SEITB

MODULE - III

→ NEED FOR MODULATION -

→ Need a carrier to travel long distances.

→ Modulation is the process of changing one or more properties of a high frequency signal, called carrier signal in accordance with modulating signal.

Baseband signal → Info → low freq (f_m)

⇓

modulating signal.

Carrier → high freq (f_c) → gen. by oscillator.

constant amplitude

⇓

carrier signal.

Modulator/Mixer

modulating signal → ⊗ → Modulated signal

↑

carrier signal

BASEBAND SIGNAL ⟹ BAND PASS SIGNAL

$$v_c = V_c \sin(2\pi f_c t + \phi)$$

Carrier signal

V_c → Amplitude Modulation

f_c → Frequency Modulation

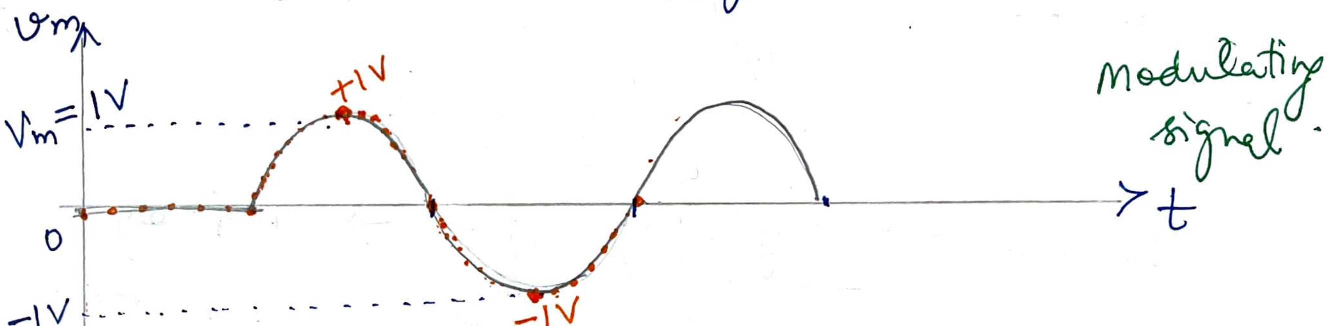
ϕ → phase modulation

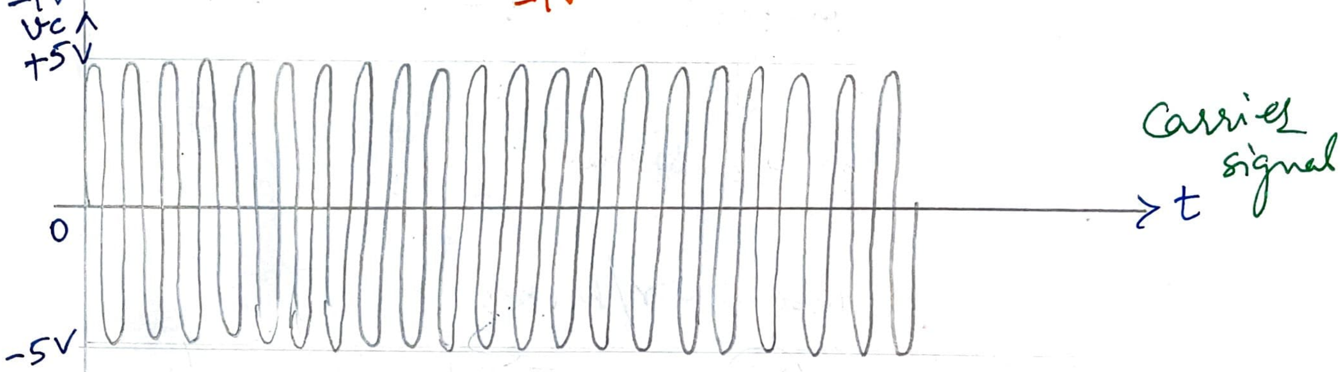
Amplitude Modulation

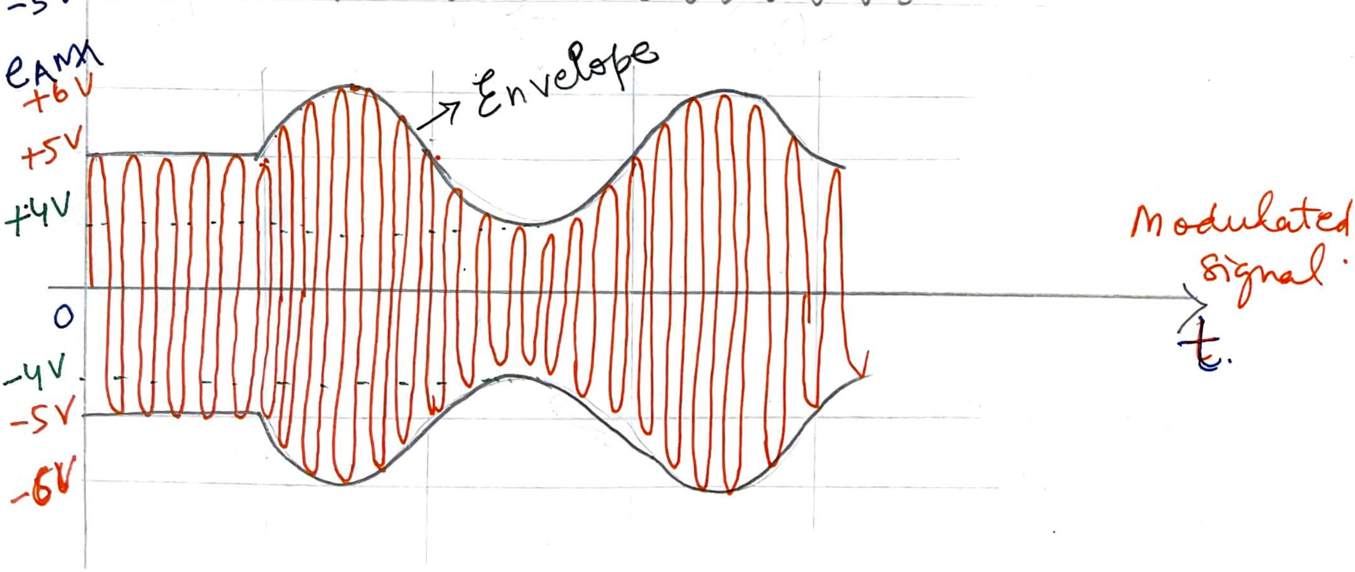
changing the amplitude of the carrier in accordance with the amplitude of the modulating signal.

Frequency Modulation

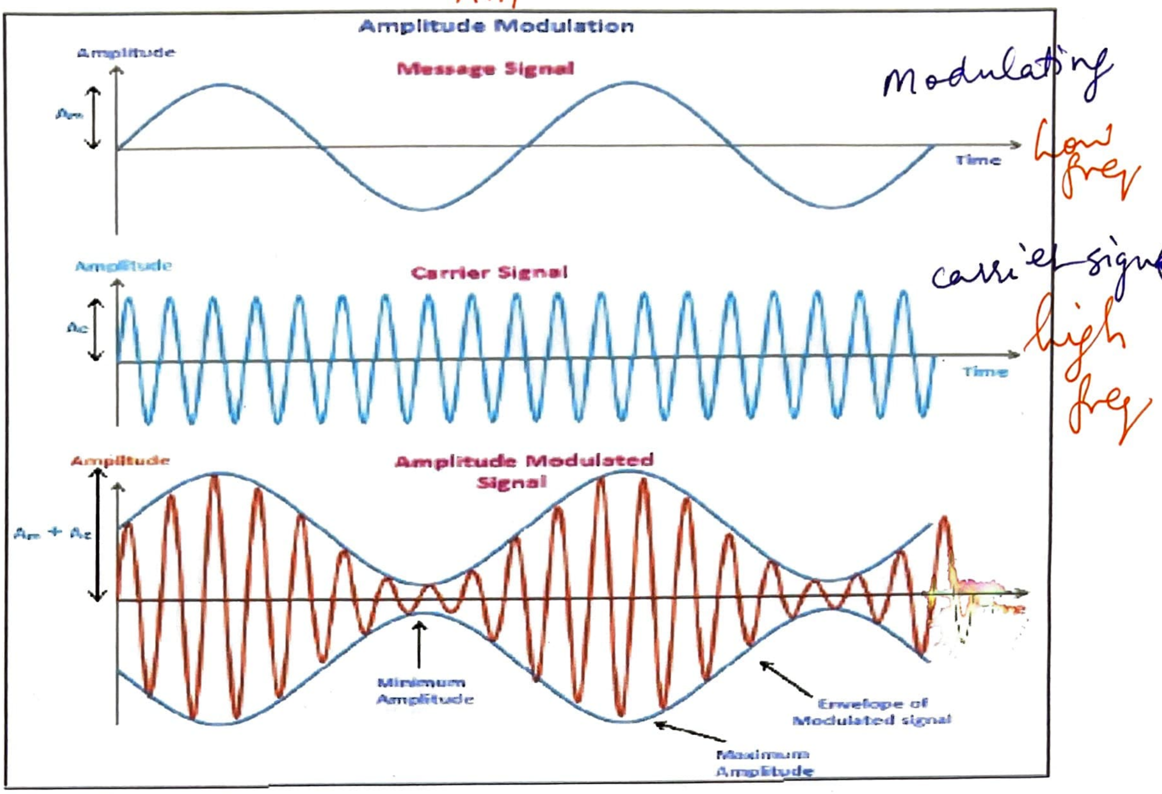
changing the frequency of the carrier in accordance with the amplitude of the modulating signal.





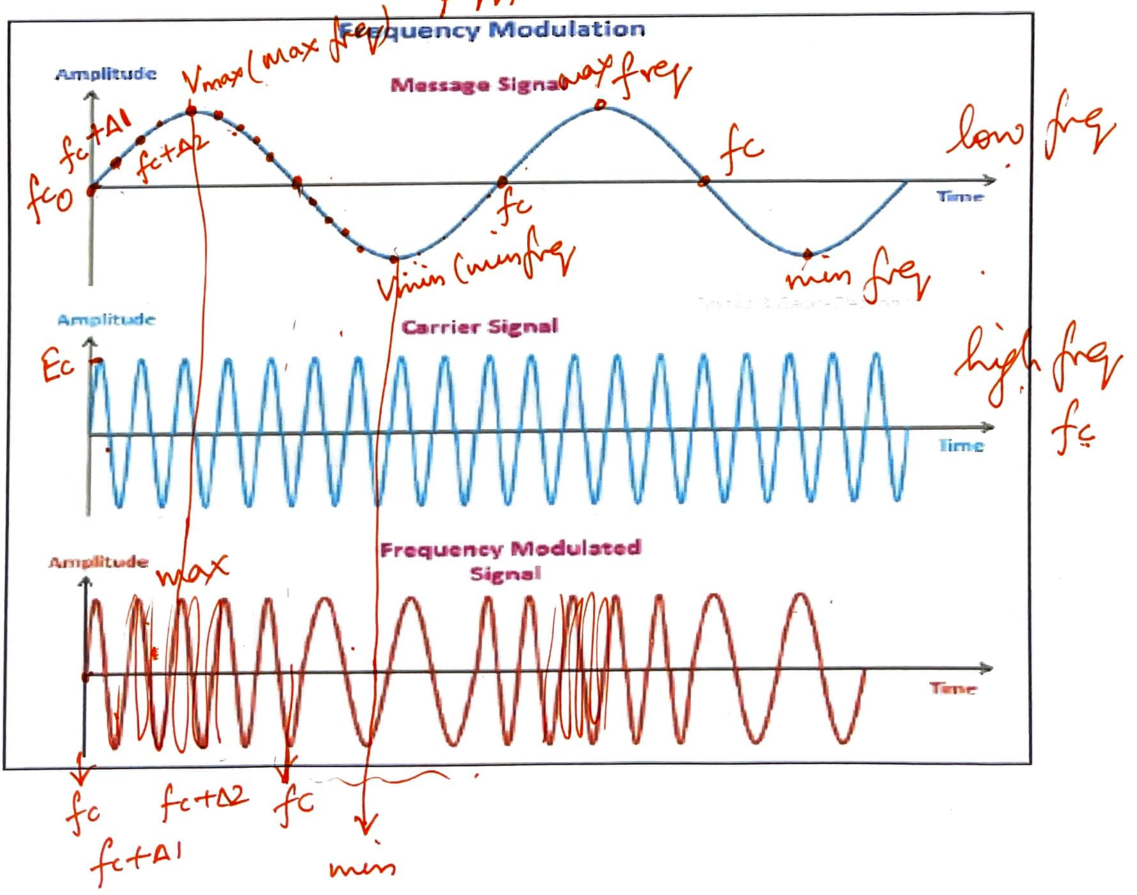


AM



Amplitude Modulation
Amplitude
Message Signal
Am
Time
Modulating
Low freq
Amplitude
Carrier Signal
Ac
Time
carrier signal
high freq
Amplitude
Amplitude Modulated Signal
Am + Ac
Minimum Amplitude
Envelope of Modulated signal
Maximum Amplitude

FM



Frequency Modulation
Amplitude
Message Signal
Vmax (max freq)
max freq
fc0
fc+Δ1
fc+Δ2
fc
fc
Vmin (min freq
min freq
low freq
Time
Amplitude
Carrier Signal
Ec
high freq
fc
Time
Amplitude
Frequency Modulated Signal
max
Time
fc
fc+Δ2
fc
fc+Δ1
min

WHY MODULATION –

I. Increase the range of communication

II. Reduction in height of antenna

height of antenna $= \frac{\lambda}{4}$

Eg. $f_m = 1\,\text{kHz}$

$$h = \frac{\lambda}{4} = \frac{300000}{4} = 75000\,\text{m} \qquad \lambda = \frac{c}{f} = \frac{3\times 10^8}{1000} = 300000\,\text{m}$$

