^2}{2}\right]}{P_c\left[1+\frac{m_a^2}{2}\right]}$$

$$= \frac{1}{1+\frac{m_a^2}{2}} = \frac{2}{2+m_a^2}$$

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

* If $m_a = 1$ (100% modulation), then the power saving is

$$= \frac{2}{3} \times 100$$

$$= 66.67\%$$

* In DSB-SC, 66.67% of power is saved due to the suppression of carrier wave.

(15)

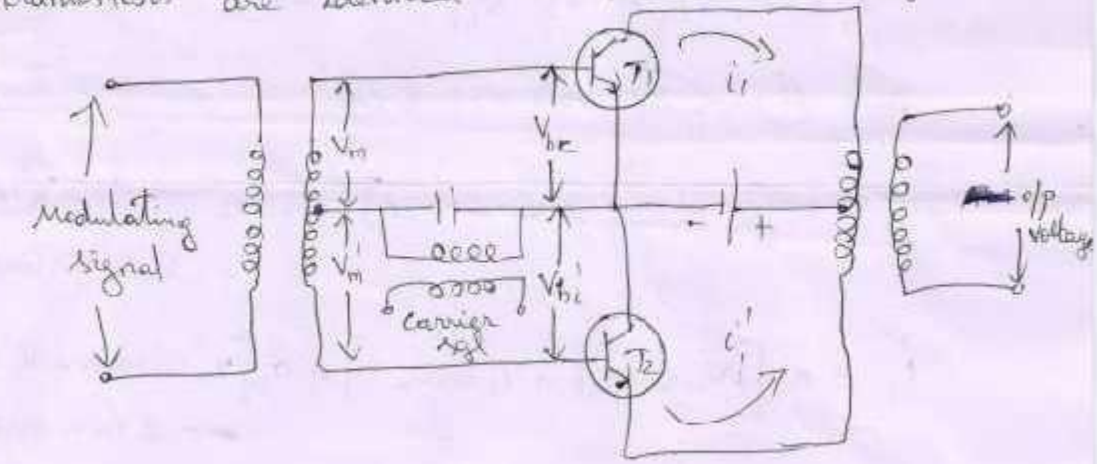
Generation of DSB-SC-AM

Two ways

* Balanced Modulator
* Ring Modulator.

Balanced Modulator

→ Two non-linear devices are connected in balanced mode i.e it is assumed that the two transistors are identical & the circuit is symmetrical.



* The modulating voltage across two windings of a centre-tap transformer are equal, & opposite in phase i.e. $V_m = -V_m'$
* The i/p voltage to transistor T_1 is given by

$$V_{bc} = V_m + V_c$$

$$V_{bc} = V_m \cos W_m t + V_c \cos W_c t \quad \text{— (1)}$$

* The i/p voltage to transistor T_2 is given by

$$V'_{bc} = V'_m + V_c$$

$$V'_{bc} = -V_m \cos \omega_m t + V_c \cos \omega_c t \quad \text{——} (2).$$

By the non-linearity relationship, the collector Current can be written as

$$i_1 = a_1 V_{bc} + a_2 V_{bc}^2 \quad \text{——} (3)$$

$$i'_1 = a_1 V'_{bc} + a_2 V'^2_{bc} \quad \text{——} (4)$$

sub (1) & (2) in (3) & (4)

$$i_1 = a_1 [V_m \cos \omega_m t + V_c \cos \omega_c t] + a_2 [V_m^2 \cos^2 \omega_m t + V_c^2 \cos^2 \omega_c t + 2 V_m V_c \cos \omega_m t \cos \omega_c t]$$

$$i'_1 = a_1 [-V_m \cos \omega_m t + V_c \cos \omega_c t] + a_2 [V_m^2 \cos^2 \omega_m t + V_c^2 \cos^2 \omega_c t - 2 V_m V_c \cos \omega_m t \cos \omega_c t]$$

The o/p voltage is given as,

$$V_o = K(i_1 - i'_1)$$

$$= K(a_1 V_m \cos \omega_m t + a_1 V_c \cos \omega_c t + a_2 V_m^2 \cos^2 \omega_m t + a_2 V_c^2 \cos^2 \omega_c t + 2 a_2 V_m V_c \cos \omega_m t \cos \omega_c t + a_1 V_m \cos \omega_m t - a_1 V_c \cos \omega_c t - a_2 V_m^2 \cos^2 \omega_m t - a_2 V_c^2 \cos^2 \omega_c t + 2 a_2 V_m V_c \cos \omega_m t \cos \omega_c t]$$

$$V_o = k\left[2a_1 V_m \cos\omega_m t + 4\, a_2 V_m V_c \cos\omega_m t \cos\omega_c t\right]$$

$$= 2k a_1 V_m \cos\omega_m t + 4k\, a_2 V_m V_c \cos\omega_m t \cos\omega_c t$$

$$= 2k a_1 V_m \left[1 + \frac{2a_2 V_c}{a_1}\cos\omega_c t\right] \cos\omega_m t$$

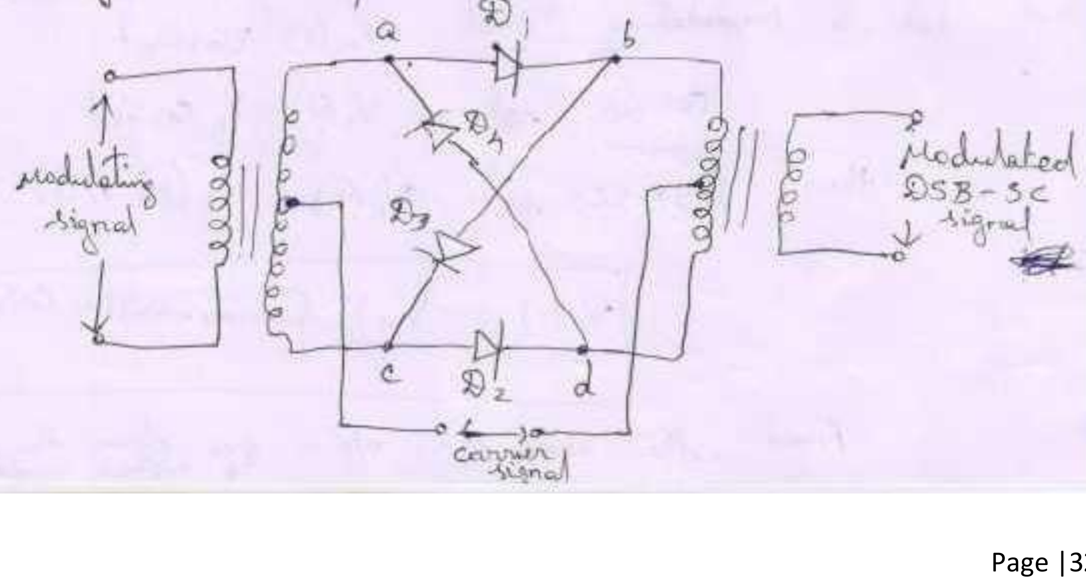
$$\boxed{V_o = 2k a_1 V_m \left[1 + m_a \cos\omega_c t\right] \cos\omega_m t}$$

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

(ii) Ring Modulator:

* It is another Product Modulator, which is used to generate DSB-SC signal.

* In a ring modulator circuit, four diodes are connected in the form of a ring in which all four diodes Point in the same Manner.



* All the four diodes are controlled by a square wave carrier signal $V_c(t)$ of frequency f_c, applied through a centre-tapped transformer.

operation:

* when both the carrier & modulating signals are present, during (+ve) half cycle of the carrier, diodes D_1 & D_2 conduct, whiles diodes D_3 & D_4 does not conduct.

* During (-ve) half cycle of the carrier, diodes D_3 & D_4 conduct & D_1 & D_2 does not conduct

Phase reversal:

when polarity of the modulating sgl changes, the result is a 180° phase reversal.

* Hence the ring modulator is a product modulator for a square wave carrier & modulating signal

Let, a modulating signal, $V_m(t) = V_m \cos \omega_m t$

Carrier sgl, $V_c(t) = V_c \cos \omega_c t$

then DSBSC sgl, $V_0(t) = V_m(t)\, V_c(t)$

$$V_0(t) = \frac{V_m V_c}{2}\left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\right]$$

From the above eqn, o/p is free from the carrier & higher order terms

(17)

* A ring modulator is also known as a double-balanced modulator since it is balanced with respect to the modulating signal as well as the square wave carrier signal.