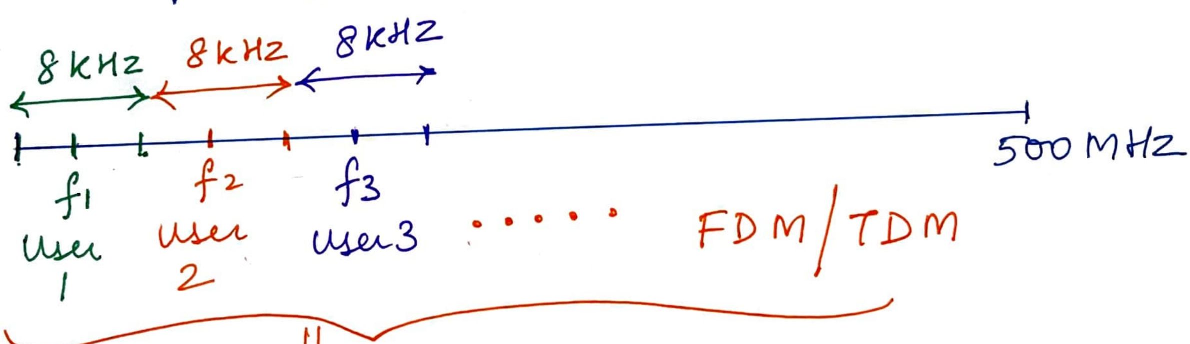
$= 75\,\text{km}$

$$f = 1\,\text{MHz} \qquad \lambda = \frac{c}{f} = \frac{3\times 10^8}{1\times 10^6} = 300\,\text{m}$$

$$h = \frac{\lambda}{4} = \frac{300}{4} = 75\,\text{m}$$

III. Avoid mixing of signals.

IV. multiplexing is possible



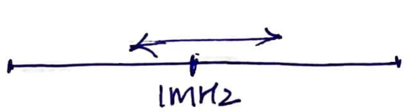
Combining signals ⇒ multiplexing

V. Improves quality of reception

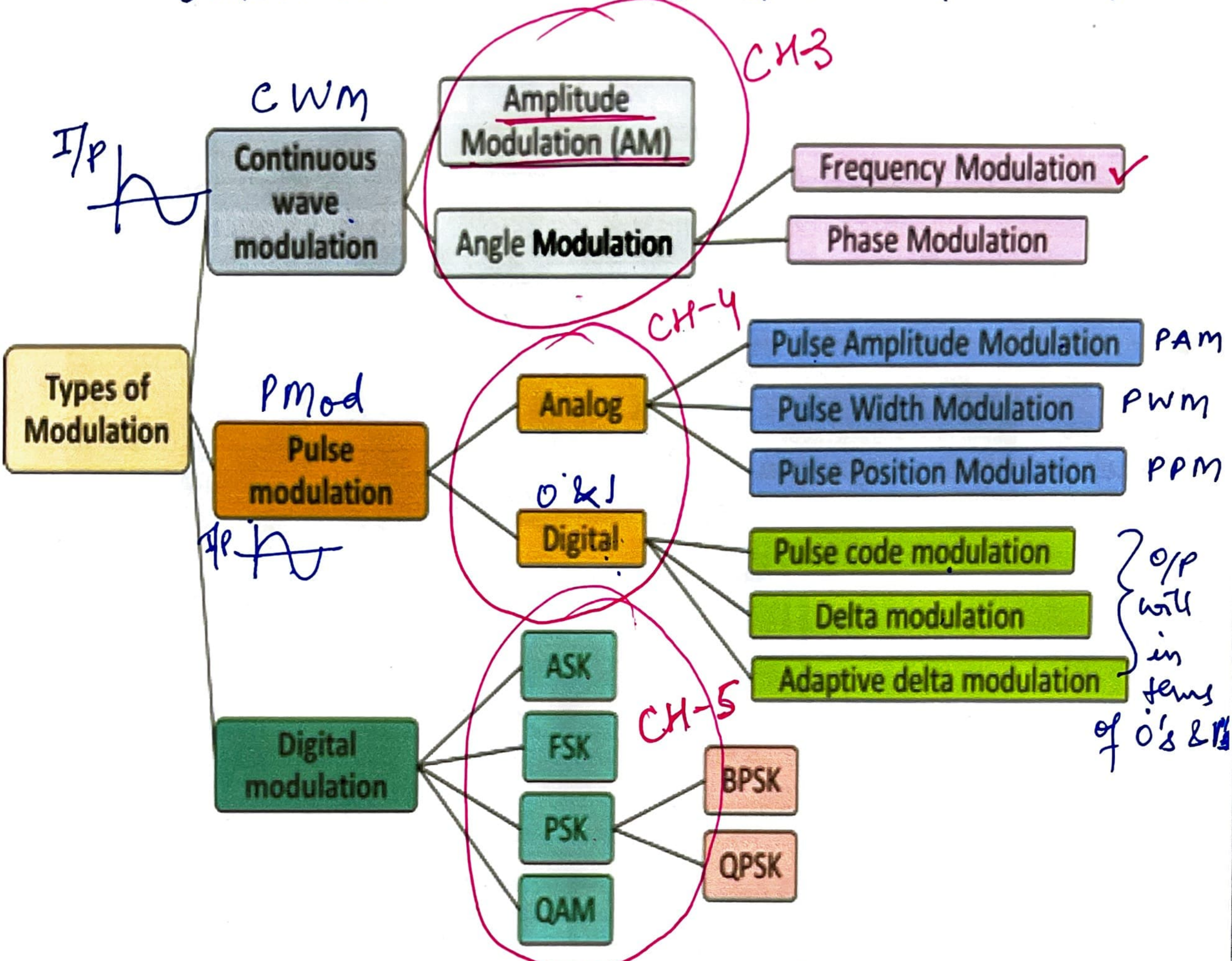
VI. Allows adjustment in BW → Leads to simplification of design & processing of signal.

20 Hz – 20 kHz ; Ratio $= \frac{20\,\text{kHz}}{20\,\text{Hz}} = 1000$

1 MHz = 1000 kHz ; Ratio $= \frac{1020000}{1000020} = 1.01$



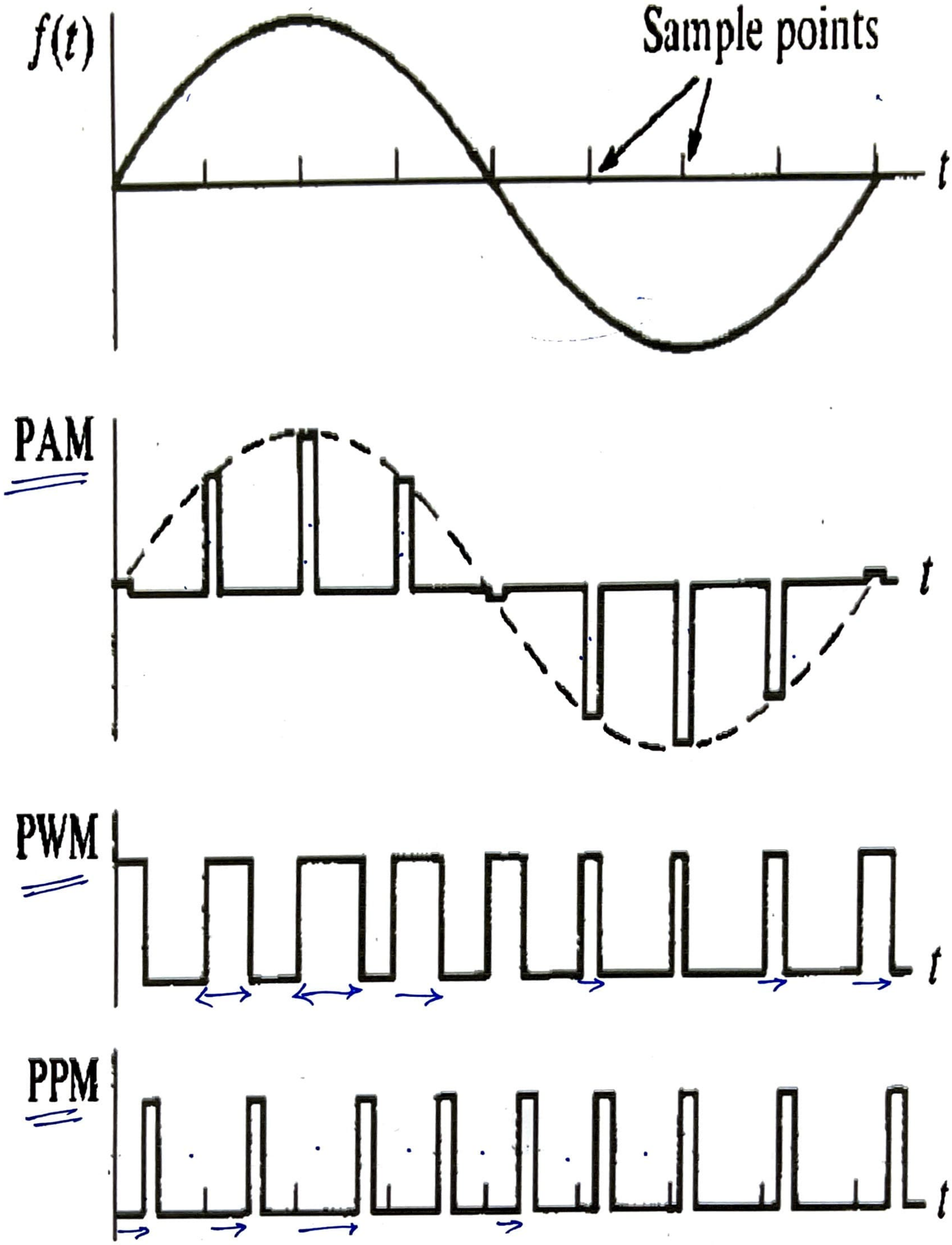
TYPES OF MODULATION TECHNIQUES / CLASSIFICATION OF MODULATION TECHNIQUES



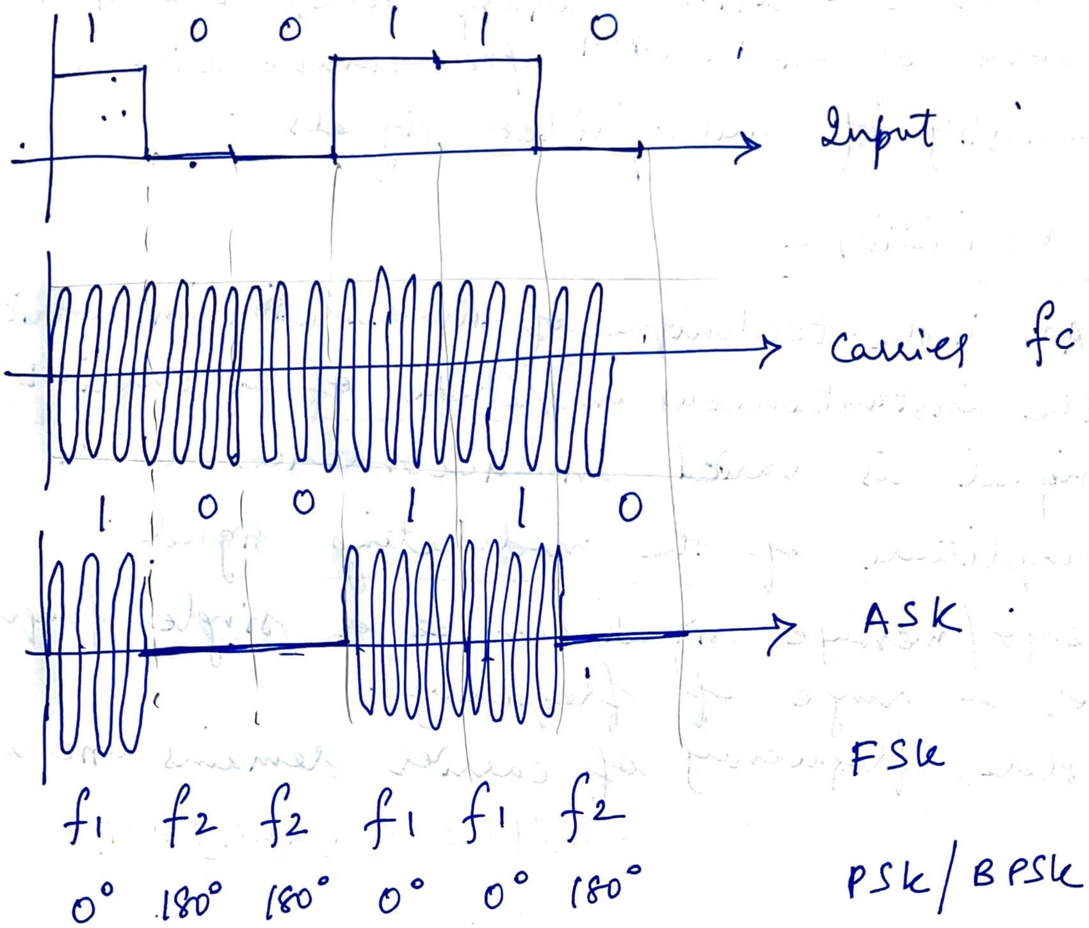
CWM → modulating signal → analog
carrier signal → analog.

PMod → mod'ing signal analog
carrier signal → pulses

Dig Mod → I/p → mod'ing signal → 0's & 1's repr as pulses
carrier → analog


f(t)
Sample points
t
PAM
t
PWM
t
PPM
t

Dig Mod Tech



ASK → Amplitude shift keying

FSK → Frequency shift keying.

PSK → Phase shift keying
- BPSK → Bipolar phase shift keying
- QPSK ⇒ Quadrature PSK

QAM → Quadrature amplitude mod.

AMPLITUDE MODULATION

→ It is a relatively inexpensive, low quality form of modulation for commercial broadcasting of audio/video signals.

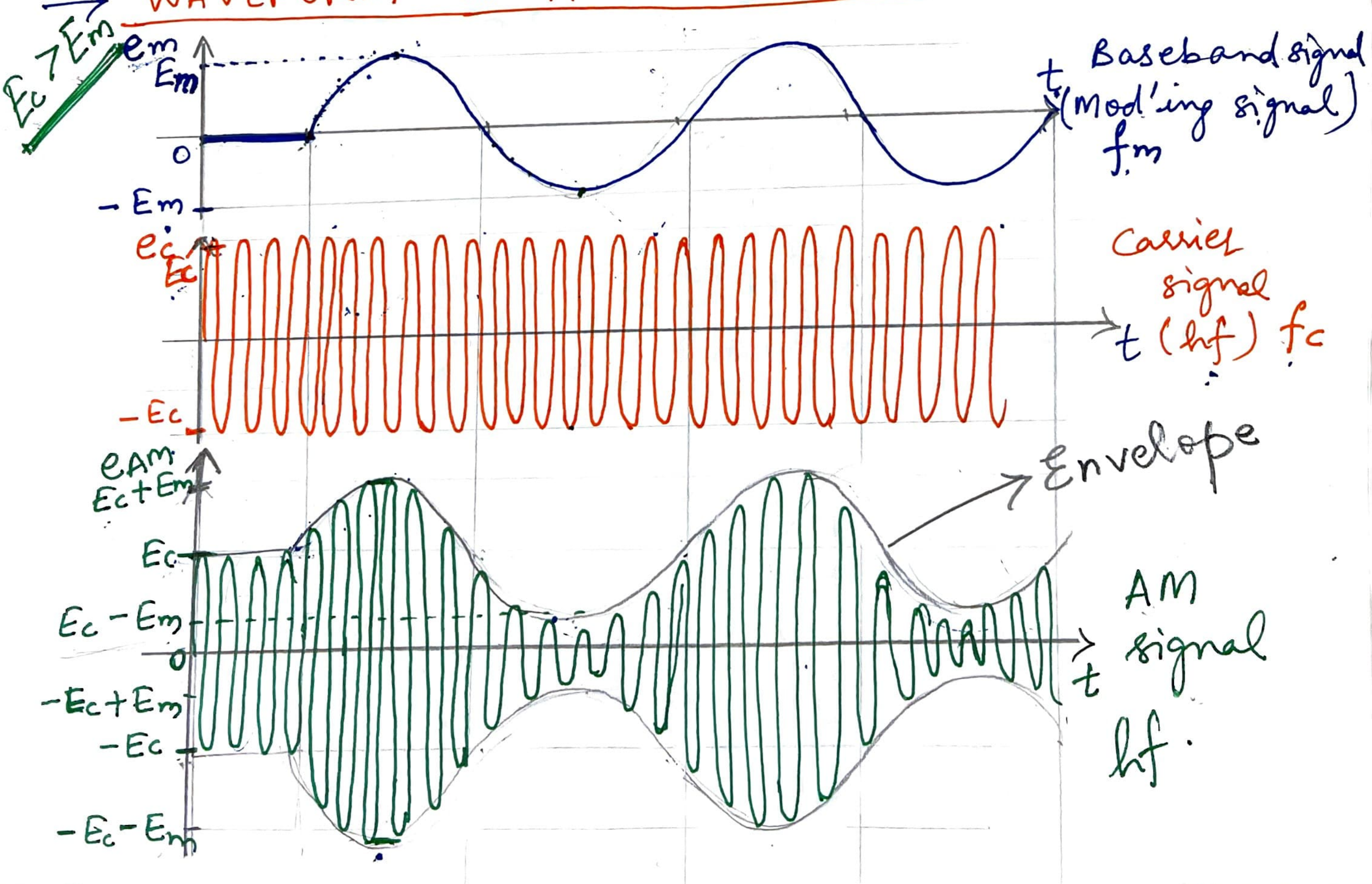
→ Definition–

AM is the technique of modulation in which the instantaneous amplitude of a carrier signal is varied in accordance with amplitude of the modulating signal.

→ Info/message signal can be a single frequency or a range of frequency.

→ Here, frequency of carrier remains unchanged.

→ WAVEFORM OF AMPLITUDE MODULATION –



→ NOTE –

→ Repetition rate of envelope = frequency of modulating signal

→ Shape of the envelope is identical to shape of modulating signal

→ frequency of AM signal = freq. of carrier.

→ MATHEMATICAL EXPRESSION OF AM –

→ Let the modulating signal be represented by –

$$e_m = E_m \cos w_m t \qquad [w = 2\pi f]$$

→ Let the carrier signal be represented by –

$$e_c = E_c \cos w_c t$$

[where, $w_c >> w_m$]

→ We know, the modulating signal value is added or subtracted from the peak value of carrier, E_c.

→ ∴ Instantaneous value of the envelope of AM wave,

$$A = E_c + e_m = E_c + E_m \cos w_m t$$

→ ∴ Amplitude modulated signal can be expressed as –

$$e_{AM} = A \cos w_c t$$ [∵ freq of AM wave is same as freq of carrier]

$$\Rightarrow \boxed{e_{AM} = [E_c + E_m \cos w_m t] \cos w_c t}$$

This is the mathematical expression for AM signal.

→ AM computes product of carrier & mod'ing signal

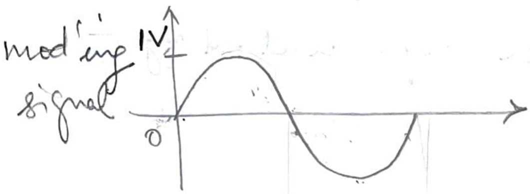
$$e_{AM} = E_c \left[1 + \frac{E_m}{E_c} \cos w_m t \right] \cos w_c t$$

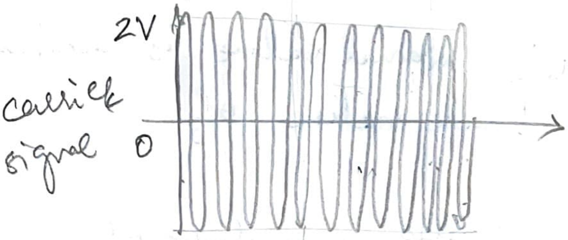
$\frac{E_m}{E_c} \rightarrow m$

→ We define modulation index, m of AM wave as the ratio of modulating signal max. voltage to the carrier signal voltage.

→ m describes the amount of change or amount of modulation.

I. When $E_m < E_c \Rightarrow m < 1 \Rightarrow$ Under modulation

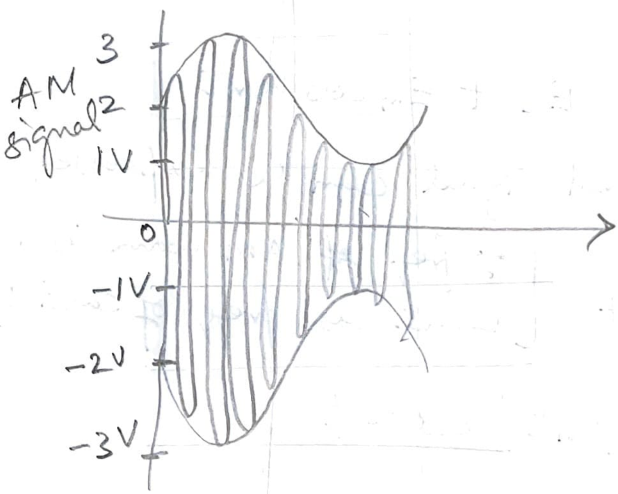


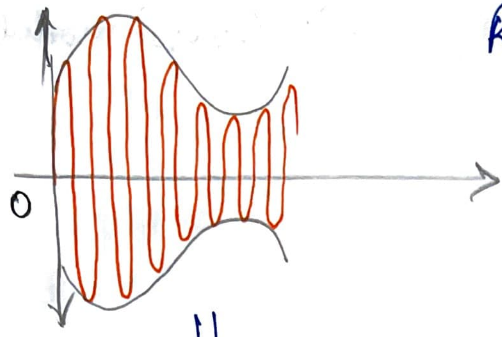


$E_m = 1\,V$

$\Rightarrow m = \frac{1}{2}$

$E_c = 2V \qquad = 0.5$



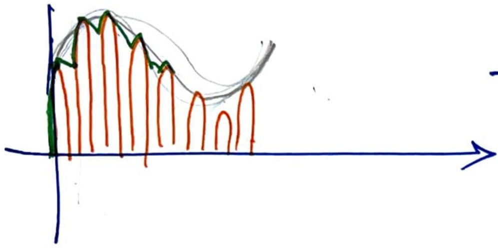


$R_x \rightarrow$ RECTIFIER

$\downarrow$

Forward bias

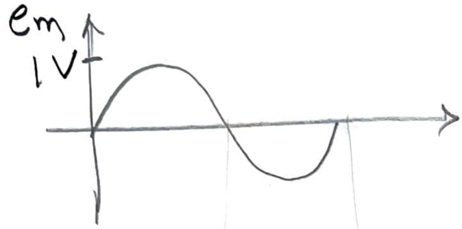
+ve signal



$\rightarrow$ C - FILTER

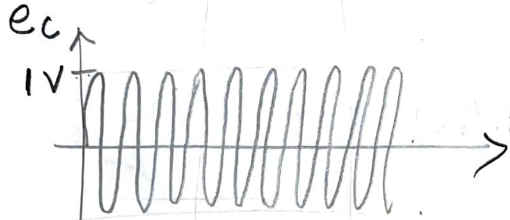
NO DISTORTION

II. When $E_m = E_c \Rightarrow m = 1 \Rightarrow 100\%$ modulation

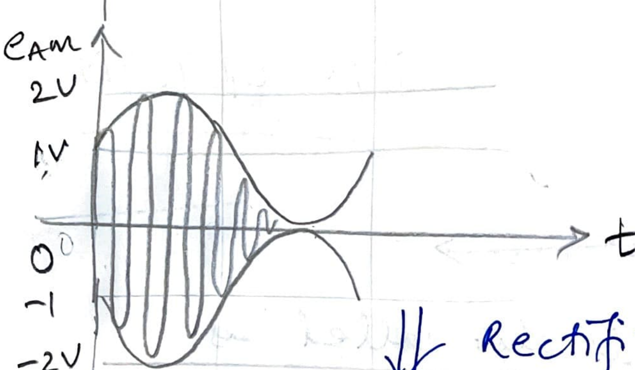


$E_m = 1V$

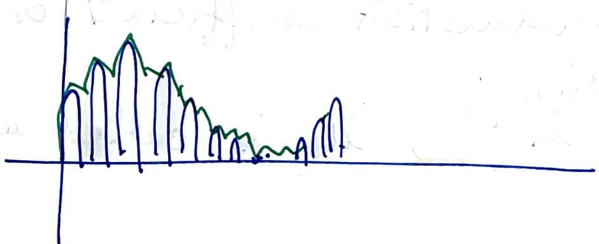
$\Rightarrow m = \frac{1}{1} = 1$



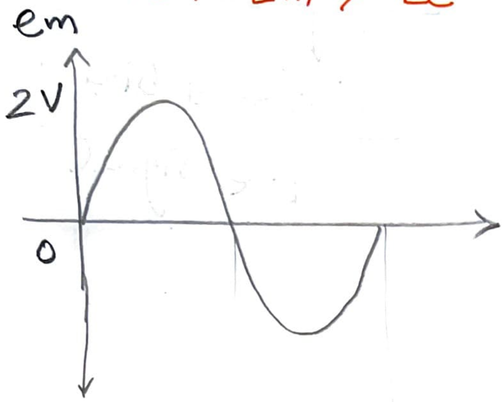
$E_c = 1V$



$\Downarrow$ Rectifier

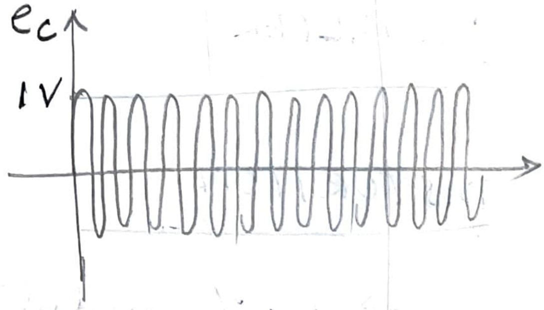


III. When $E_m > E_c \Rightarrow m > 1 \Rightarrow$ Over-modulation

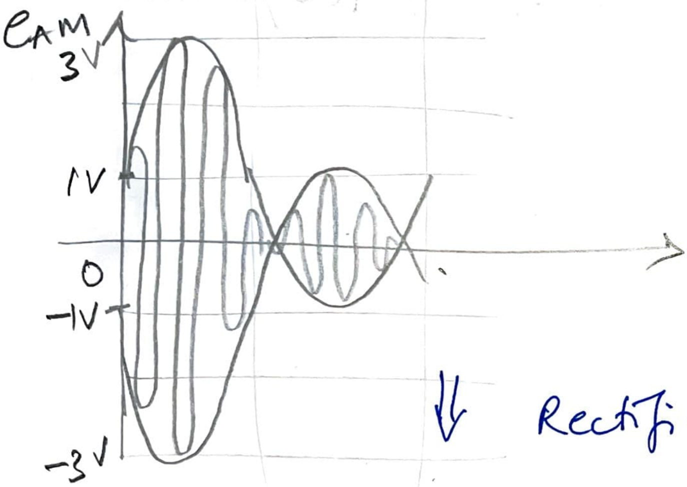


$E_m = 2\,V$

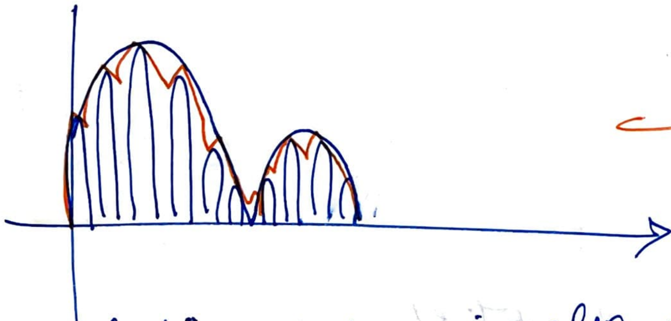
$$\Rightarrow m = \frac{2}{1} = 2$$



$E_c = 1\,V$



⇓ Rectifier



DISTORTION

→ Modulation index is also called as modulation factor, modulation coefficient or degree of modulation.

→ If it is expressed in %, it is called as % modulation.

→ FREQUENCY SPECTRUM OF AM WAVE –

→ frequency spectrum is freq vs amplitude graph.

→ Frequency spectrum of AM wave tell us about what frequency components are present in the AM wave and what are their amplitudes.

→ We know –

$$e_{AM} = [E_c + E_m \cos \omega_m t] \cos \omega_c t$$

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

$$= E_c[1 + m \cos \omega_m t] \cos \omega_c t$$

$$= E_c \cos \omega_c t + mE_c \cos \omega_c t \cos \omega_m t$$

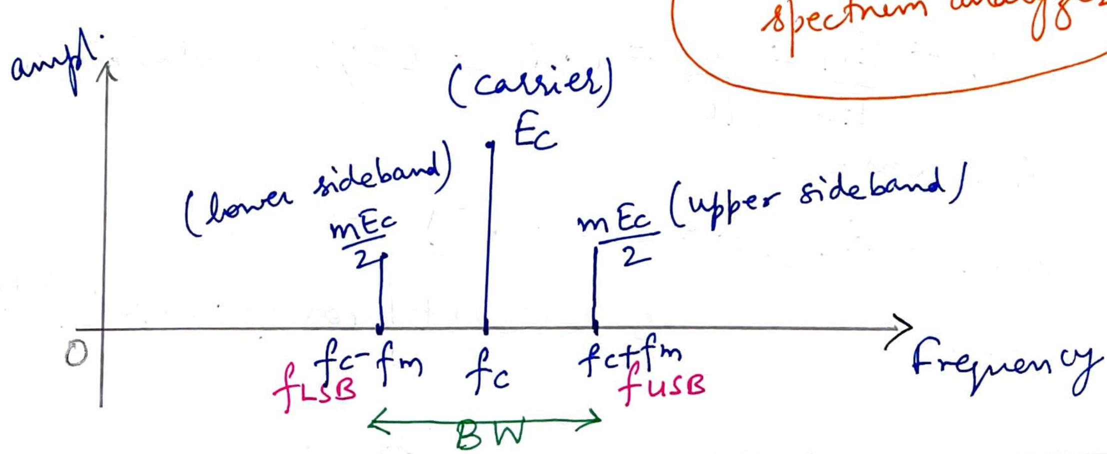
$$= E_c \cos \omega_c t + \frac{mE_c}{2}[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

[using $2\cos A \cos B = \cos(A+B) + \cos(A-B)$]

$$= \underbrace{E_c \cos \omega_c t}_{\text{carrier}} + \underbrace{\frac{mE_c}{2} \cos(\omega_c + \omega_m)t}_{\text{USB}} + \underbrace{\frac{mE_c}{2} \cos(\omega_c - \omega_m)t}_{\text{LSB}}$$

→ Frequency Response is –

This can be on spectrum analyzer



→ Bandwidth – Range of frequencies that the signal occupies.

⇒ Obtained by subtracting lowest frequency from the highest frequency

$$\Rightarrow BW = (f_c + f_m) - (f_c - f_m)$$

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

$$\boxed{BW = 2f_m}$$ BW of AM wave.

NUMERICALS –

Q. A modulating signal given by $(6\cos 628t)$ is modulated using a carrier signal given by $(10 \cos 6.28 \times 10^6 t)$. Compute the expression of AM wave & draw the AM waveform and the frequency spectrum. Also calculate the BW required.

Soln: $e_m = 6\cos 628t$ | $e_m = E_m \cos 2\pi f_m t$

$e_c = 10\cos 6.28\times 10^6 t$ | $e_c = E_c \cos 2\pi f_c t$

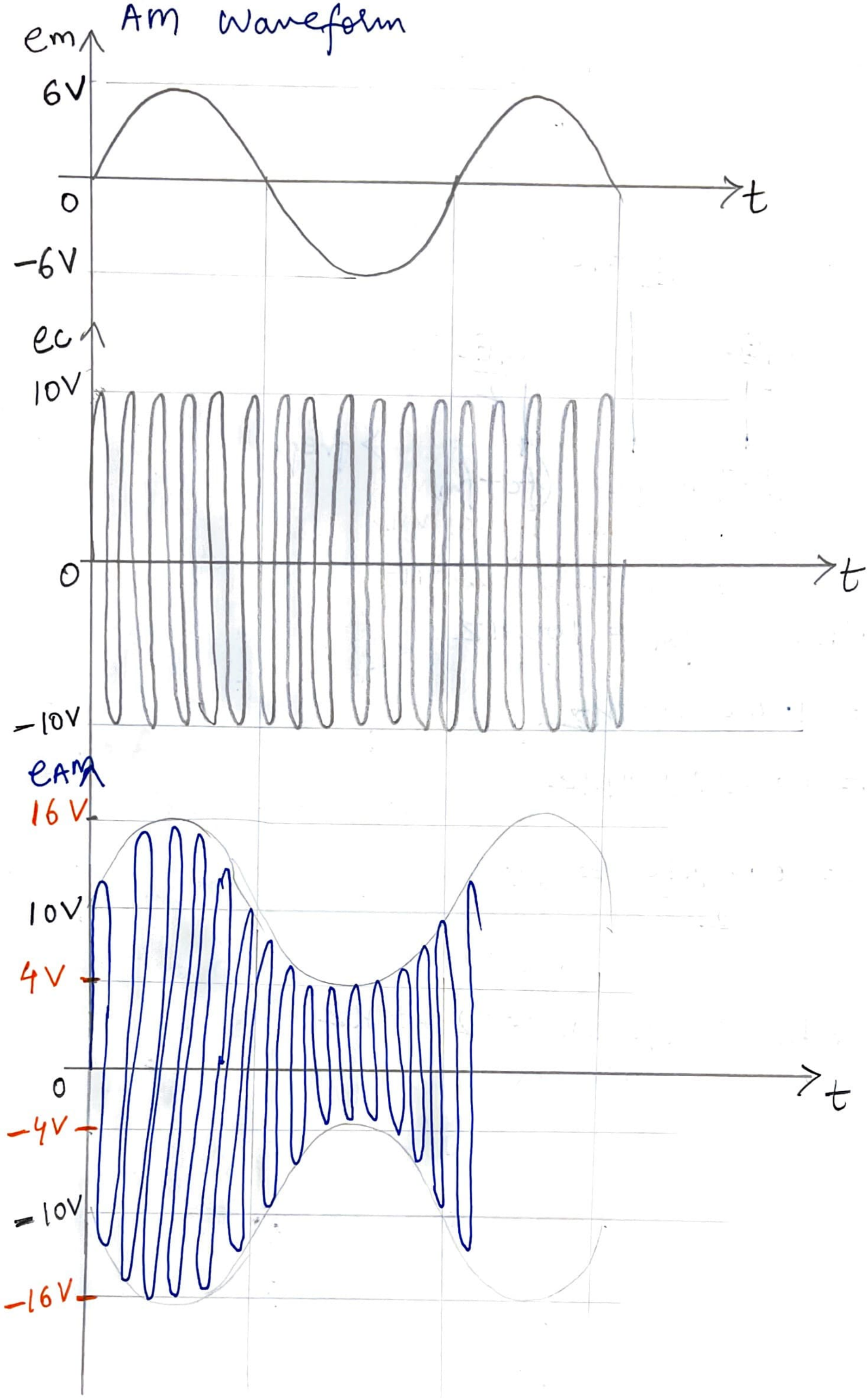
$E_m = 6\text{ V}$; $E_c = 10\text{V}$; $f_m = 100\text{Hz}$; $f_c = 1\text{MHz}$

$$m = \frac{E_m}{E_c} = \frac{6}{10} = 0.6 = 60\%$$ modulation.