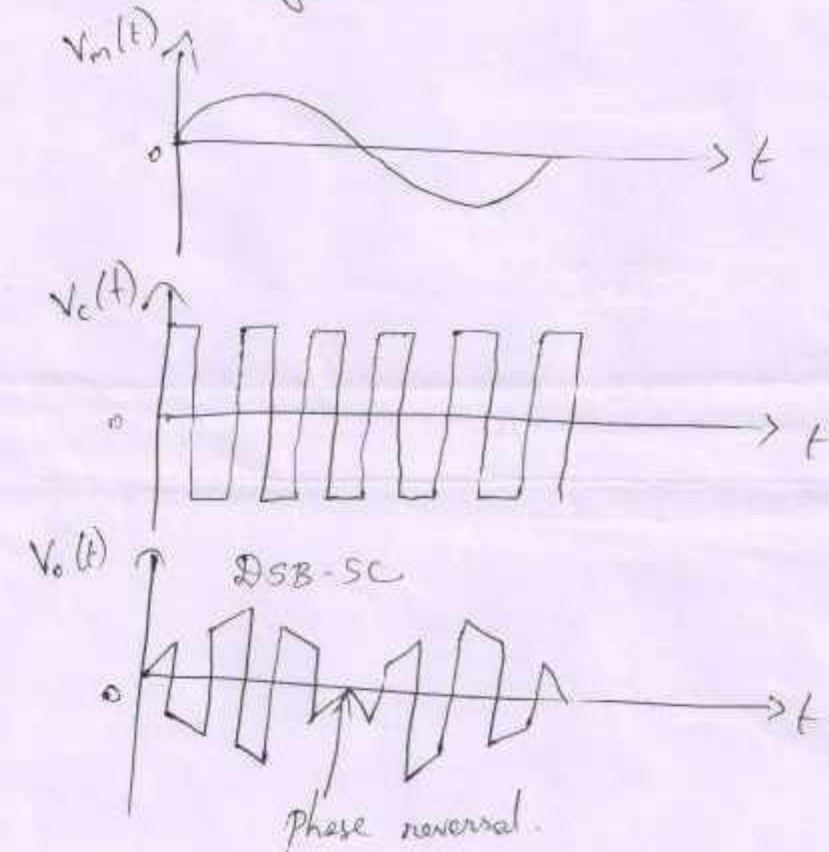


Fig: Graphical representation of DSB-SC signal

Adv:

-> More efficient in txed Power
-> Better signal to noise ratio.
-> modulation system is simple.

Disadv:

-> Complex detection -> B.W remains same as DSB/

Appln:

→ Analog TV systems to transmit Colour information.

Single Sideband Suppressed Carrier (SSB-SC AM)

* In this, one sideband is enough for transmitting as well as recovering the useful Message.
* Here to increase in the Power saving by eliminating one sideband in addition to the carrier component.

-> Transmission Bandwidth
-> phasor diagram
-> power calculation
-> Generation

(i) Transmission Bandwidth:

It requires half of the bandwidth of DSB-SC.

$$BW = f_m$$

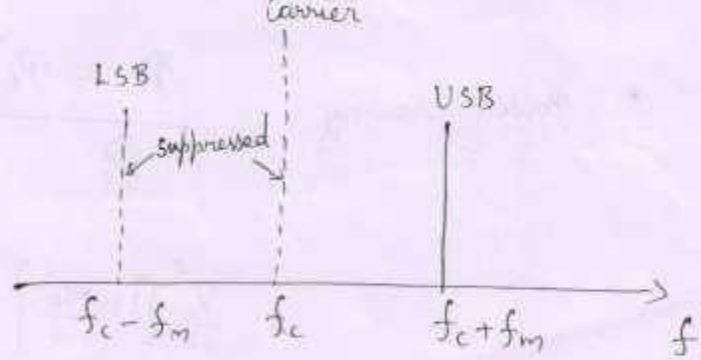
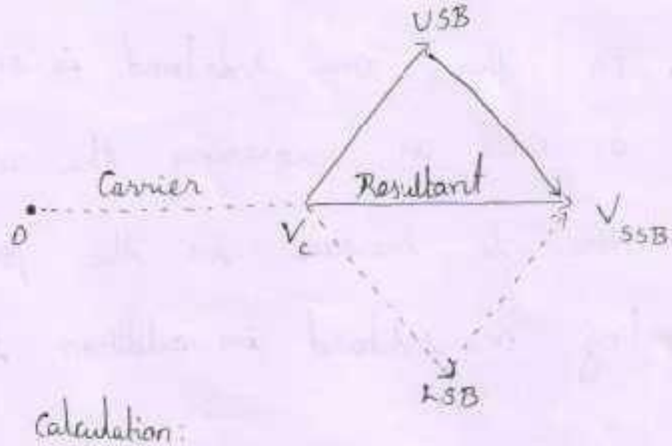


Fig: Frequency spectrum of SSB-SC-AM

(ii) Phasor Diagram of SSB-SC-AM



(iii) Power calculation:

Total power saved in SSB-SC-AM is calculated as follows:

* Total power transmitted in AM is,

$$P_t = P_c\left[1+\frac{m_a^2}{2}\right] = \frac{V_c^2}{2R}\left[1+\frac{m_a^2}{2}\right]$$

* Power in SSB-SC-AM is

$$P_t'' = \frac{m_a^2 V_c^2}{8R}$$

* Power saving $= \dfrac{P_t - P_t''}{P_t}$

$$= \frac{\frac{V_c^2}{2R}\left[1+\frac{m_a^2}{2}\right] - \frac{V_c^2}{2R}\cdot\frac{m_a^2}{4}}{\frac{V_c^2}{2R}\left[1+\frac{m_a^2}{2}\right]}$$

$$= \frac{\frac{V_c^2}{2R}\left[1 + \frac{m_a^2}{2} - \frac{m_a^2}{4}\right]}{\frac{V_c^2}{2R}\left[1 + \frac{m_a^2}{2}\right]}$$

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

If $m_a = 1$, then

$$\% \text{ Power saving} = \frac{5}{6} = 83.33\%$$

* In addition to the Carrier, one of the sidebands is also suppressed the power savings is 83.3% over AM with Carrier

ii) <u>Generation of SSB</u>

Two Methods

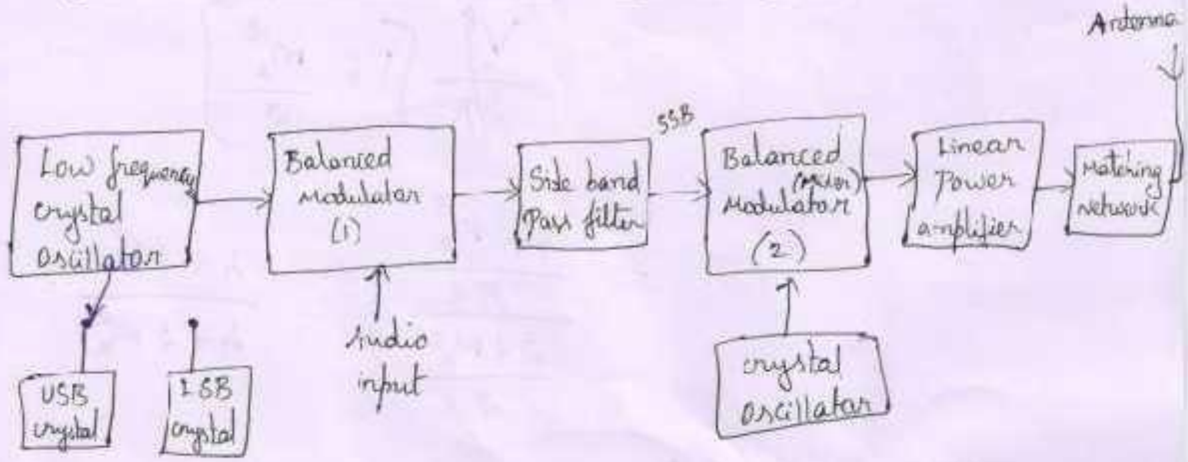
(i) Frequency discrimination Method

(ii) Phase discrimination Method

→ Phase shift Method

→ Modified phase shift (or) Weaver's Method

(i) Frequency discrimination (or) Filter method



* Balanced modulator (1) generates DSB-SC signal, that signal is transmitted into the filter to remove the unwanted sideband.
* The filter is a single side band filter with sharp cut off.
* The filtered signal is upconverted in mixer to the final transmitted frequency and then amplified before being coupled with the antenna.
* Linear power amplifiers are used to avoid distorting signal.
* Initial modulation takes place in the balanced modulator (1) at a low frequency (100 KHZ).
* Mechanical filters are used often because of the following advantages.

(20)

-> small size
-> good bandpass characteristics
-> good attenuation characteristics.

* crystal filters may be cheaper but are preferable only at frequency greater than 1MHZ.

* In the mixer, the frequency of the crystal oscillator is added to the SSB signal. thus the frequency is increased to the desired value of the transmitting frequency.

* In this Method, the mixer is followed by linear amplifiers. Here class 'B' amplifier is used because it is more efficient than class 'A' output.

(ii) Phase shift Method:

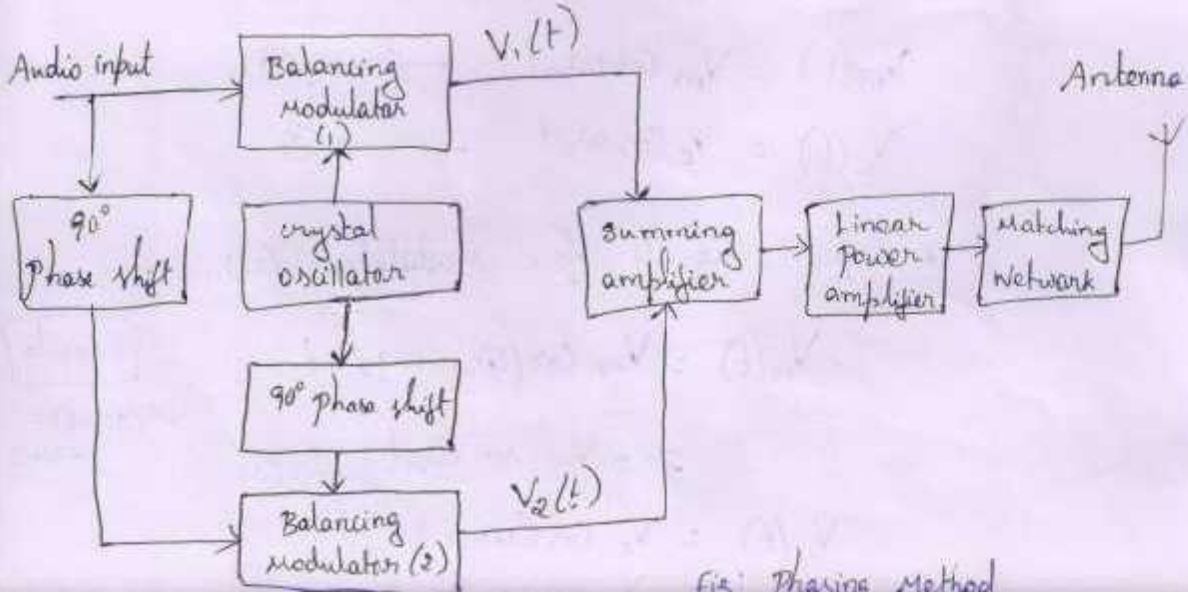


Fig: Phasing Method

* Two balance modulators and two phase shifters are used in this phasing method. One of the modulators receives the input signal directly and another receives with a phase shift of 90°.

* The carrier signal is passed through the second modulator with a phase shift of 90° and the another modulator receives the signal directly.

* The carrier signal is cancelled out in this circuit by both of the balanced modulators, and the unwanted sidebands cancel at the output of the summing amplifiers.

* Input signals for Modulator (1),

$$V_m(t) = V_m \cos \omega_m t \longrightarrow ①$$

$$V_c(t) = V_c \cos \omega_c t \longrightarrow ②$$

* Input signals for Modulator (2),

$$V_m(t) = V_m \cos(\omega_m + 90^\circ)t$$

$$= -V_m \sin \omega_m t \longrightarrow ③$$

Formula: $\cos(90^\circ + \theta) = -\sin\theta$

$$V_c(t) = V_c \cos(\omega_c + 90^\circ)t$$

$$= -V_c \sin \omega_c t \longrightarrow ④$$

output from modulator (1),

$$V_1(t) = V_m \cos\omega_m t \cdot V_c \cos\omega_c t$$

$$= V_m V_c \cos\omega_m t \cdot \cos\omega_c t$$

$$= V_m V_c \cdot \left[\frac{\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t}{2}\right]$$

$$V_1(t) = \frac{V_m V_c}{2}\left[\cos(\omega_c - \omega_m)t + \cos(\omega_c + \omega_m)t\right] \quad \longrightarrow (5)$$

Output from modulator (2).

$$V_2(t) = V_m \sin\omega_m t \cdot V_c \sin\omega_c t$$

$$= V_m V_c \sin\omega_m t \cdot \sin\omega_c t$$

$$V_2(t) = \frac{V_m V_c}{2}\left[\cos(\omega_c - \omega_m)t - \cos(\omega_c + \omega_m)t\right] \quad — (6)$$

* From equation (5) & (6), the output from the summing amplifier is,

$$\frac{V_m V_c}{2}\cos(\omega_c - \omega_m)t + \frac{V_m V_c}{2}\cos(\omega_c + \omega_m)t$$

$$\frac{V_m V_c}{2}\cos(\omega_c - \omega_m)t - \frac{V_m V_c}{2}\cos(\omega_c + \omega_m)t$$

$$V_m V_c \cos(\omega_c - \omega_m)t$$ (LSB) USB cancelled

* The outputs of two balanced Modulators are summed to Produce lower sideband signal.

Merits:

(i) It doesnot require any sharp cut off filter).

(ii) It is Possible to generate the desired side band in a single frequency translation step, regardless of how large the carrier frequency May be.

Demerits:

→ Less Popular because of the following Constraints should be accurately in order to suppress the Carrier and undesired side band

* Each balanced modulator need to be carefully balanced in order to suppress the Carrier.

* Each Modulator should have equal sensitivity to the base band signal.

* The carrier phase-shifting network must Provide an exact 90° phase shift at Carrier frequency.

(Advantages, Disadvantages, & Application of SSB

Advantages

* Band width required is half as that required by DSBFC system

* Power is saved

(23)

* Because of narrow bandwidth of SSB, the effect of noise at the receiver circuits is reduced. This gives better quality of reception in SSB.

Disadvantages

* Transmission and reception of SSB becomes more Complex and the required Performance standard is very high

* SSB receivers requires accurate tuning than conventional AM receivers.

Applications:

* Point to Point radio telephone communication
* SSB telegraph system
* Police wireless Communication
* VHF & UHF Communication

Vestigial Sideband Modulation (VSB)

* picture signals of television occupy a bandwidth of about 6MHZ. If the transmission is done using the normal AM system, a bandwidth of 12MHZ is required. In order to save the bandwidth, we will transmit only one sideband

* SSB is obtained by using appropriate

filters. But the filter does not have abrupt cut-off frequencies. Hence some of the wanted frequencies also dropped. It will cause high damage in picture transmission.

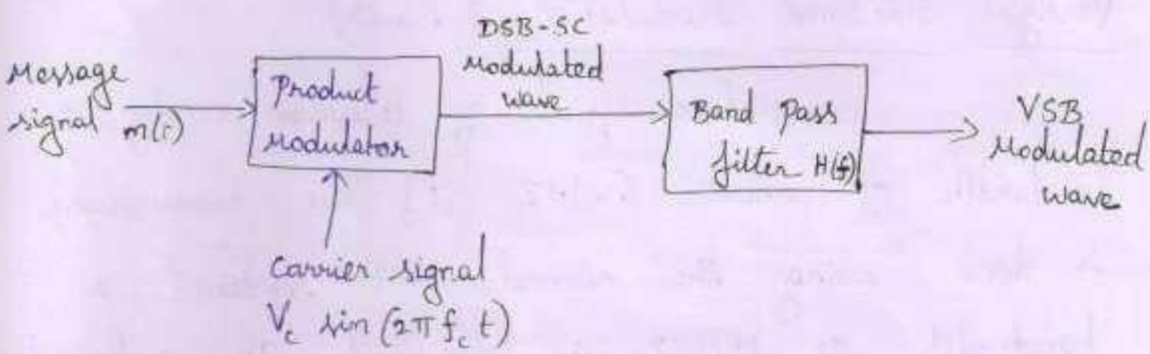
* This difficulty is overcome by the method known as Vestigial sideband (VSB) modulation, which is a compromise between SSB-SC and DSB-SC modulation.

Definition

In VSB modulation, one of the sidebands is partially suppressed and a vestige of the other sideband is transmitted to compensate for that suppression.