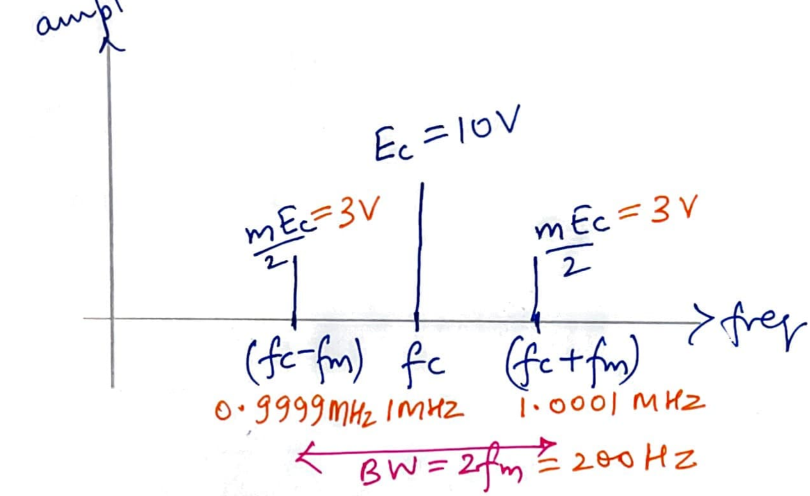
AM wave –

$$e_{AM} = E_c[1 + m\cos w_m t]\cos w_c t$$

$$e_{AM} = 10[1 + 0.6\cos 628t]\cos(6.28\times 10^6)t$$


AM Waveform
em
6V
0
-6V
t
ec
10V
0
-10V
t
eAM
16V
10V
4V
0
-4V
-10V
-16V
t

→ Frequency Spectrum –



$f_c = 1\,MHz \qquad f_m = 100\,Hz$

$f_c + f_m = 1.0001\,MHz$

$f_c - f_m = 0.9999\,MHz$

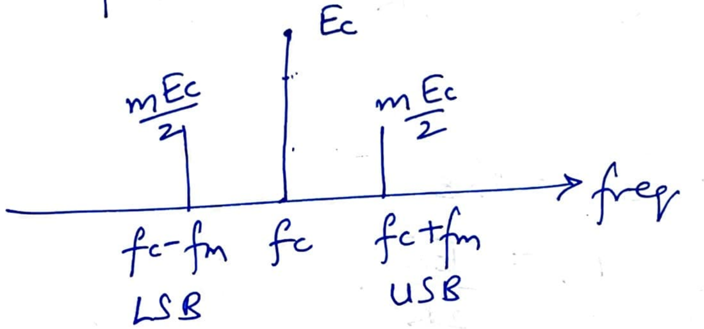
$$\frac{mE_c}{2} = \frac{0.6 \times 10}{2} = 3V$$

$$BW = 2f_m = 2 \times 100 = 200\,Hz$$

→ POWER RELATIONS IN AM WAVE –

→ We know, AM wave consists of carrier and 2 sidebands.

→ Obviously, AM wave contains more power than power of unmodulated carrier



→ As amplitude of SB components are dependent on m, ∴ Total power $\propto m$.

→ Total power in an AM wave is –

P_t = carrier power + power in USB + power in LSB

$$P_t = \frac{E_{carr}^2}{R} + \frac{E_{USB}^2}{R} + \frac{E_{LSB}^2}{R}$$

where, E_{carr}, E_{USB}, E_{LSB} are rms values & R is characteristic resistance of antenna in which total power will be dissipated.

$$P_t = \frac{\left(E_c/\sqrt{2}\right)^2}{R} + \frac{\left(\frac{mE_c}{2}/\sqrt{2}\right)^2}{R} + \frac{\left(\frac{mE_c}{2}/\sqrt{2}\right)^2}{R}$$

$$P_t = \underbrace{\frac{E_c^2}{2R}}_{\text{carrier}} + \underbrace{\frac{m^2 E_c^2}{8R}}_{\text{USB}} + \underbrace{\frac{m^2 E_c^2}{8R}}_{\text{LSB}}$$

$$P_t = \underbrace{\frac{E_c^2}{2R}}_{\text{carrier}} + \underbrace{\frac{m^2 E_c^2}{4R}}_{\text{Total SB}}$$

$$P_t = P_c + P_{SB}$$

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

$$P_{SB} = \frac{m^2 E_c^2}{4R} = \frac{m^2}{2} \times \frac{E_c^2}{2R} = \frac{m^2 P_c}{2}$$

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

where,

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

Power in each side band (LSB or USB),

$$P_{USB} = P_{LSB} = \frac{m^2 P_c}{4}$$

→ Modulation index in terms of P_t & P_c –

We know,

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

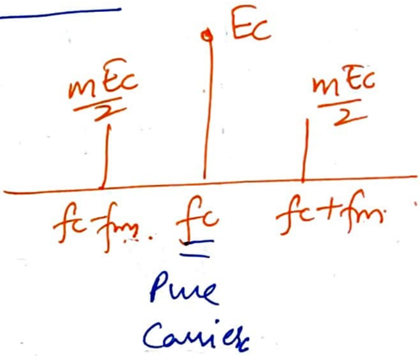
$$\Rightarrow \cancel{1+\frac{m^2}{2} = \frac{P_t}{P_c}} \qquad 1+\frac{m^2}{2} = \frac{P_t}{P_c}$$

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

$$\Rightarrow \boxed{m = \left\{2\left[\frac{P_t}{P_c} - 1\right]\right\}^{1/2}}$$

→ Transmission Efficiency –

→ It is the ratio of the transmitted power which actually contains the information (ie. total SB power) to the total transmitted power.



$$\therefore \eta = \frac{P_{USB} + P_{LSB}}{P_t} = \frac{\frac{m^2}{4}P_c + \frac{m^2}{4}P_c}{P_c\left[1+\frac{m^2}{2}\right]}$$

$$\therefore \eta = \frac{m^2/2}{1+\frac{m^2}{2}} = \frac{m^2/2}{\frac{2+m^2}{2}} = \frac{m^2}{2+m^2}$$

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

→ AM power in terms of current –

→ Assume I_c ~~to~~ be the rms current corresponding to unmodulated carrier & I_t be rms current of AM wave.

→ If these currents flow in the characteristic impedance, R of an antenna.

$$P_c = I_c^2 R$$

$$P_t = I_t^2 R$$

$$\therefore \frac{P_t}{P_c} = \frac{I_t^2 R}{I_c^2 R} = \left(\frac{I_t}{I_c}\right)^2 \quad \text{—— (1)}$$

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

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

from (1) & (2),

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

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

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

→ Modulation index in terms of current –

$$I_t = I_c \left[1 + \frac{m^2}{2} \right]^{1/2}$$

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

$$\Rightarrow \frac{m^2}{2} = \left(\frac{I_t}{I_c}\right)^2 - 1$$

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

Q. An AM signal has a peak unmodulated carrier voltage, $E_c = 100\,V$, load resistance, $R = 50\,\Omega$ and $m = 1$. Determine –
(a) Carrier Power (b) LSB & USB power
(c) Total SB power (d) Total power of AM signal (e) ~~Draw~~ power spectrum.

Soln: $E_c = 100\,V$ $R = 50\,\Omega$ $m = 1$

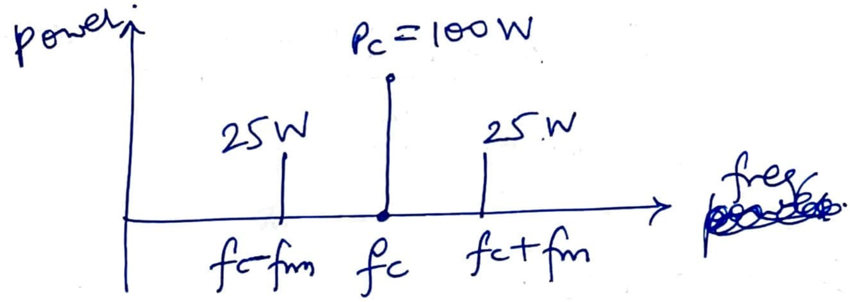
(a) $P_c = \frac{E_c^2}{2R} = \frac{100^2}{2 \times 50} = 100\,W$

(b) $P_{USB} = P_{LSB} = \frac{m^2}{4} P_c = \frac{1^2}{4} \times 100 = 25\,W$

(c) $P_{SB} = \frac{m^2}{2} P_c = \frac{1^2}{2} \times 100 = 50\,W$

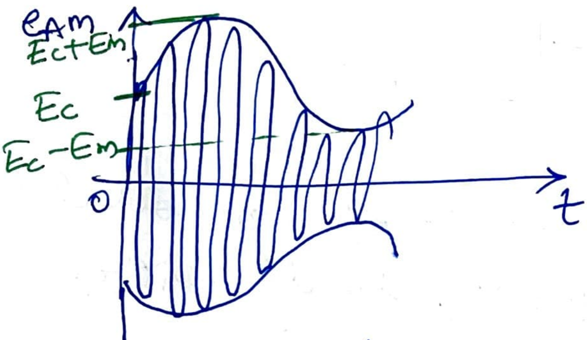
(d) $P_t = P_c \left[1 + \frac{m^2}{2}\right] = 100\left[1 + \frac{1^2}{2}\right] = 150\,W$

(e)



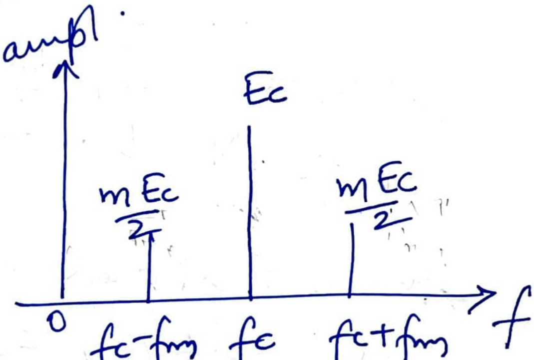
TYPES OF AM

→ I. DSB-FC AM –



AM waveform

(Repr. of AM signal in Time domain)



freq spectrum

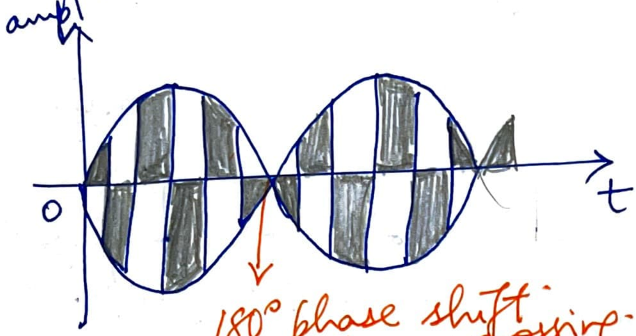
Math. Expr –

$$e_{AM} = \underbrace{E_c \cos \omega_c t}_{\text{carrier}} + \underbrace{\frac{mE_c}{2} \cos(\omega_c + \omega_m)t}_{\text{USB}} + \underbrace{\frac{mE_c}{2} \cos(\omega_c - \omega_m)t}_{\text{LSB}}$$

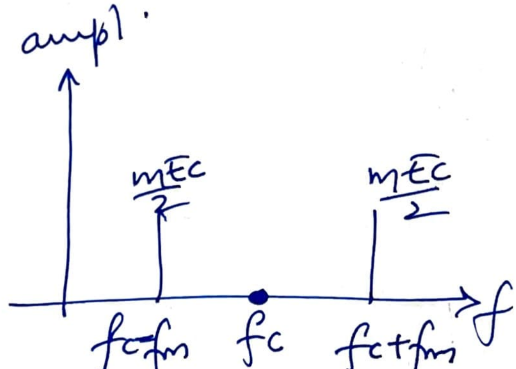
$$P_t = P_c \left[1 + \frac{m^2}{2}\right] \quad \text{where, } P_c = \frac{E_c^2}{2R}$$

$$\Rightarrow P_t = \underbrace{\cancel{P_c}}_{\text{P of carrier}} + \underbrace{\cancel{\frac{m^2}{4} P_c}}_{\text{P of USB}} + \underbrace{\frac{m^2}{4} P_c}_{\text{P of LSB}}$$

II. DSB-SC AM



Amplitude spectrum



Freq spectrum

Math. Eqn. -

$$e_{DSB-SC} = \underbrace{\frac{mE_c}{2}\cos(\omega_c+\omega_m)t}_{USB} + \underbrace{\frac{mE_c}{2}\cos(\omega_c-\omega_m)t}_{LSB}$$

$$P_{t_{DSB-SC}} = \frac{m^2 P_c}{4} + \frac{m^2 P_c}{4} = \frac{m^2 P_c}{2}.$$

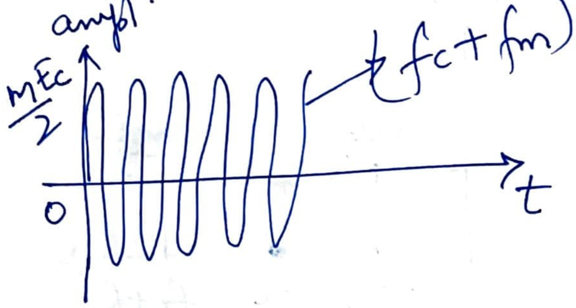
When $m=1$,

$$P_{t_{DSB-FC}} = P_c\left(1+\frac{m^2}{2}\right) = 1+\frac{1^2}{2} = 1.5\,P_c$$

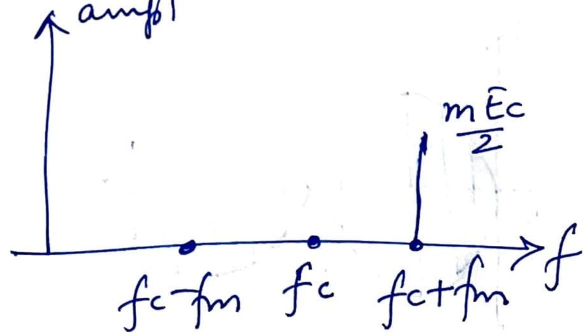
$$P_{t_{DSB-SC}} = \frac{m^2 P_c}{2} = \frac{1^2 P_c}{2} = 0.5\,P_c$$

% Power saving = 66.66 %

III. SSB-SC AM — no carrier / only 1 SB



Amplitude spectrum



freq spectrum

Math. Eqn.

$$e_{SSB-SC} = \underbrace{\frac{mE_c}{2}\cos(\omega_c+\omega_m)t}_{USB}$$

$$P_{t_{SSB-SC}} = \frac{m^2}{4} P_c$$

when $m = 1$

$P_{t_{DSB-FC}} = 1.5\, P_c$

$P_{t_{SSB-SC}} = \frac{1^2}{4} P_c = 0.25\, P_c$

% power saving;

$= 83.33\%$

SEITB. 2021

NUMERICALS

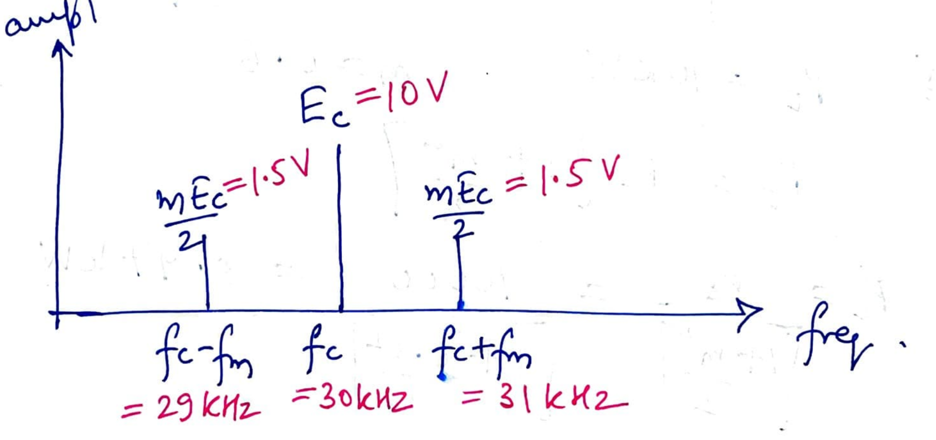
Q1. The amplitude modulated AM wave, $e_{AM} = 10\left[1 + 0.3\cos(2\pi \times 1000t)\right]\cos(2\pi \times 30 \times 10^3 t)$ is developed across $50\,\Omega$ resistance. Draw the frequency spectrum.