Generation of VSB

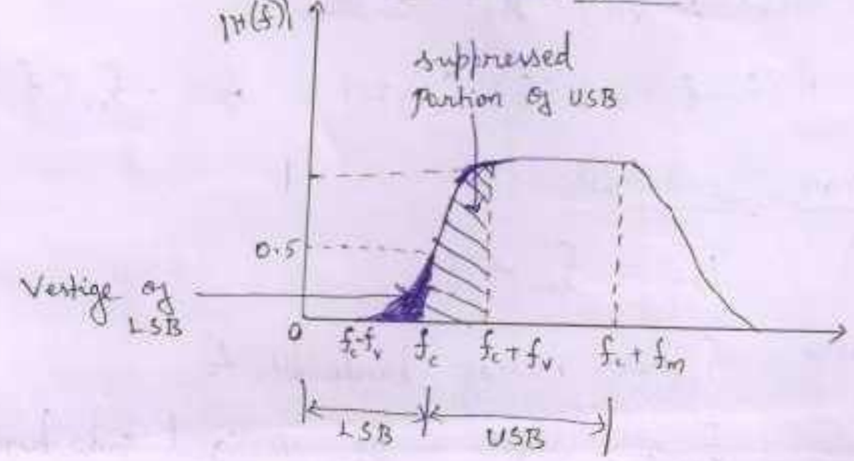
(i) Filter Method (or) Frequency discrimination method



* In this, first we generate DSB-SC modulated wave and then pass it through a BPF.

* It is the special design of the band-pass f that distinguishes VSB modulation from SSB modulation.

<u>magnitude response of VSB filter</u>



* Here f_c to $f_c + f_m$ is upper side band (U. Its portion from f_c to $f_c + f_v$ is suppressed portio

* f_c to $f_c - f_m$ is lower sideband (LSB). Its portion from f_c to $f_c - f_v$ is to be transmitt as vestige.

* The filter response is only for positive frequencies. This frequency response is normalized, so that at the carrier frequency we have $|H(f_c)| = 1/2$

* In the transition interval $f_c - f_v \le |f| \le f_c +$ the following two conditions are satisfied

(i) The sum of the values of the magnitude response $|H(f)|$ at any two frequencies equally displaced above and below f_c is unity.

(ii) The phase response $\arg(H(f))$ is linear. That is, $H(f)$ satisfies the condition

$$H(f-f_c)+H(f+f_c)=1 \quad \text{for } -f_m \le f \le f_m$$

Transmission Bandwidth

$$B_T = f_m + f_v$$

where, $f_m \rightarrow$ message bandwidth &

$f_v \rightarrow$ width of the vestigial side band.

* The VSB modulated wave is described in the time domain as,

$$s(t) = \tfrac{1}{2} V_c m(t) \cos(2\pi f_c t) \pm \tfrac{1}{2} V_c m'(t) \sin(2\pi f_c t)$$

where plus sign $\rightarrow$ transmission of a vestige of USB

& Minus sign $\rightarrow$ " " " " LSB

* The signal $m'(t)$ in the quadrature component of $s(t)$ is obtained by passing the message signal $m(t)$ through a filter whose frequency response $H_Q(f)$ satisfies the following requirement.

$$H_Q(f) = j\left[H(f-f_c) - H(f+f_c)\right] \text{ for } -f_m \le f \le f_m$$

Application:

$\rightarrow$ VSB is used in television for transmission of picture signal.

AM Transmitter & Receiver

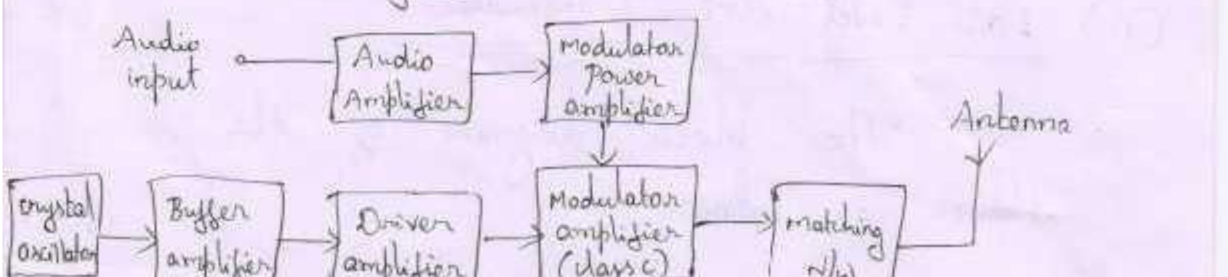
AM Transmitter Two types
- → High Level Modulated AM transmitter
- → Low Level Modulated AM transmitter.

Comparison of High level & Low level Modulation

Parameter	High Level Modulation	Low Level Modulation
1. Power Level	High power level	Low power Level
2. Types of amplifiers	Highly efficient class C amplifiers are used	Linear amplifiers are used (class A, B or AB)
3. Efficiency	Very high	Lower than high level Modulation
4. Devices used	Vacuum tubes, transistors, FET	Transistors, FET, OP-Amp, Diodes.
5 Design of AF P.A	complex due to high power involved	Easy due to low power.
6 Modulation	modulation takes place prior to the o/p element of the final stage of the txer	modulation takes place in the last RF amplifier stage of the transmitter
7. Application	High power broadcast transmitters	Used for wireless intercom, remote control, walkie-Talkie

High Level AM Transmitter

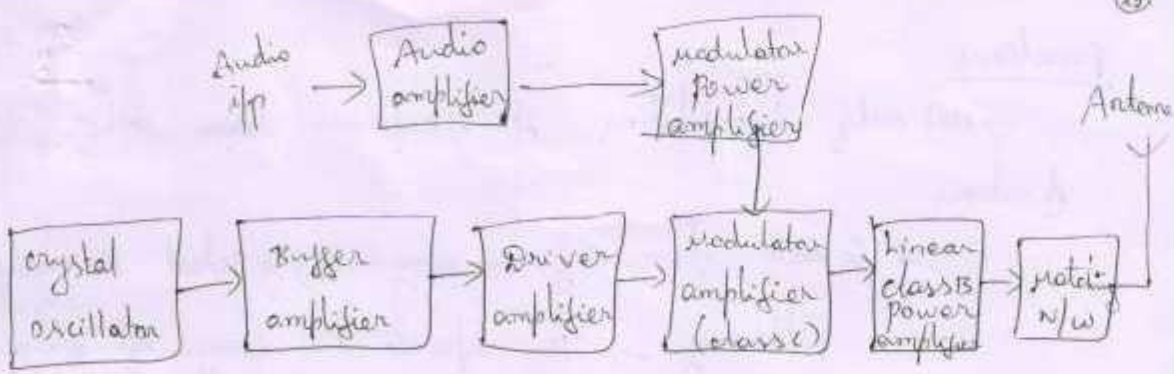
Block Diagram



* The crystal oscillator generates Carrier frequency.
* The buffer amplifiers & driver amplifiers amplify the power level of the Carrier to the required value.
* The amplified carrier is given to class C Modulator amplifier.
* The Modulating signal is audio signal & given to audio amplifier.
* It is further amplified by audio Power amplifier at a level suitable for modulation.
* The class C Modulator amplifier Modulates the Carrier signal according to Modulating audio signal.
* The o/p of the class C Modulating amplifier is AM & it is given to antenna through some antenna Matching N/w
* In the AM Txer, the modulator amplifier operates at high power levels & delivers Power directly to the antenna. The antenna Matching N/w is generally tuned LC Circuit.

(ii) Low Level AM Transmitter

The block diagram of this is shown as below.



* In this, note that a linear class B power amplifier is used after class C modulator amplifier.
* The linear class B power amplifier performs the major power amplification & feeds the amplified AM signal to antenna.
* In this, the modulator amplifier performs modulation at relatively low power levels.
* The modulated AM signal is amplified by class B power amplifier to avoid distortion in the output.

AM Receiver:

At the receiver, signals from various transmitters at different frequencies are present. In addition to this, noise is also present. The receiver is expected to receive the wanted signal from this crowd of the signals.

Functions

→ not only demodulating, it Performs some other functions.

* Carrier frequency tuning → To select the desired signal.
* Filtering → To separate the desired sgl from other Modulated sgl
* Amplification → To compensate the loss of sgl during txion.

Receivers Parameter

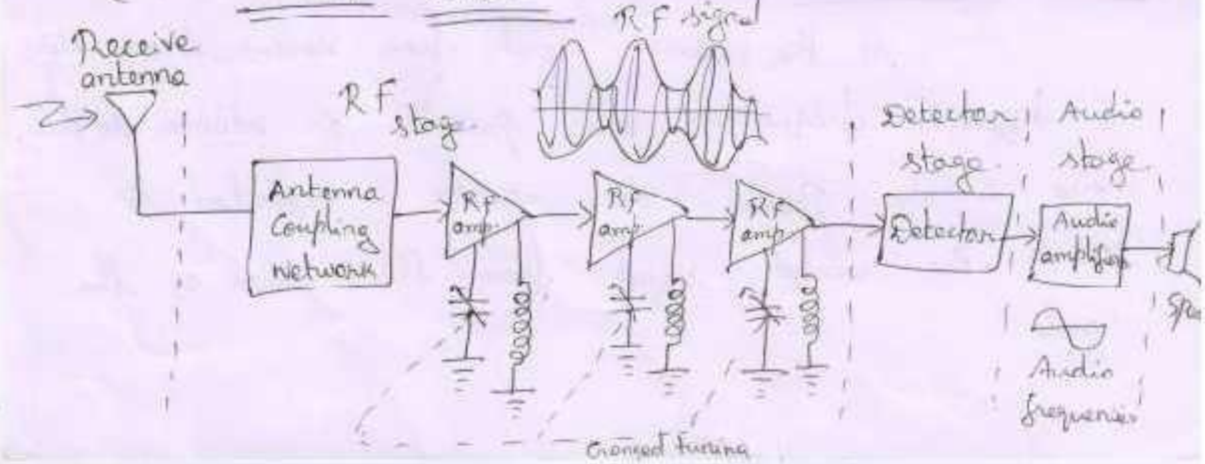
Three Parameters

* Selectivity → Ability of the rxer to select a desired sgl while rejecting all others
* Sensitivity → Ability of the rxer to detect the weakest Possible signal & amplify them.
* Fidelity → To reproduce all the range of modulating signal at the o/p of the rxer.

Two types of AM receiver

(i) Tuned Radio frequency (TRF) receiver
(ii) Super heterodyne receiver

(i) TRF rxer

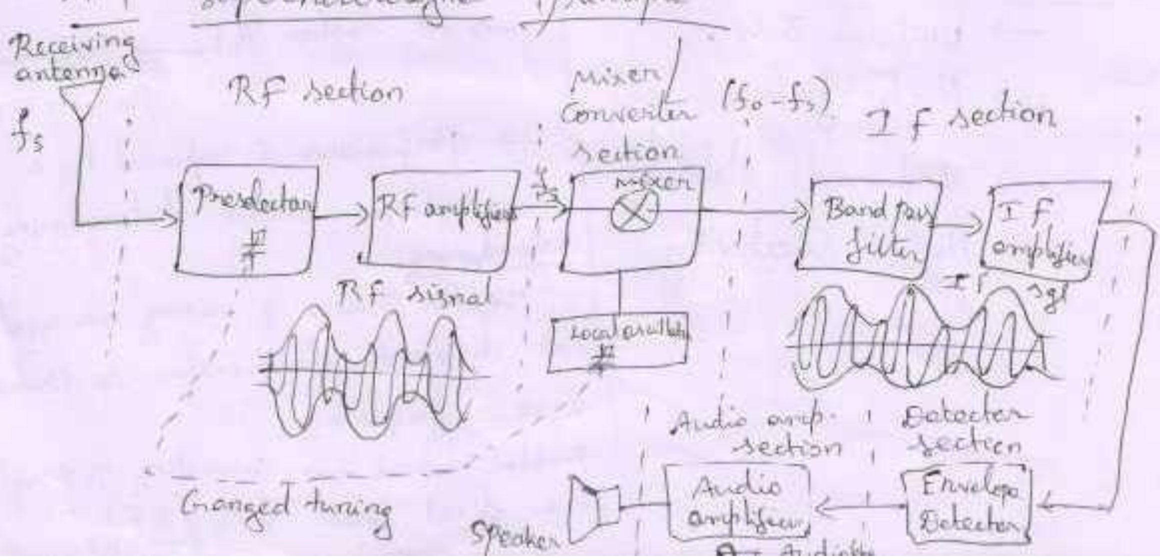


* Two or three RF amplifiers, all tuning together, to select & amplify the incoming frequency and simultaneously reject all others.
* After the sgl was amplified to a suitable level, it was demodulated by using detector.
* In the demodulation process, the carrier signal is by passed & only the modulating signal is recovered.
* The detected sgl is amplified to the adequate Power level using the audio amp. & given to the loudspeaker for reproduction.

Adv:
-> cheaper
-> Simple to implement
-> High sensitivity.

Disadv:
-> Variation in B.W
-> Variation in gain.
-> Instability.
-> Insufficient selectivity.

AM Superheterodyne Principle:



* By turing the RF amplifier & local oscillator select the desired frequency f_s

* Local oscillator is tuned to frequency f_o with $f_o > f_s$

* Mixer Produces IF. $(f_i = f_o - f_s)$

* o/p of Mixer is an AM signal with two sidebands & carrier equal to IF. The IF amplifier amplifies this signal.

* Detector will demodulate this signal to recover the Modulating signal (AF signal)

* The audio amplifier will amplify the AF sgl & apply it to the loud speaker.

Adv:

→ Uniform B.W.
→ High gain
→ Improved stability
→ High selectivity.

Note:

→ At higher RF → Performance Poor in TRF

→ Performance is improved by a technique called heterodyning.

Heterodyning:

→ The Process of mixing two signals at different frequencies to produce a new frequency.

Problem solved → Converting RF sgl to a fixed lower freq (IF) → 455 KHZ

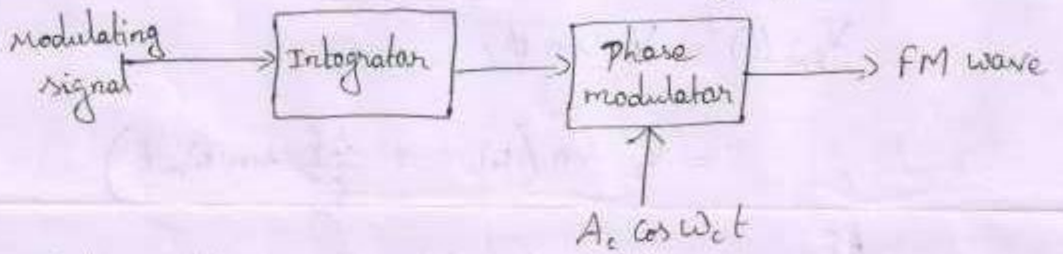
Angle modulation

- FM
- PM

FM: (Frequency modulation)

It is defined as the process by which frequency of the carrier wave is varied in accordance with the instantaneous amplitude of modulating signal.

Generating FM wave using phase modulator



Representation of FM

For the single tone FM, the modulating signal is given as,

$$V_m(t) = V_m \cos \omega_m t \quad \text{—— (1)}$$

The instantaneous angular velocity ω_i is given by.

$$\omega_i = \omega_c + K_f V_m(t) \quad \text{—— (2)}$$

Where, $K_f \rightarrow$ deviation sensitivity $\Rightarrow K_f = \frac{\Delta\omega}{V_m}$

substitute (1) in (2)

$$\omega_i = \omega_c + K_f V_m \cos \omega_m t \quad \text{—— (3)}$$

Integrating equation (3) gives the instantaneous phase angle of the FM wave.

$$K_f = \frac{\Delta\omega}{V_m}$$

$$\Delta\omega = K_f V_m$$

$$\phi_i = \int \omega_i \, dt$$

$$= \int \left(\omega_c + K_f V_m \cos \omega_m t\right) dt$$

$$= \int \left(\omega_c + \Delta\omega \cos \omega_m t\right) dt$$

$$= \omega_c t + \frac{\Delta\omega}{\omega_m} \sin \omega_m t = \omega_c t + \frac{2\pi\Delta f}{2\pi f_m} \sin \omega_m t$$

Hence FM wave is given by

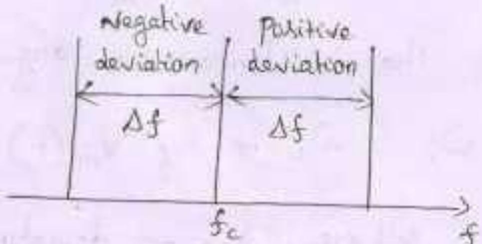
$$V_{FM}(t) = V_c \sin \phi_i$$

$$= V_c \sin\left(\omega_c t + \frac{\Delta f}{f_m} \sin \omega_m t\right)$$

$$\frac{\Delta f}{f_m} = m_f \longrightarrow \text{Modulation index}$$

$$V_{FM}(t) = V_c \sin\left(\omega_c t + m_f \sin \omega_m t\right)$$

Frequency deviation:



Modulation index: It is defined as the ratio of frequency deviation to the modulating frequency

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

Where $\Delta f \rightarrow$ Frequency deviation

$f_m \rightarrow$ Modulating frequency.