Soln: Std. AM eqn is –

$$e_{AM} = E_c\left[1 + m\cos(\omega_m t)\right]\cos\omega_c t$$

$E_c = 10\,V \qquad m = 0.3 \qquad f_m = 1000\,Hz = 1\,kHz$

$f_c = 30\,kHz$



$f_c + f_m = 30 + 1 = 31\,kHz = USB$

$f_c - f_m = 30 - 1 = 29\,kHz = LSB$

Amplitude of each SB $= \dfrac{mE_c}{2} = \dfrac{0.3 \times 10}{2} = 1.5\,V$

Q2. A 400 W carrier is modulated to a depth of 75%. Find the total power in the AM wave.

Soln:

$P_c = 400W \qquad m = 0.75$

$$P_t = P_c\left[1+\frac{m^2}{2}\right] = 400\left[1+\frac{0.75^2}{2}\right]$$

$$= 512.5\,W.$$

Q3. An AM broadcast radio radiates 10 KW of power if mod % is 60. Calculate how much of this is carrier power & calculate the amplitude of carrier signal if the value of R is 50 Ω.

Soln:

$P_t = 10\,KW \qquad m = 0.6$

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

$$P_c = \frac{P_t}{\left[1+\frac{m^2}{2}\right]} = \frac{10000}{\left[1+\frac{0.6^2}{2}\right]} = 8.47\,KW$$

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

$$E_c = \sqrt{2RP_c} = \sqrt{2\times 50\times 8470}$$

$$= 920\,V$$

Q4. The antenna current of an AM transmitter is 8A if only carrier is sent, but it increases to 8.93 A if carrier is modulated by a sinusoidal signal. Determine % mod, and transmission efficiency.

Soln. $I_t = 8.93A$ $\quad I_c = 8\ A$

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

$$\Rightarrow m = \sqrt{2\left[\left(\frac{I_t}{I_c}\right)^2 - 1\right]} = \sqrt{2\left[\left(\frac{8.93}{8}\right)^2 - 1\right]}$$

$$= 0.701 = 70.1\%$$

$$\%\eta = \frac{m^2}{2+m^2} = \left[\frac{0.701^2}{2+0.701^2}\right] \times 100$$

$$= 19.7\%$$

AM Receivers

→ Functions of Receiver –

→ Select the desired signal from all other unwanted signals.

→ Amplify desired signal

→ Demodulate amplified signal

→ Amplify modulating signal

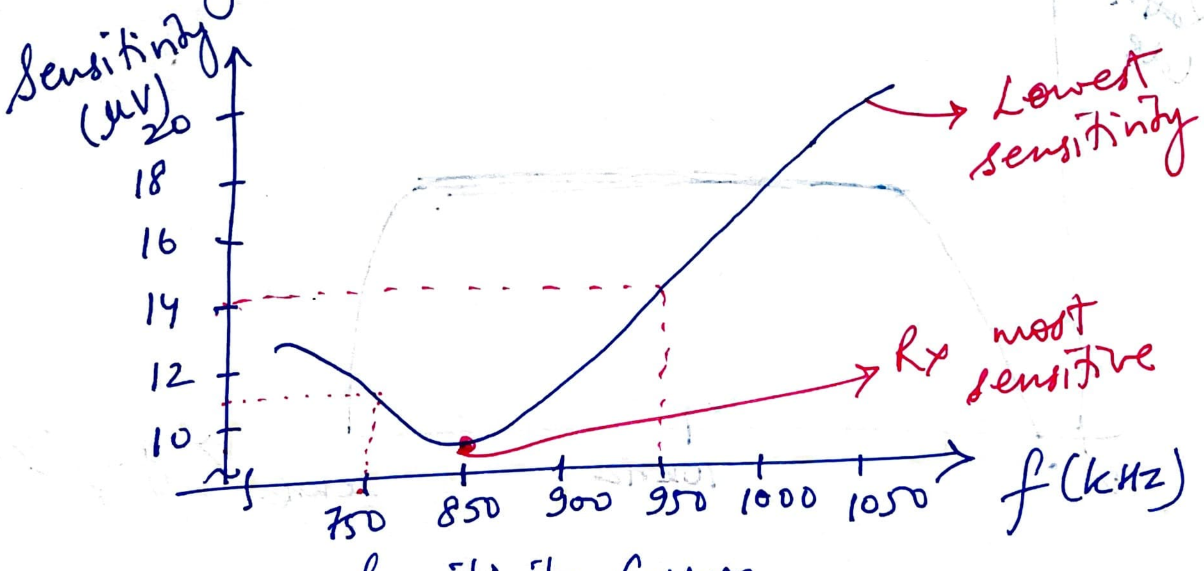
→ Apply this to a transducer to get back any original info.

→ Characteristics of Radio Receivers –

I. **Sensitivity** – The sensitivity of a radio receiver is defined as its ability to amplify weak signals.

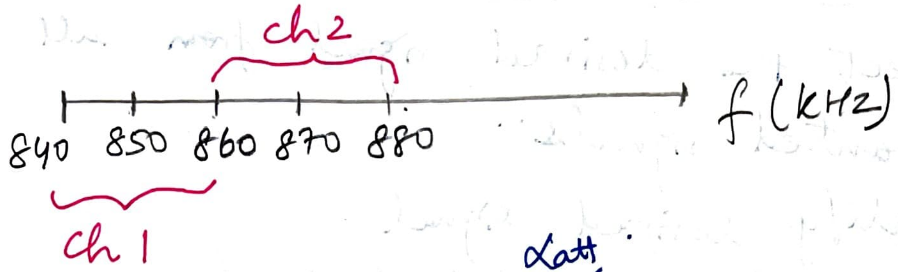
→ The minimum voltage/power level that the receiver will be able to demodulate

→ Sensitivity is measured in μV or dB.

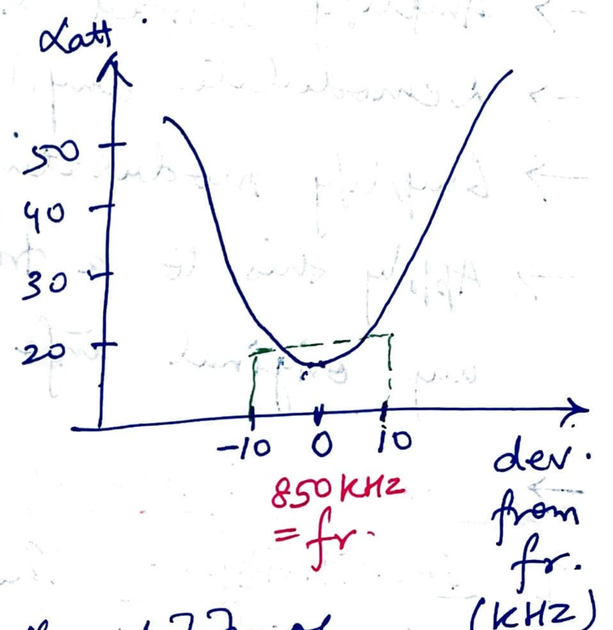


Sensitivity Curve

II. **Selectivity** – Selectivity of a receiver is its ability to reject unwanted signals.

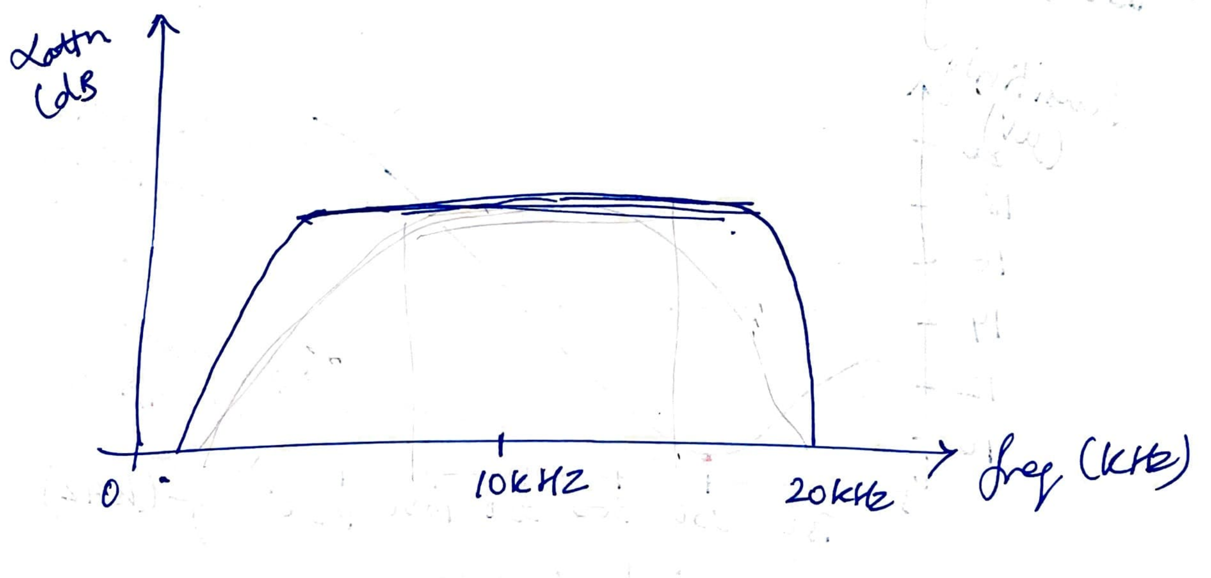


→ Selectivity is majorly determined by frequency response characteristics of IF amplifier & also by response of mixer & RF amplifier.



III. **Fidelity** – Fidelity is the ability of a receiver to reproduce all modulating frequencies equally.

High fidelity ⇒ Good quality music



RECEIVER TYPES

→ There are 3 types of receivers which have real, practical and commercial significance

- TRF - Rx (Tuned Radio frequency Rx)
- SH - Rx (Superheterodyne Rx)
- Double conversion Rx (for comm; not for reception)

→ TRF-Rx - Oldest and simplest. But, there are many short comings.

→ SH-Rx - most popular & widely used.

→ Components of a Receiver -

→ RF, IF, AF amplifiers

→ mixer

→ oscillator

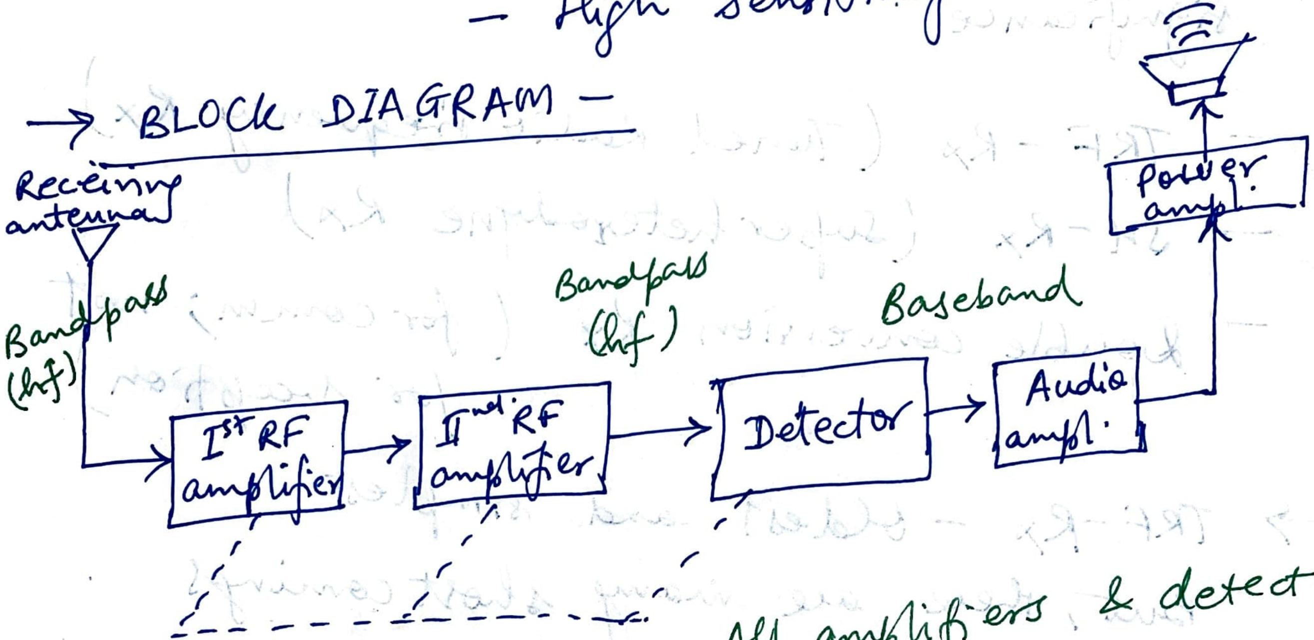
→ Detectors.

→ TUNED RADIO FREQUENCY RECEIVER –

→ These were used before World-War II.

→ Advantages – Its simplicity
– High sensitivity.

→ BLOCK DIAGRAM –



Ganged Tuning → All amplifiers & detector is tuned ~~to~~ simultaneously to the desired frequency.

→ AM Transmission takes place in Medium wave (MW) or short wave (SW) Band.

In Mumbai
MW → 530 – 1640 KHz
→ A – 1044 KHz (Samvadita Vahini)
→ B – 558 KHz (Asmita Vahini)
→ C – 1188 KHz (Viridh Bharti)

SW → 3 MHz – 30 MHz
→ 4840 KHz
→ 7240 KHz

→ LIMITATIONS OR PROBLEMS ASSOCIATED WITH TRF - RECEIVERS -

→ Instability
→ Variation in BW over the tuning range
→ Insufficient selectivity at higher frequency and poor adjacent channel rejection.

I. Instability -

→ Overall gain of RF amplifier stage is very high.
→ So, a very small feedback signal from its output to input in correct phase (+ve feedback) can initiate oscillations in RF stage ($A\beta = 1$)

$\therefore$ If $A = 40000$, $\beta = \frac{1}{40000}$ th $\Rightarrow$ Oscillations.

This feedback takes place through stray capacitances in the circuit.

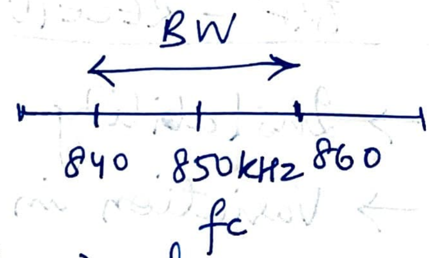
$\therefore$ There is a possibility of oscillatory behaviour

$\Rightarrow$ Instability will increase with increased gain.

Once oscillations begin, RF amplifiers cannot amplify desired signal.

→ Variation in BW –

→ When receiver is tuned, it is tuned to f_c. And the tuner circuit is expected to select carrier & SBs of the desired signal



⇒ It must have adequate BW.

→ For a tuned circuit –

$$BW = \frac{f_c}{Q}$$

where, $f_c = f_r$ = resonant frequency
Q = Quality factor.

Eg. $BW = 10\ KHz$

This will remain constant at all f_c.