Deviation Ratio: ratio of maximum frequency deviation to the maximum modulating frequency

$$DR = \frac{\Delta f_{(max)}\ (Hz)}{f_{m(max)}\ (Hz)}$$

Percentage Modulation: ratio of actual frequency deviation to the maximum frequency deviation

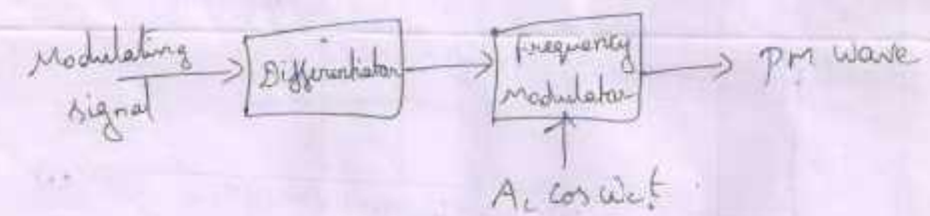
$$\% \text{ modulation} = \frac{\Delta f_{(actual)}}{\Delta f_{(max)}} \times 100$$

PM:

It is defined as the process by which phase of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal)

→ amplitude of the modulated carrier remains constant.

Generating PM using frequency modulator



Representation of PM:

$$V_{pm}(t) = V_c \sin(\omega_c t + m_p \sin \omega_m t)$$

m_p → Modulation index of PM

Modulation index

It is defined as the product of deviation sensitivity & amp. of modulating signal.

$$m_p = K_p V_m \text{ (radians)} \qquad K_p = \frac{\Delta \phi}{V_m}$$

K_p → Deviation sensitivity

V_m → amp. of the modulating signal.

$$V_{pm}(t) = V_c \sin(\omega_c t + k_p V_m \sin \omega_m t)$$

Frequency analysis of angle Modulated wave

$$V_{Fm}(t) = V_c \sin(\omega_c t + m_f \sin \omega_m t)$$

This eqn represents the angle modulated wave

$$\sin(A+B) = \sin A \cos B + \cos A \sin B$$

$$V_{Fm}(t) = V_c \left[\sin \omega_c t \cos(m_f \sin \omega_m t) + \cos \omega_c t \sin(m_f \sin \omega_m t) \right.$$

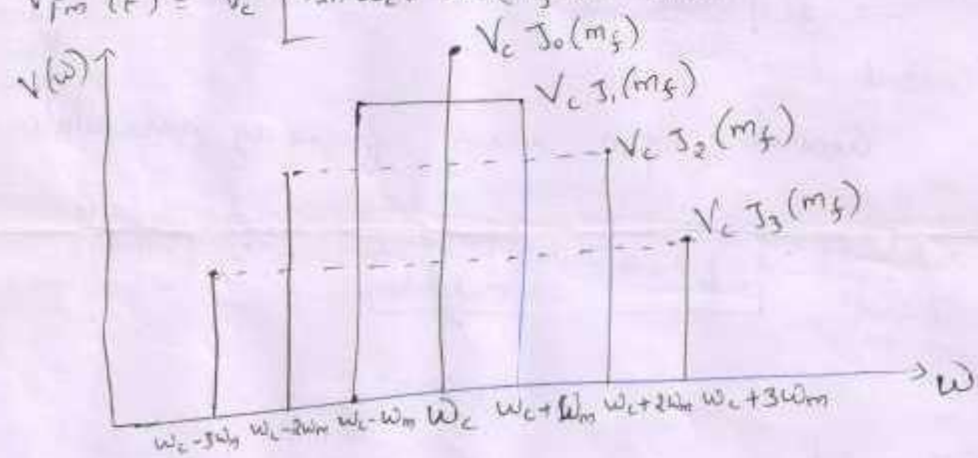


Fig: spectral representation of FM.

The above eqn can be simplified using Bessel function.

$$V_{Fm}(t) = V_c \Big\{ J_0(m_f) \sin \omega_c t + J_1(m_f) [\sin(\omega_c + \omega_m)t - \sin(\omega_c - \omega_m)$$

$$+ J_2(m_f) [\sin(\omega_c + 2\omega_m)t + \sin(\omega_c - 2\omega_m)t]$$

$$+ J_3(m_f) [\sin(\omega_c + 3\omega_m)t - \sin(\omega_c - 3\omega_m)t] \Big\}$$

$$+ \cdots$$

(49)

* It is seen that (each pair of side band is represented / preceded by J coefficients) The order of the coefficient is denoted by m.

* We observe that FM has infinite number of sidebands as well as carrier and they are separated from carrier by $\omega_m, 2\omega_m, 3\omega_m$. but in AM they are only 3 terms (carrier, LSB, USB)

* If 'm_f' is large, More number of significant side bands are present. if 'm_f' is small, less number of side bands exist)

* The total power of FM signal depends upon the power of the unmodulated carrier. Whereas in AM the total power depends on the modulation index.

(* For small values of m_f i.e ($m_f < 1$) only the amplitudes of $J_0(m_f)$ and $J_1(m_f)$ are significant and other terms are neglected).

Average Power of angle modulated waves:

The instantaneous power of angle modulated wave is,

$$P_{inst} = \frac{V_{FM}^2(t)}{R} (W)$$

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

$$V_{fm}^2(t) = V_c^2 \sin^2(\omega_c t + m_f \sin \omega_m t)$$

$R \rightarrow$ load resistance

$$P_{inst} = \frac{V_c^2}{R} \sin^2(\omega_c t + m_f \sin \omega_m t)$$

$$\sin^2(A+B) = \frac{1 - \cos 2(A+B)}{2}$$

$$P_{inst} = \frac{V_c^2}{R}\left[\frac{1 - \cos 2(\omega_c t + m_f \sin \omega_m t)}{2}\right]$$

$$= \frac{V_c^2}{R}\left[\frac{1}{2} - \frac{1}{2}\cos 2(\omega_c t + m_f \sin \omega_m t)\right]$$

Averge Value of above eqn gives the average Power of angle modulated wave)

average Power of angle Modulated wave

Hence average Power of angle Modulated wave will be

$$P_{tot} = \frac{V_c^2}{2R}$$

total Power = carrier Power.

(The total Power is equal to the Sum of Carrier Power & sideband ~~frequency~~ Power

(30)

$P_{total} = P_c + P_1 + P_2 + \cdots + P_n$

$P_c \rightarrow$ Modulated Carrier Power

$P_1 \rightarrow$ Power in first set of sidebands.

$P_2 \rightarrow$ " " 2^{nd} " " "

$P_n \rightarrow$ " " n^{th} " "

$P_c \rightarrow$ only one component.

$P_1, P_2 \ldots P_n$ have two components each of which are centered around P_c.

$$P_{total} = \frac{V_c^2}{2R} + \frac{2V_1^2}{2R} + \frac{2V_2^2}{2R} + \cdots \frac{2V_n^2}{2R}$$

$$\boxed{P_{total} = \frac{V_c^2}{2R} + \frac{V_1^2}{R} + \frac{V_2^2}{R} + \cdots \frac{V_n^2}{R}}$$

wave form

Types of FM

* Two types
  - → Narrow Band FM
  - → Wide band FM.

Narrow Band FM: (m_f is small compared to one radian)

* When m_f is small, then bandwidth of FM is narrow.

* also called as low-index FM.
* B.W of a narrow band FM is same as that of AM.

$$B.W = 2 f_m$$

FM modulated wave is expressed as

$$V_{FM}(t) = V_c \sin(\omega_c t + m_f \sin \omega_m t) \quad \text{--- (1)}$$

$$V_{FM}(t) = V_c \sin \omega_c t \cdot \cos(m_f \sin \omega_m t) + V_c \cos \omega_c t \cdot \sin(m_f \sin \omega_m t) \quad \text{--- (2)}$$

for narrow band FM, assume the modulation index m_f is small compared to one radian. hence we use the following approximation

$$\cos(m_f \sin \omega_m t) \approx 1$$

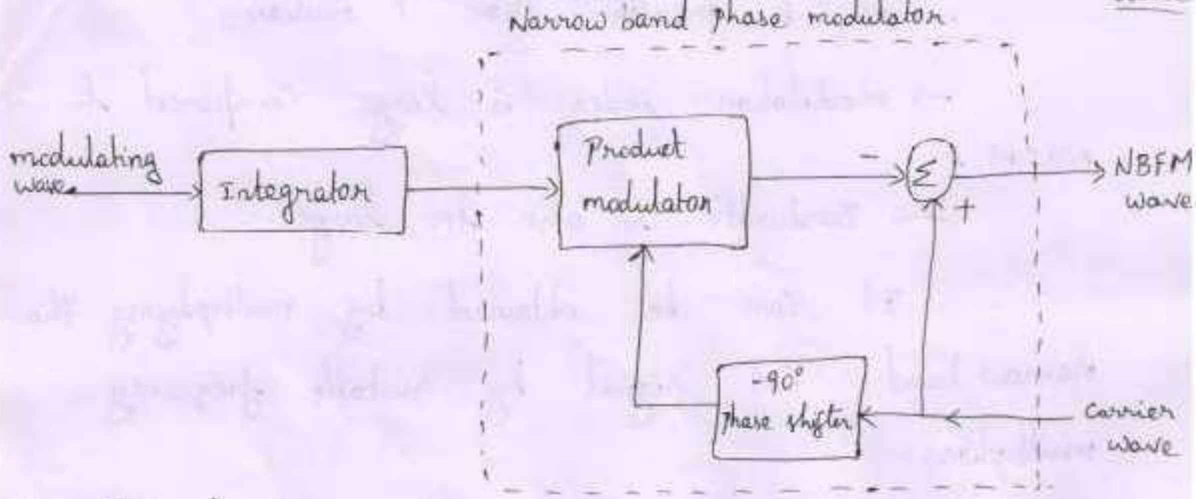
$$\sin(m_f \sin \omega_m t) \approx m_f \sin \omega_m t$$

$$V_{FM}(t) = V_c \sin \omega_c t + V_c \cos \omega_c t \cdot m_f \sin \omega_m t$$

$$V_{FM}(t) = V_c \sin \omega_c t + m_f V_c \cos \omega_c t \cdot \sin \omega_m t$$

→ This eqn is the approximate form of narrowband FM signal

Block Diagram of a Method for generating a Narrow band FM wave

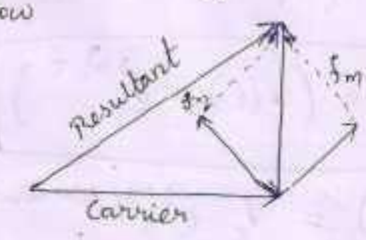


Principle of operation:

* This modulator involves splitting the carrier wave into two paths. one is direct and other path contains −90° phase shifter & product modulator, the combination of which generates DSB-SC modulated signal.

* The difference between two signals produce the narrow band FM signal, but with some distortion.

The phasor diagram of NBFM signal is shown as below



Here we have used carrier phasor as reference. The resultant of two side frequency phasors is always at right angles to the carrier phasor. The effect of this produces a resultant phasor representing NBFM signal

Wide band FM

→ m_f is greater than 1 radian.

→ modulation index is large compared to NBFM.

→ Bandwidth is also too large.

It can be obtained by multiplying the narrow band FM signal by suitable frequency multipliers.

$$V_{FM}(t) = V_c \sin(\omega_c t + m_f \sin \omega_m t) \quad \text{——} \; (1)$$

Equation (1) can be rewritten as exponential form

$$V_{FM}(t) = V_c \, e^{j(\omega_c t + m_f \sin \omega_m t)}$$

$$= Re\left(V_c \, e^{j(\omega_c t + m_f \sin \omega_m t)}\right)$$

$$= Re\left(V_c \, e^{j\omega_c t} \cdot e^{j m_f \sin \omega_m t}\right)$$

$$\boxed{V_{FM}(t) = Re\left(V(t) \cdot e^{j\omega_c t}\right)} \quad \text{——} \; (2)$$

$$V(t) = V_c \, e^{j m_f \sin \omega_m t} \quad \text{——} \; (3)$$

$V(t)$ → complex envelope of FM signal

$V(t)$ can be expanded by fourier series.

$$V(t) = \sum_{n=-\infty}^{\infty} C_n \exp(j n \omega_m t) \quad \text{——} \; (4)$$

The complex fourier coefficient C_n is gn by.

$$C_n = \omega_m \int_{-1/2f_m}^{1/2f_m} v(t)\, e^{-jn\omega_m t}\, dt$$

$$-\frac{1}{2f_m} \le t \le \frac{1}{2f_m}$$

$$= \omega_m \int_{-\frac{1}{2f_m}}^{\frac{1}{2f_m}} V_c\, e^{j m_f \sin \omega_m t} \cdot e^{-jn\omega_m t}\, dt$$

Let $x = \omega_m t = 2\pi f_m t$

$$\frac{dx}{dt} = \omega_m = 2\pi f_m$$

$$dx = \omega_m dt = 2\pi f_m dt.$$

Limit will change from $-\pi$ to π

$$C_n = \frac{V_c}{2\pi} \int_{-\pi}^{\pi} e^{j m_f \sin x} \cdot e^{-jnx}\, \omega_m dt$$

$$= \frac{V_c}{2\pi} \int_{-\pi}^{\pi} \exp\left[j(m_f \sin x - nx)\right] 2\pi f_m\, dt$$

$$= \frac{V_c}{2\pi} \int_{-\pi}^{\pi} \exp\left[+j(m_f \sin x - nx)\right] dx$$

→ Recognized as n^{th} order Bessel function of first kind. Denoted as $J_n(m_f)$.

$$J_n(m_f) = \frac{1}{2\pi}\int_{-\pi}^{\pi} \exp[j(m_f \sin x - nx)]\, dx$$

$$\boxed{C_n = V_c\, J_n(m_f)} \quad \text{sub in } ④$$

$$V(t) = \sum_{n=-\infty}^{\infty} V_c\, J_n(m_f) \exp(jn\omega_m t)$$

$$V(t) = V_c \sum_{n=-\infty}^{\infty} J_n(m_f) \exp(jn\omega_m t)$$

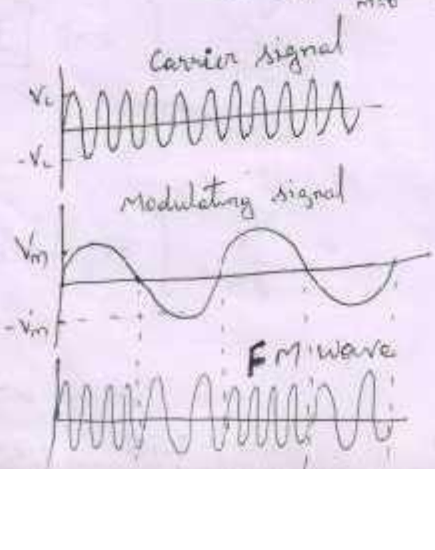
$$V_{fm}(t) = Re\left\{V_c \sum_{n=-\infty}^{\infty} J_n(m_f) \exp(jn\omega_m t)\, e^{j\omega_c t}\right\}$$

$$= Re\left\{V_c \sum_{n=-\infty}^{\infty} J_n(m_f)\, e^{jn\omega_m t} \cdot e^{j\omega_c t}\right\}$$

$$\boxed{V_{fm}(t) = V_c \sum_{n=-\infty}^{\infty} J_n(m_f) \cos(\omega_c t + n\omega_m t)}$$

$$J_n(m_f) = \sum_{m=0}^{\infty} \frac{(-1)^m \left(\frac{1}{2} m_f\right)^{n+2m}}{m!\,(n+m)!}$$

Generation of FM



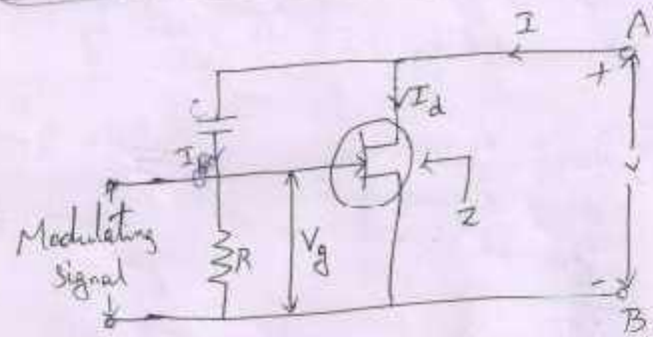
Properties

* Two Methods

(i) Direct method (Reactance Tube Modulator)
(ii) Indirect Method (Armstrong Method)

(i) Reactance Tube Modulator

Inductor → poor amplifier



$X_c >> R$
$V_g = V_{gs}$

* Figure shows the basic circuit of reactance tube Modulator. It behaves as a reactance across terminals A-B

* The terminals A-B Connected across the tuning Circuit of oscillator to get fm output

* The varying voltage V, across terminal A-B changes the reactance of the FET. This change in reactance can be Capacitive (or) inductive.