Now, $f_c = 535\ KHz$

$$Q = \frac{535}{10} = 53.5$$

Now, $f_c = 1640\ KHz$ $(BW = 10\ KHz)$

$$Q = \frac{1640}{10} = 164$$

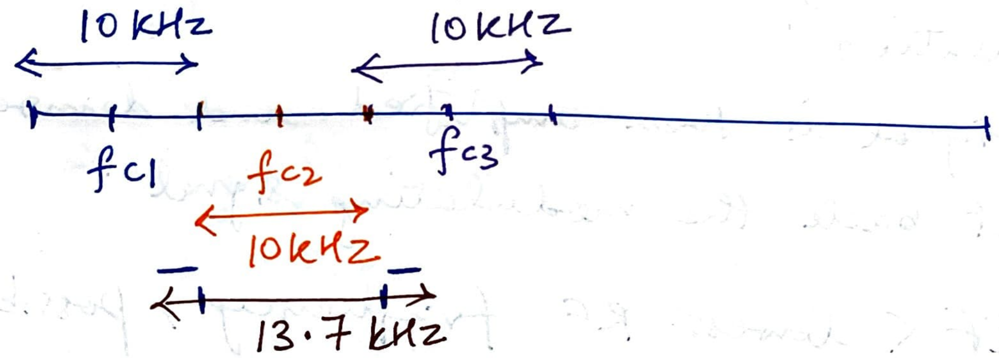
This value of Q is practically not obtainable due to various types of losses that occur at higher frequency.

At most, $Q = 120$

If $Q = 120$ at $f_r = 1640$ KHz

Corresp. BW $= \frac{1640}{120} = 13.7$ kHz

But, desired was $= 10$ KHz



⇒ Due to increased BW, Rx picks up adjacent channels along with desired one.

III. <u>Insufficient Selectivity</u> –

→ Due to increased BW at higher frequencies, the ability of TRF-Rx to select desired signal and reject all others are seriously affected.

This is called as loss of selectivity, ie. Poor adjacent channel rejection.

SUPERHETERODYNE RECEIVERS

→ Problems in TRF-Rx solved by converting every selected RF signal to a fixed lower frequency signal called Intermediate frequency (IF)

→ This frequency contains same amount of modulation.

→ IF signal is then amplified and demodulated to get back the modulating signal.

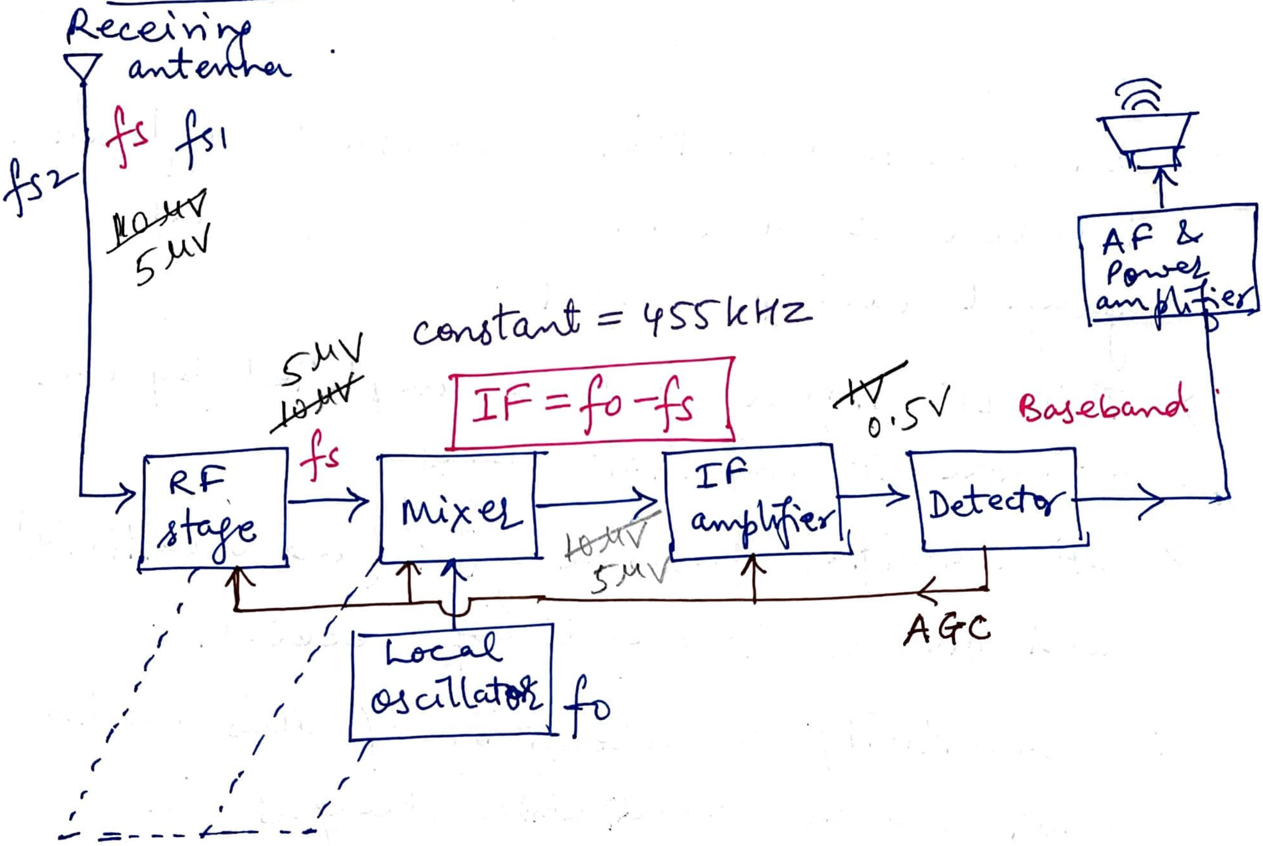
→ As IF < lowest RF frequency, possibility of oscillations and instability is minimized.

→ Also, the required value of Q for constant BW does not depend on frequency of desired signal because IF is constant and it is same for all incoming RF signal

⇒ Selectivity is not hampered.

∴ SH-Rx solves all problems associated with TRF-Rx.

BLOCK DIAGRAM OF SH-Rx



Ganged Tuning

→ RF stage is used to select wanted / desired signal, reject all other signals and hence reduce the effect of noise.

→ We get a signal of frequency, fs at output of RF amplifier.

→ Mixer receives signal from RF stage (fs) and local oscillator (fo)

→ These two signals are mixed together to produce IF,

ie. $IF = (f_o - f_s)$

Typically, IF = 438 – 465 KHZ

IF = 455 KHZ

→ In order to maintain a constant difference between LO and incoming frequency, ganged tuning is used.

→ This IF signal is then amplified by one or more IF amplifier stages.

→ IF amplifier provide gain (and sensitivity) and BW requirement of receiver.

∴ Sensitivity & Selectivity of this receiver do not change much with changes in incoming frequency.

→ Amplified IF signal is detected by the detector to recover original modulating signal.

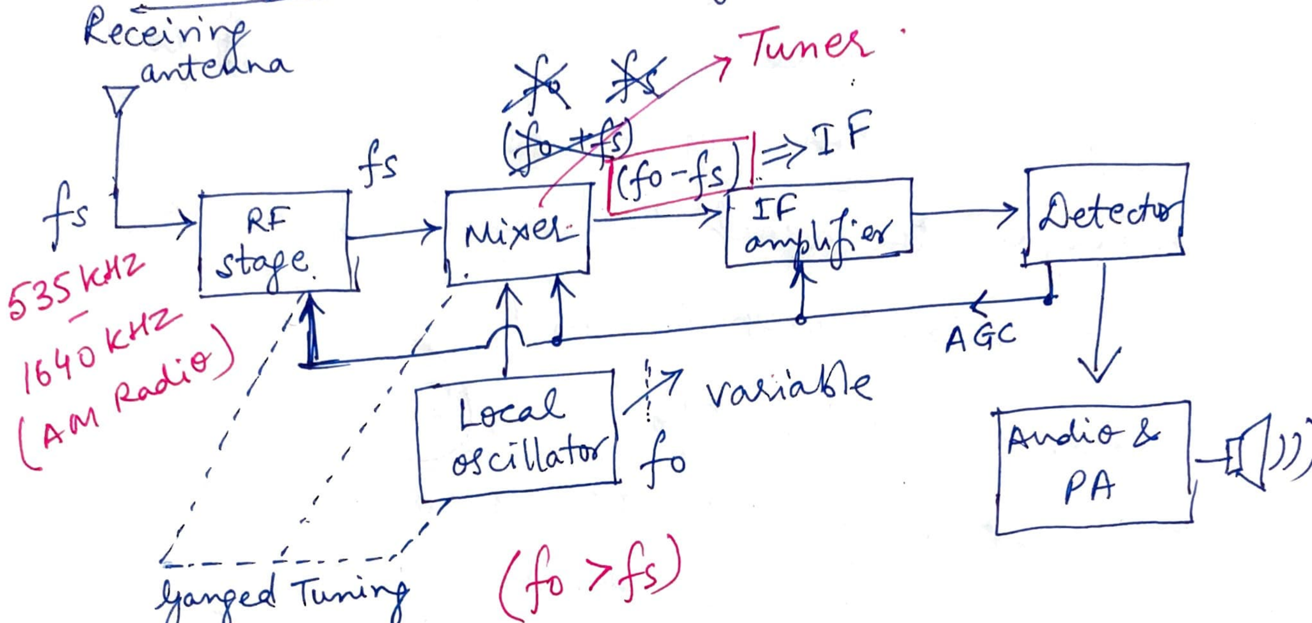
→ This is then amplified using audio and power amplifiers & given to loudspeaker.

→ AGC → Automatic Gain Control.

This circuit controls the gain of RF & IF stages to maintain constant output.

— IMAGE FREQUENCY REJECTION —

→ SH-Rx — Superheterodyne Receiver.



→ IF → 455 KHZ

$f_s \rightarrow 535$ KHZ $\Rightarrow f_o = 990$ KHZ

$f_s \rightarrow 1640$ KHZ $\Rightarrow f_o = 2095$ KHZ

→ In broadcast AM-Rx,

$f_o > f_s$ by IF.

$f_o \rightarrow$ local oscillator frequency

$f_s \rightarrow$ incoming signal frequency.

$\Rightarrow f_o = f_s + IF$

$\Rightarrow \boxed{IF = (f_o - f_s)}$

→ Output of mixer → $f_o, f_s, (f_o+f_s), (f_o-f_s)$

Out of these, $(f_o - f_s)$ is only selected using a tuned circuit after the mixer.

→ Image frequency and its Rejection –

→ Let us assume LO frequency is set to f_o and unwanted signal, $f_{si} = (f_o + IF)$ manages to reach the input of mixer.

→ Then, mixer output will be –

$$f_o,\ (f_o + IF),\ 2f_o + IF,\ IF$$

This last component, IF is actually the difference between f_{si} & f_o.

This component will also be amplified by IF amplifier alongwith the desired signal, at frequency, f_s.

→ This will create interference because both the station corresponding to frequency f_s and f_{si} will be tuned at the same position.

→ This unwanted signal at frequency, f_{si} is known as image frequency and it is said to be the image of signal frequency, f_s.

→ Relation between f_s and f_{si} —

$$IF = (f_o - f_s)$$

$$\Rightarrow f_o = (f_s + IF) \quad \text{——— (1)}$$

We also know,

$$f_{si} = (f_o + IF)$$

from (1),

$$f_{si} = ((f_s + IF) + IF)$$

$$\boxed{f_{si} = f_s + 2IF}$$

→ Remedy —

→ Image frequency must be rejected by the receiver.

→ Image rejection depends on front end selectivity of receiver, i.e. selectivity of the RF circuit.

→ Also, image rejection must be achieved before IF stage because once it reaches IF stage, it cannot be removed.

→ Use of RF amplifier improves image frequency rejection.

→ **Double Spotting** –

→ Let us understand this with an example –

→ Assume, We select IF of SH-Rx to be 470 kHz.

→ Assume a strong station at $f_s = 1640$ kHz

(a) Corresponding, $f_o = 2110$ kHz

($\because 2110 - 1640 = 470$) = IF.

Hence, strong station will be picked up.

(b) I want to tune to 700 kHz.

then, $f_o = 1170$ kHz ($\because 1170 - 700 = 470$) = IF

(IDEAL) → expected to pick 700 kHz

But ...

This signal, $f_s = 700$ kHz is very weak

1640 ↑ strong → Tries to mask

700 kHz ↓ weak

$f_o = 1170$

→ Now, when 1170 kHz of LO frequency is present, 1640 kHz signal will also beat with this f_o.

$(1640 - 1170) = 470$ kHz

Hence, this station will also get picked up at this point on the dial.

→ Image rejection using a single tuned circuit –

→ Rejection of image frequency by a single tuned circuit is given by –

$$\alpha = \frac{\text{gain at signal frequency}}{\text{gain at image frequency}}$$

$$\alpha = \sqrt{1 + Q^2 \rho^2}$$

where, $Q \rightarrow$ loaded Q of tuned circuit

$$\rho = \left[\frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} \right]$$

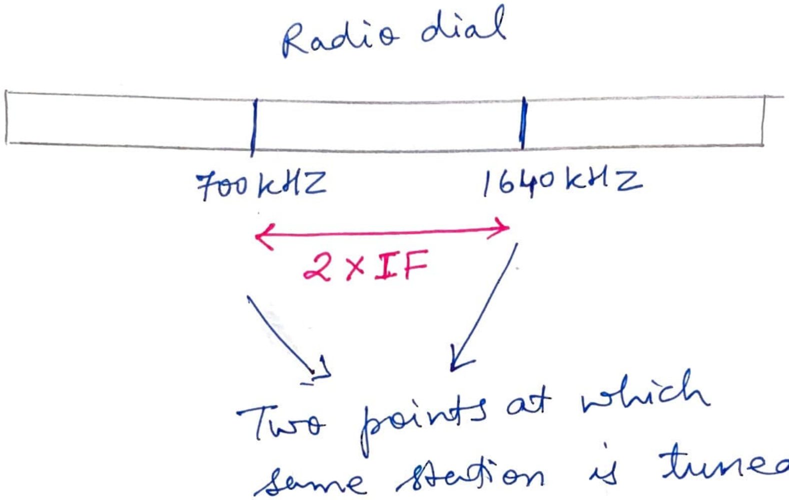
→ If the receiver has an RF stage, then there will be two tuned circuits both of them tuned to f_s.

→ Rejection can then be calculated using same formula and total rejection will be the product of individual rejection introduced by individual tuned circuits.

Q1. In a SH-Rx having no RF amplifier, the loaded Q of antenna coupling circuit (at the input of mixer) is 90. If IF is 455 kHz, calculate –

(a) Image frequency and image frequency rejection ratio at 950 KHz

→ 700 KHZ is weak and hence is masked by a strong signal at 1640 KHZ



→ Double spotting means the same station gets picked up at two different nearby points on the receiver dial.

→ It is due to poor front end selectivity. i.e. inadequate image frequency rejection.

→ It is harmful because a weak station may masked by reception of a strong station at the same point, on the dial.

→ It can be reduced by increasing front end selectivity of receiver.

→ Inclusion of RF amplifier stage will help in avoiding double spotting.

b) Image frequency and its rejection at 10 MHz.

Soln. (a) $Q = 90$ IF $= 455$ KHz $f_s = 950$ KHz

$$f_{si} = f_s + 2IF$$
$$= 950 + (2 \times 455)$$
$$= 1860 \text{ KHz}$$

$$\Rightarrow \alpha = \sqrt{1 + Q^2 \rho^2}$$
$$= \sqrt{1 + (90^2 \times 1.45^2)} = \boxed{130.5}$$ good rejection

We know,
$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{1860}{950} - \frac{950}{1860} = 1.45$$

(b) $Q = 90$ IF $= 455$ KHz $f_s = 10$ MHz

$$f_{si} = f_s + 2IF = 10 + (2 \times 0.455)$$
$$= 10.91 \text{ MHz}$$

$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}} = \frac{10.91}{10} - \frac{10}{10.91} = 0.174$$

$$\Rightarrow \alpha = \sqrt{1 + Q^2 \rho^2} = \sqrt{1 + (90^2 \times 0.174^2)}$$
$$= \boxed{15.72}$$ pretty less rejection.

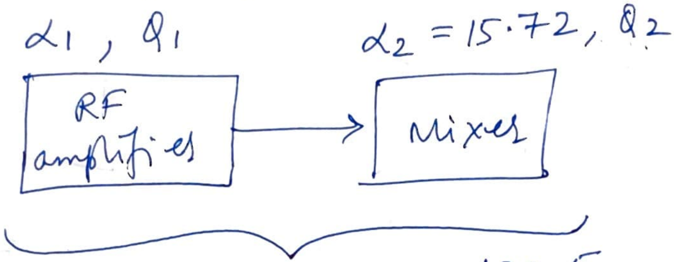
→ Without RF amplifier, image rejection is adequate at low frequency. However, it is inadequate at higher frequency.

∴ RF amplifiers may be used at high freq.

Q2. In order to make image frequency rejection of receiver of previous example as good as 950 kHz for 10 MHz as well, calculate the loaded Q which an RF amplifier for this receiver would have to use.

$$f_s = 10 \text{ MHz}$$

Soln:



$$\alpha = \alpha_1 \alpha_2 = 130.5$$

$$\alpha_1 = \frac{\alpha}{\alpha_2} = \frac{130.5}{15.72} = 8.3$$

$$\alpha_1 = \sqrt{1 + Q_1^2 \rho_1^2}$$

Substituting, $\rho = 0.174$

$\Rightarrow Q = 47.35$ → value of loaded Q of RF amplifier.

→ A well designed receiver would have same Q for tuned circuits of mixer and RF amplifier.

$\therefore Q_1 = Q_2 =$ geometric mean of 90 and 47.35

$$= \sqrt{90 \times 47.35} = 65.28$$

Q3. With respect to previous example, calculate the new IF that would be needed if RF amplifier is not to be used.

Soln: At 950 kHz, $\rho = 1.45$ $\quad \alpha = 130.5$

~~Let new f_{si}'~~

Let new value of image frequency be f_{si}''

We know,

$$\rho = \frac{f_{si}}{f_s} - \frac{f_s}{f_{si}}$$

$$\Rightarrow 1.45 = \frac{1860}{950} - \frac{950}{1860} = \frac{f_{si}'}{10\,MHz} - \frac{10\,MHz}{f_{si}'}$$

By equating,

$$\frac{f_{si}'}{10MHz} = \frac{1860}{950} = 1.9578$$

$$\Rightarrow f_{si}' = f_s + 2\,IF'$$

$$\Rightarrow IF' = \frac{19.578 - 10}{2} = 4.789\,MHz$$

$\Rightarrow$ Increase in image frequency will improve image rejection.

→ Generation of AM –

→ The circuits generating AM waves are called amplitude modulator circuits.

→ The location of the modulator circuit in the transmitter determines whether it is a low or high level transmitter.

→ Low Level Modulated Transmitter –

→ modulation takes place in initial stages of amplification, ie. generation of AM wave takes place at a low power level.

→ Generated AM signal is then amplified using a chain of linear amplifiers (Class A) (in order to avoid any waveform distortion)

→ Advantages –

- Less modulating signal power required to achieve a higher percentage of modulation.
- More efficient RF amplification with simple circuitry.

→ Disadvantages –

- In LLM, each amplifier stage following modulator must handle sideband power as well as carrier. Thus all subsequent amplifiers must have sufficient bandwidth for sideband frequency
- Linear amplifiers used ~~to~~ because all stages

must be capable of handling amplitude variations caused by modulation (Transistors and opamps used)

→ <u>High Level modulated Transmitter</u> –

→ Modulation takes place in final stages of amplification, ie - generation of AM wave takes place at high power levels.

→ Carrier and modulating signal both are amplified first to the adequate power level and modulation takes place in the last RF amplifier stage of transmitter.

→ Carrier signal is at its maximum amplitude. ∴ modulation circuitry has to handle high power.

→ Final modulating signal amplifier must supply all sideband power which could be as much as 33% of total transmit power.

→ Highly efficient class C amplifiers are used.

→ Vacuum tubes and power transistors are used.

→ Efficiency of high level modulated transmitter is higher than that of low level modulated transmitter.

→ Buffer amplifier is a low gain, high input impedance linear amplifier. Its function is to isolate oscillator from high power amplifiers.

→ Buffer amplifier provides a relatively constant load to the oscillator which helps to reduce occurrence and magnitude of short-term frequency variations. Emitter followers or IC op-amps often used as buffers.

→ Modulators can use either collector or emitter modulation.

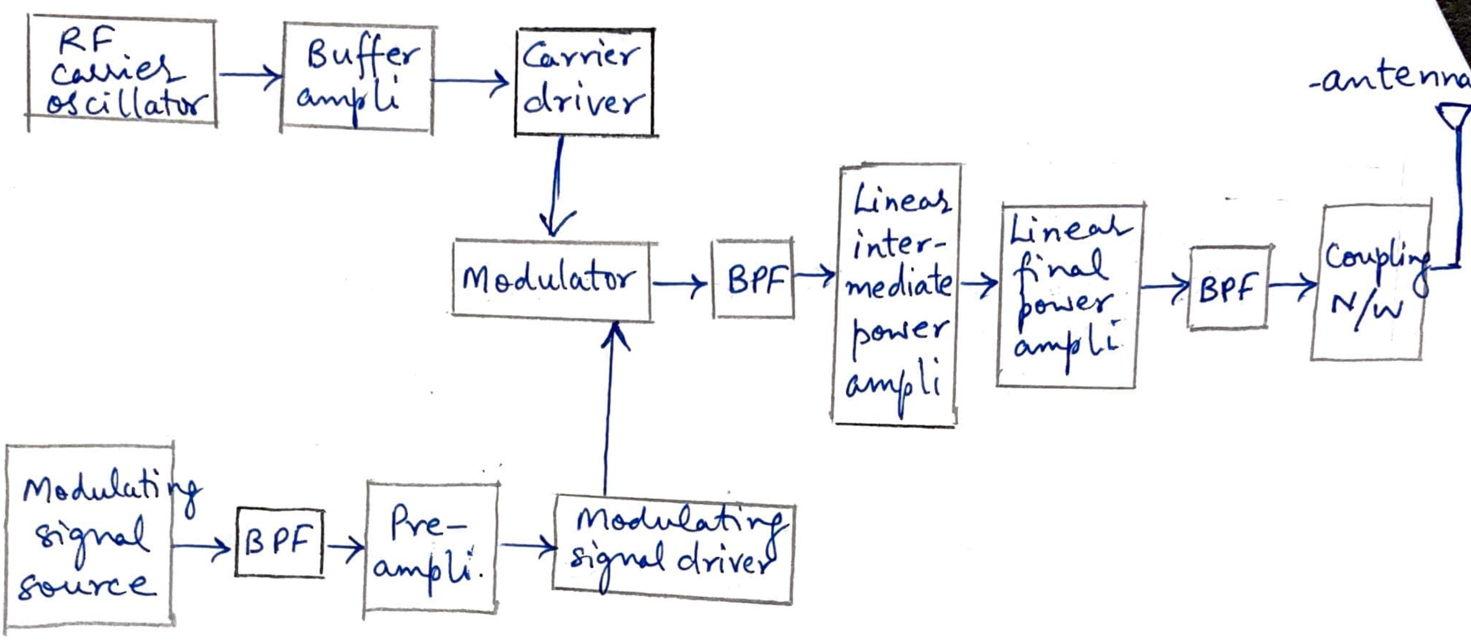
→ Amplified modulating signal is applied to modulator along with carrier.

→ Output of modulator is AM signal.

→ Intermediate and final power amplifiers are either linear Class A or Class B push-pull modulators. This is required to maintain symmetry in AM envelope. ie. Linear amplifiers are used to raise its power level such that it avoids waveform distortion in AM wave.

→ Antenna coupling networks matches output impedance of final power amplifier to transmission line and antenna.

→ LOW LEVEL MODULATED TRANSMITTER –



→ Source of modulating signal is a transducer.

→ Pre-amplifier is a sensitive class A linear voltage amplifier with a high input impedance. Its function is to raise the amplitude of the source signal to a usable level while producing minimum non-linear distortion and adding as little thermal noise as possible.

→ Modulating signal driver is also a linear power amplifier that simply amplifies the info signal to an adequate level to sufficiently drive the modulator. More than one drive amplifier may be required.

→ RF carrier oscillator can be any oscillator configuration. RF oscillator produces carrier signal. Crystal controlled oscillators are most commonly used.

→ Carrier is generated by stabilized crystal oscillator is first amplified to the adequate power level using Class C RF power amplifiers. i.e. RF carrier oscillator, its associated buffer and carrier driver are same circuits as used in LLM-Tx.

→ However, RF carrier undergoes additional power amplification prior to modulator stage and final power amplifier is the modulator itself.

→ Modulator is generally drain, plate or collector modulated Class C amplifier.

→ Modulation takes place in the last Class C RF amplifier.

→ Modulator output is AM wave which can be directly transmitted.

→ With HLM-Tx, modulator circuit has three primary functions –

- It provides circuitry necessary for modulation to occur (i.e. non-linearity)
- It is final power amplifier (Class C for efficiency)
- It is a frequency up-converter.
  (An up-converter simply translates low frequency baseband signal to RF signals that

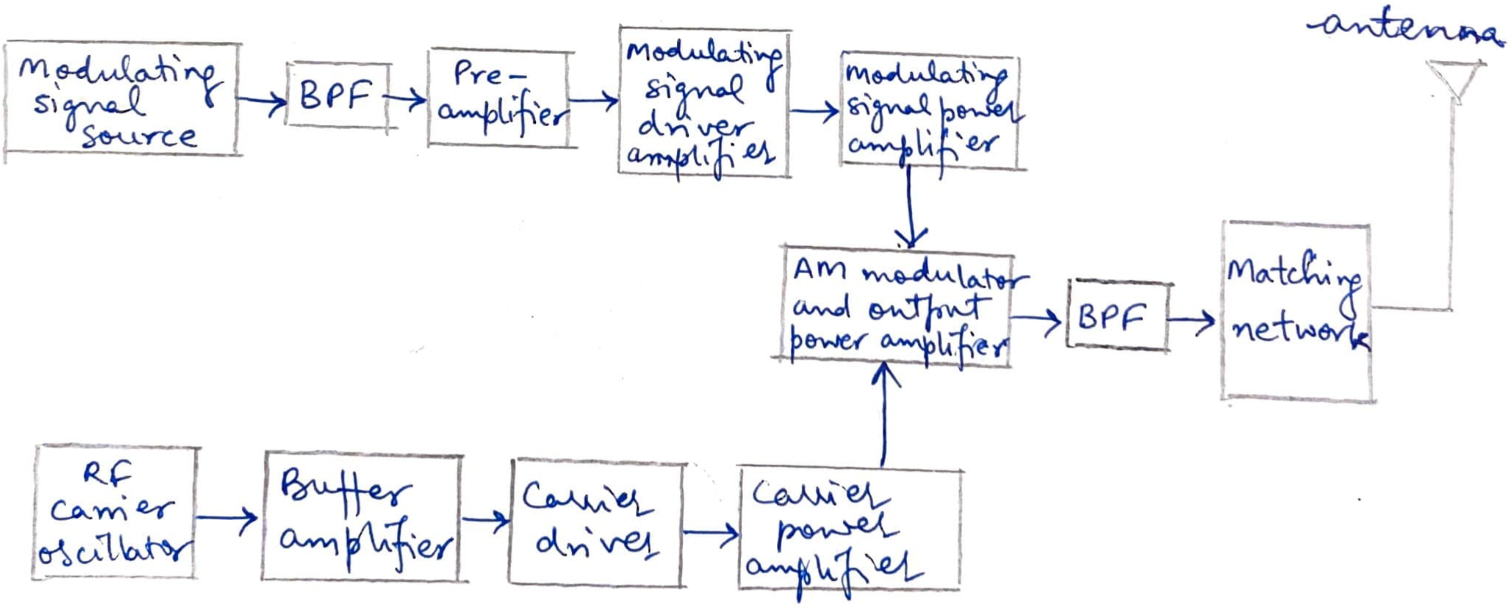
→ LLM used for low power, low capacity systems such as wireless intercom, remote control units, pagers and short range walkies-talkies.

- LLM-Tx does not require large AF modulator power, ~~so it~~ its design is simple.

→ However, overall efficiency is lower.

→ Transistorized modulator circuits can be used due to low power which it has to handle.

→ <u>High Level Modulated Transmitter</u> –



→ Modulating signal is processed in the same manner in the same manner as in LLM-Tx except for addition of power amplifier.
<u>ie</u>. modulating signal is also amplified to a high power level before modulation takes place.

can be efficiently radiated from an antenna and propagated through free space.

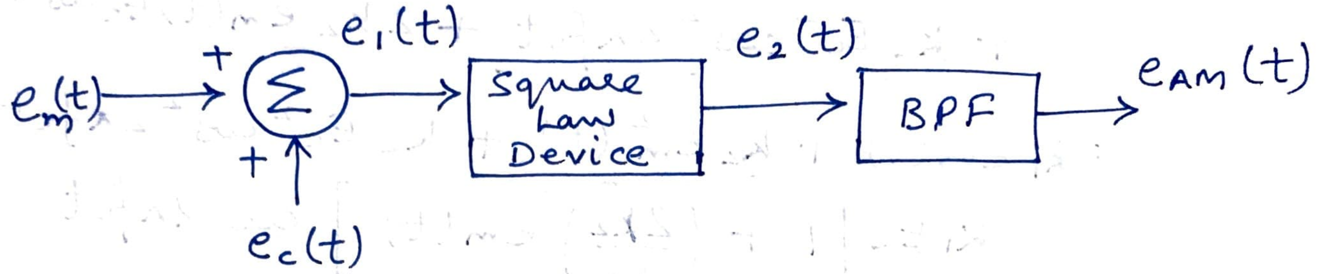
→ <u>Advantages</u> – High efficiency due to use of highly efficient Class C amplifiers.

→ <u>Disadvantages</u> – A large AF power amplifier is needed to raise the modulating signal to the adequate power level.

Mod - III

→ GENERATION OF AM (DSB-FC) USING DIODE –

→ DSB-FC AM can be generated using a square law device (eg. diode).



→ Let the modulating and carrier signal be denoted by $e_m(t)$ and $e_c(t)$ respectively.

→ Here,

$$e_c(t) = E_c \cos 2\pi f_c t$$

→ These two signals are applied to the adder.

→ Output of adder, $e_1(t)$ is –

$$e_1(t) = e_m(t) + e_c(t)$$
$$= e_m(t) + E_c \cos 2\pi f_c t$$

→ $e_1(t)$ is applied to a square law device (eg. diode).

→ Characteristics of diode governed by –

$$e_2(t) = k_1 e_1(t) + k_2 e_1^2(t) \quad \text{—— (1)}$$

where, k_1 & k_2 are constants.

→ Substituting value of $e_1(t)$ in (1), we get –

$$e_2(t) = k_1 \left[e_m(t) + E_c \cos 2\pi f_c t \right] + k_2 \left[e_m(t) + E_c \cos 2\pi f_c t \right]^2$$

$$= k_1 e_m(t) + k_1 E_c \cos 2\pi f_c t + k_2 e_m^2(t) + k_2 E_c^2 \cos^2 2\pi f_c t + 2 k_2 e_m(t) E_c \cos 2\pi f_c t$$

$$= k_1 e_m(t) + k_2 e_m^2(t) + k_2 E_c^2 \cos^2 2\pi f_c t + \underbrace{k_1 E_c \left[1 + \left(\frac{2k_2}{k_1} \right) e_m(t) \right] \cos 2\pi f_c t}_{\text{desired AM wave}}$$

→ We eliminate first three terms using BPF.