* Drain to gate impedance (X_c) must be greater than gate to source impedance (R) by more than 5:1

Expression for equivalent Capacitance (C_{eq})

(i) Gate Voltage $V_g = I_g R$

But, $I_g = V/z = \frac{V}{R - jX_c}$

$$V_g = \frac{VR}{R - jX_c}$$

(ii) The drain current to FET is given by

$$I_d = g_m \times V_g$$

where g_m is transconductance

$\frac{1}{z} = g_m$

$V = Iz$

$$I_d = \frac{g_m R V}{R - jX_c}$$

(iii) Assume I_g is very small compared to I_d

z b/w terminals AB is

$$z = V/I_d = \frac{V(R - jX_c)}{g_m R V}$$

$$z = \frac{R - jX_c}{g_m R}$$

$$= \frac{1}{g_m}\left(1 - \frac{jX_c}{R}\right)$$

iv) If $X_c >> R$, then above eqn reduces to

$$z = \frac{-jX_c}{g_m R}$$

This impedance is clearly a capacitive reactance which may be written as,

$$z = \frac{X_c}{g_m R} = X_{eq} \qquad X_c = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi f g_m R C} \qquad X_c = \frac{1}{\omega C}$$

$$z = \frac{1}{2\pi f C_{eq}} \qquad C_{eq} = g_m R C$$

where. $C_{eq} = g_m R C$ ——— ①

If the condition $X_c >> R$ is not satisfied then impedance z will not be a purely reactive.

In Practice $X_c = nR$ at f_c. Where n is b/w 5 to 10

$$X_c = \frac{1}{2\pi f C} = nR$$

[illegible]

[illegible]

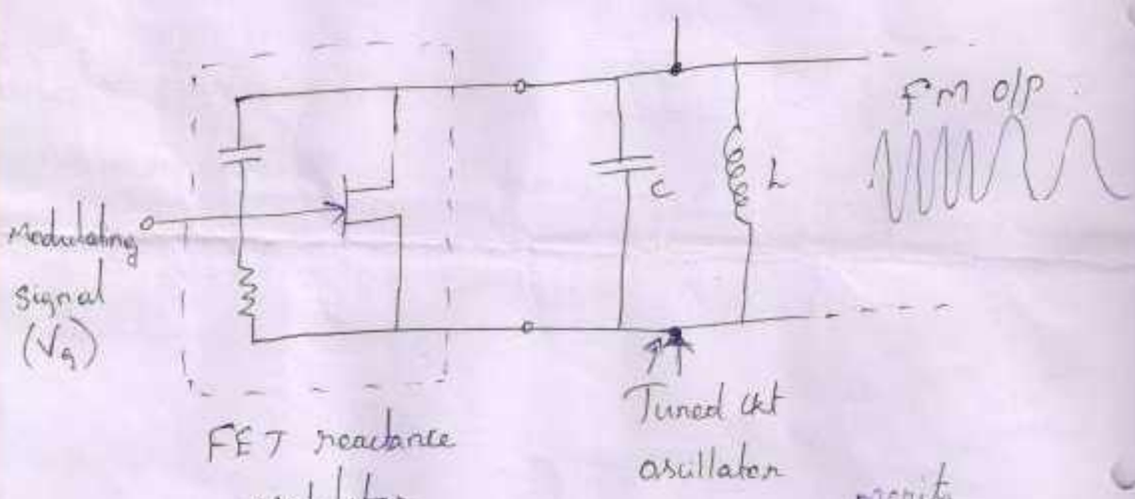
$$\frac{1}{2\pi f C} = nR$$

$$C = \frac{1}{2\pi f n R} \text{ ——— ②}$$

sub ② in ①, we get.

$$C_{eq} = \frac{g_m \cancel{R}}{2\pi f_n \cancel{R}}$$

$$\boxed{C_{eq} = \frac{g_m}{2\pi f_n}}$$



Merits
* Low cost
* Simplicity.

Demerits
* Not stable
* cannot be used for broadcast & comm purpose

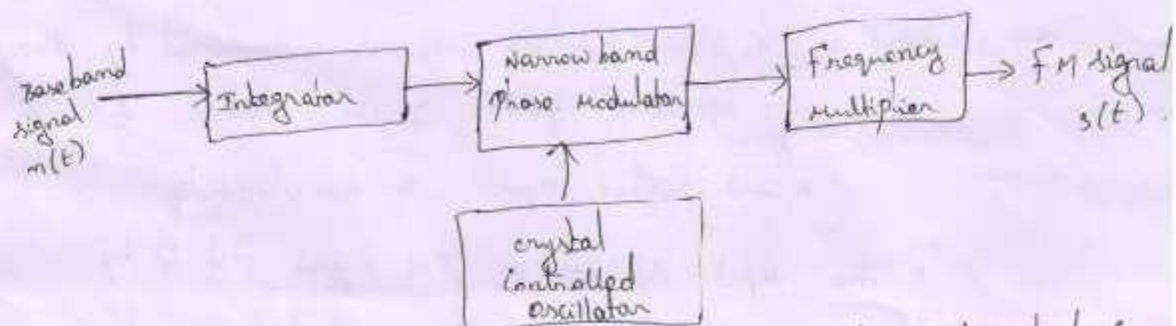
(ii) Indirect Method
(Armstrong Method)

* In this method first the modulating signal is integrated and the phase modulated with the carrier signal, as a result of which some form of FM signal is obtained

Generation of FM signals by Armstrong's Indirect method

* In the indirect method, the modulating signal is first used to produce a narrowband FM signal & frequency multiplication is next used to increase the frequency deviation to the desired level

* The block diagram of indirect method of generating a wideband FM signal is shown as below



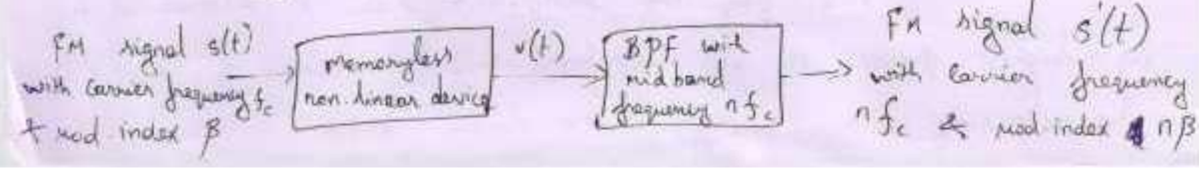
* The base band signal m(t) is first integrated & then used to phase-modulate a crystal controlled oscillator.

* the use of crystal control provides frequency stability

* To minimize the distortion inherent (inbuilt) in the phase modulator the maximum phase deviation or Mod index (m_f) (β) is kept small, thereby resulting in a NBFM signal

* The NBFM sgl is next multiplied in frequency by means of a frequency multiplier so as to produce the desired wideband FM signal

Block diagram of frequency multiplier



* A frequency multiplier consists of a non-linear device followed by a band-pass filter.

* The non-linear device is memoryless i.e it has no energy storage elements.

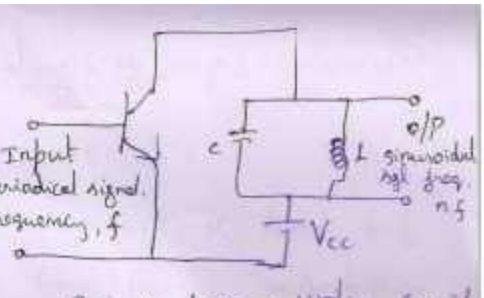


Fig: A freq-multiplier Circuit

* The i/p - o/p relation of such a device may be expressed in the general form

$$v(t) = a_1 s(t) + a_2 s^2(t) + \dots + a_n s^n(t) \quad \text{——} ①$$

where $a_1, a_2 \dots a_n \rightarrow$ Coefficients determined by the operating point of the device &

$n \rightarrow$ highest order of non linearity.

* The input $s(t)$ is an FM signal defined by

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\tau)\, d\tau\right] \quad \text{——} ②$$

whose instantaneous frequency is

$$f_i(t) = f_c + k_f m(t) \quad \text{——} ③$$

* The mid-band frequency of the band-pass filter is set equal to nf_c, where f_c is the carrier frequency of the incoming FM signal $s(t)$

* The Band-pass filter is designed to have a bandwidth equal to n times the transmission bandwidth of $s(t)$.

* After band-pass filtering of the non-linear device's o/p $v(t)$, we have a new FM signal defined by

$$s'(t) = A_c' \cos\left[2\pi n f_c t + 2\pi n k_f \int_0^t m(\tau)\, d\tau\right] \longrightarrow ④$$

whose instantaneous frequency is

$$f_i'(t) = nf_c + nk_f m(t) \quad \text{——} ⑤$$

The frequency multiplication ratio is determined by the highest power n in the input-output relation of eqn ①, characterizing the memoryless non-linear device.