∴ Output of BPF is —

$$e_{AM}(t) = k_1 E_c \left[1 + \left(\frac{2k_2}{k_1} \right) e_m(t) \right] \cos 2\pi f_c t$$

Standard equation of AM wave is

$$e_{AM}(t) = E_c \left[1 + \frac{E_m \cos W_m t}{E_c} \right] \cos W_c t$$

$e_m(t)$

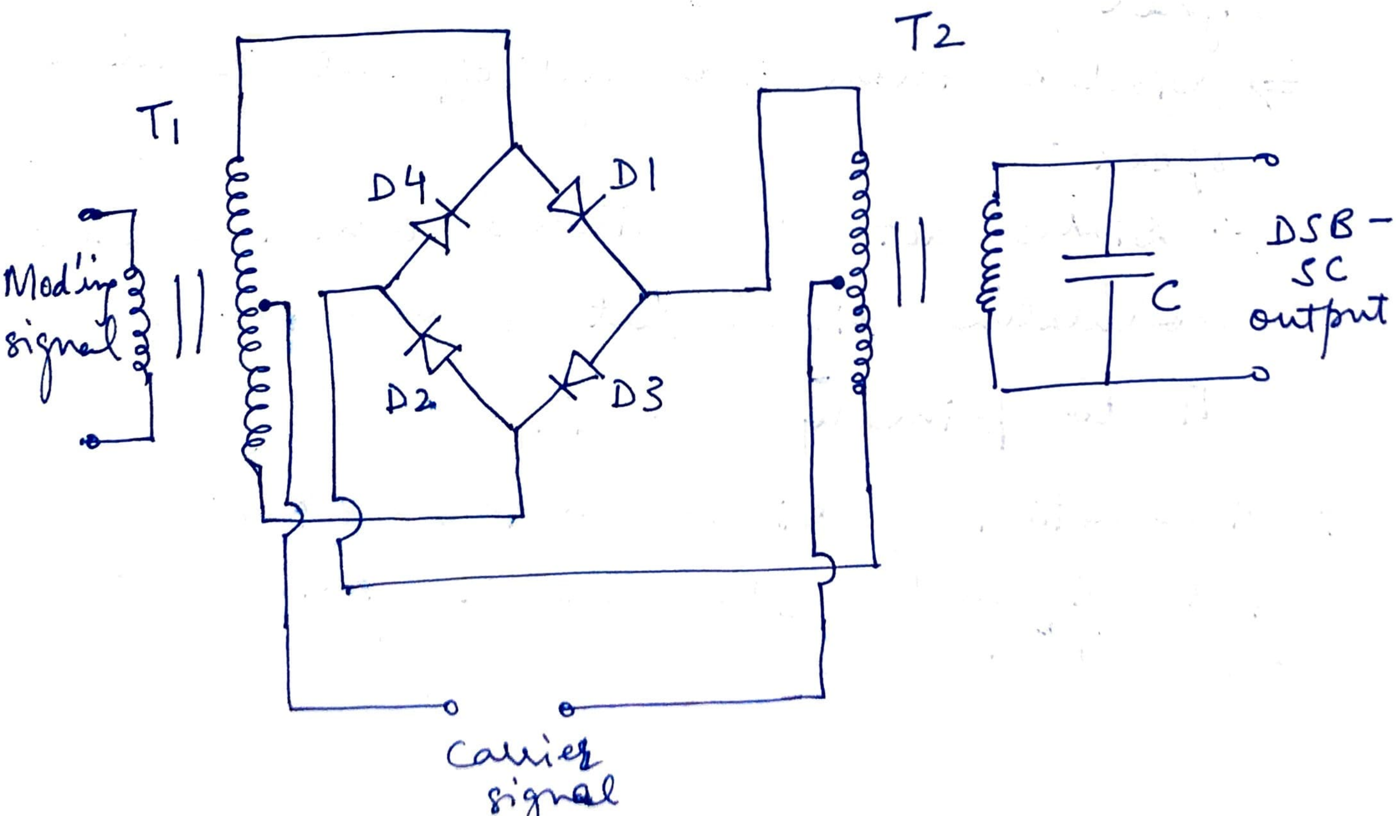
→ Here, k_1 is the scaling factor and $k_a = \frac{2k_2}{k_1}$ is the amplitude sensitivity.

→ GENERATION OF DSB-SC-AM USING BALANCED MODULATOR –

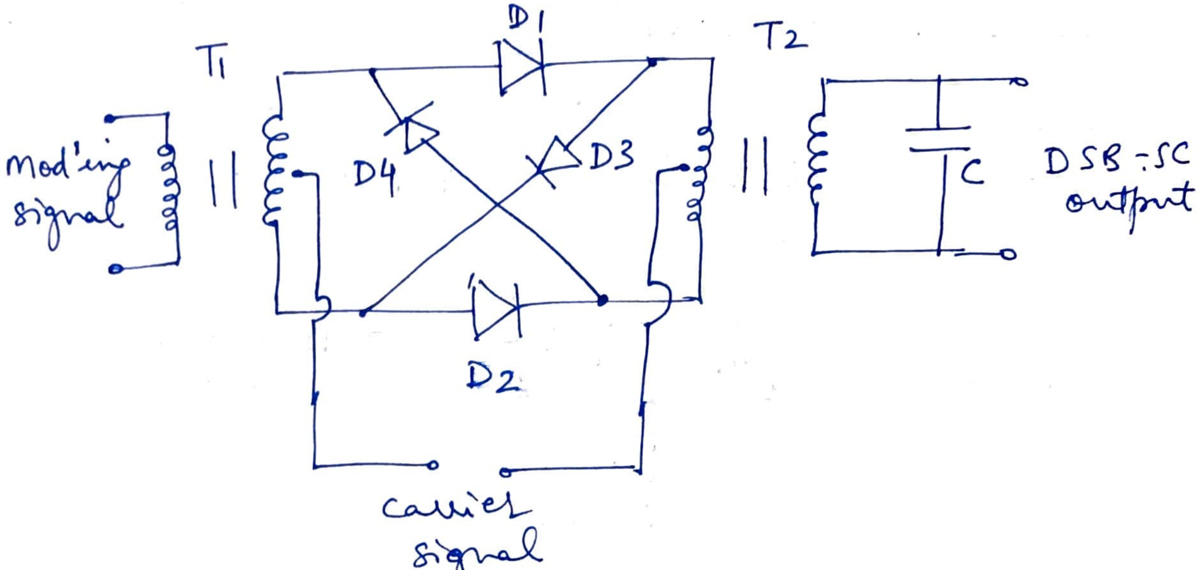
→ Balanced modulators are used to suppress carrier in an AM wave.

→ One such balanced modulator can be realised using Diodes – called as Balanced Ring modulator / Diode Ring modulator / Diode Lattice Modulator.

→ DIODE RING MODULATOR –



→ Circuit can be redrawn as -



→ Assume that diodes act as perfect switches.

→ Carrier signal is used as a source of forward bias and reverse bias of diodes because carrier is considerably higher in frequency and amplitude than modulating signal.

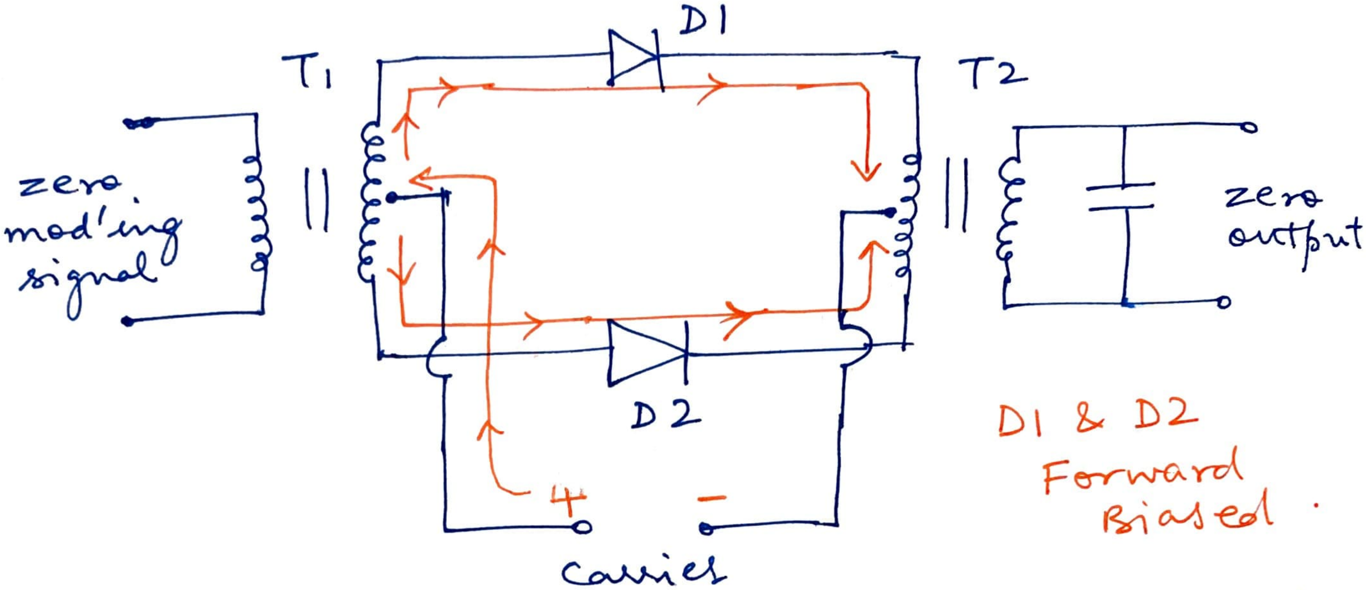
⇒ Diodes turn on and off at a high speed.

∴ Diodes act as switches which connect modulating signal at secondary of T_1 to primary of T_2.

→ <u>Assumption</u> - Diodes are perfectly matched and centre-tapped exactly at the centre.

I. Modulating Input is Zero –

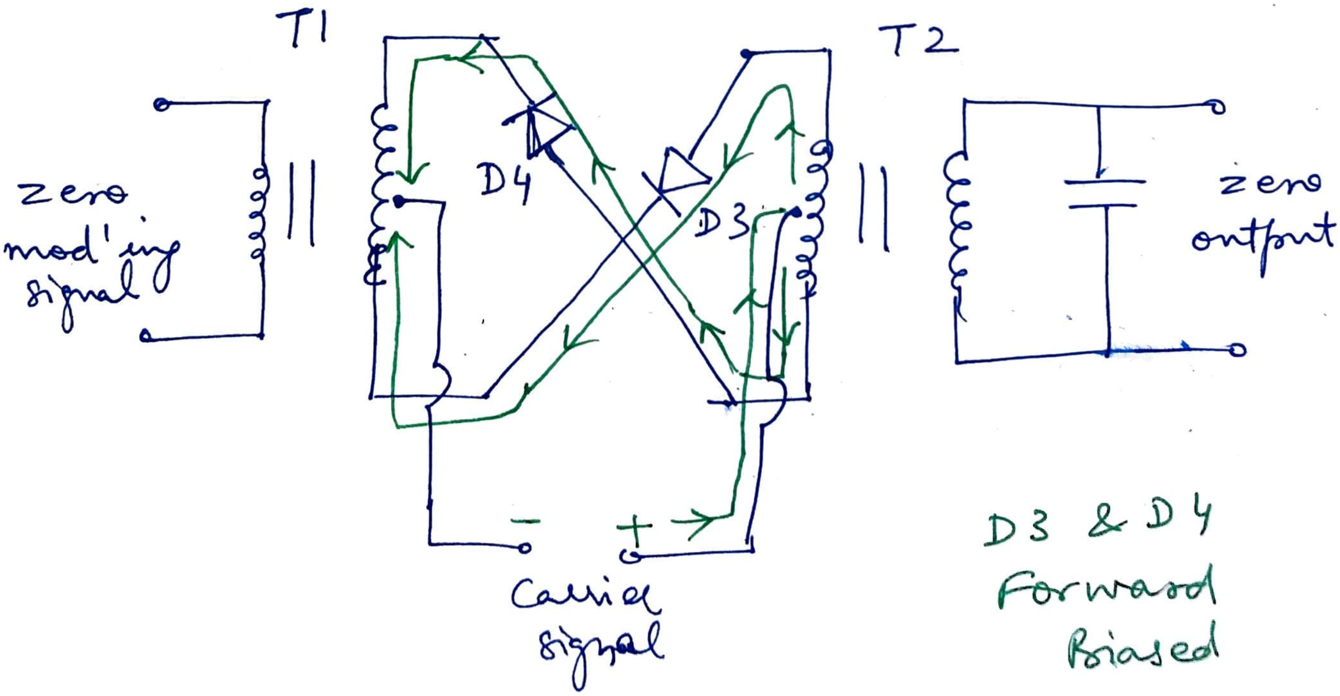
A. Positive half cycle of carrier –



→ Current in primary of T_2 is equal and opposite. ∴ They cancel each other.

⇒ Carrier is suppressed.

B. Negative half cycle of carrier –



II. Modulating signal applied –

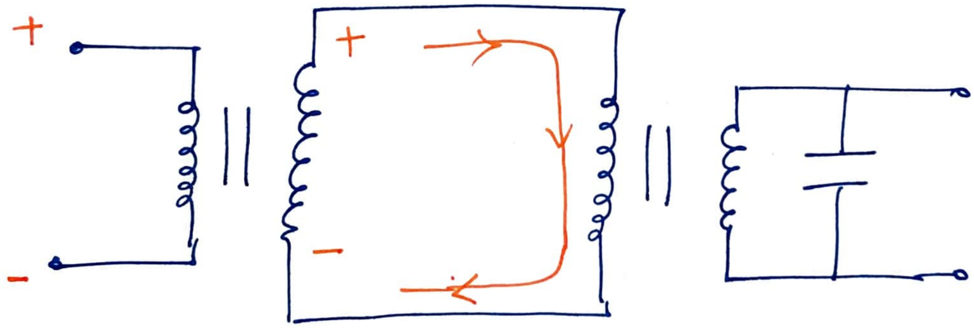
→ During +ve cycle of carrier, D1 & D2 will conduct and connect secondary of T1 to primary of T2.

→ During –ve cycle of carrier, D3 & D4 will conduct and connect secondary of T1 to primary of T2.

→ NOTE – With polarity of modulating signal reversed, 180° phase shift is present.

A. Positive half cycle of modulating signal –

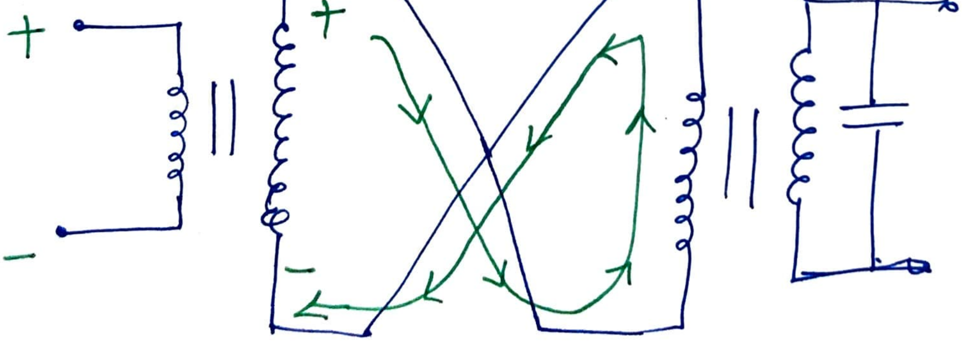
+ve cycle of carrier –



→ D1 & D2 FB as +ve cycle of carrier present.

→ +ve cycle of modulating signal there.

–ve cycle of carrier –

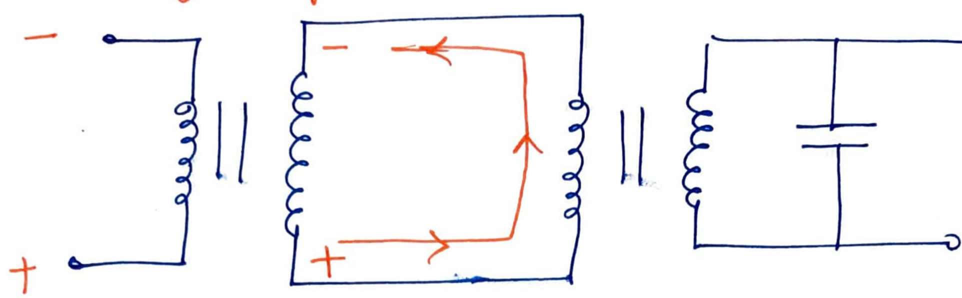


→ D3 & D4 FB as –ve cycle of carrier present

→ +ve cycle of modulating signal there.

B. Negative half cycle of modulating signal –

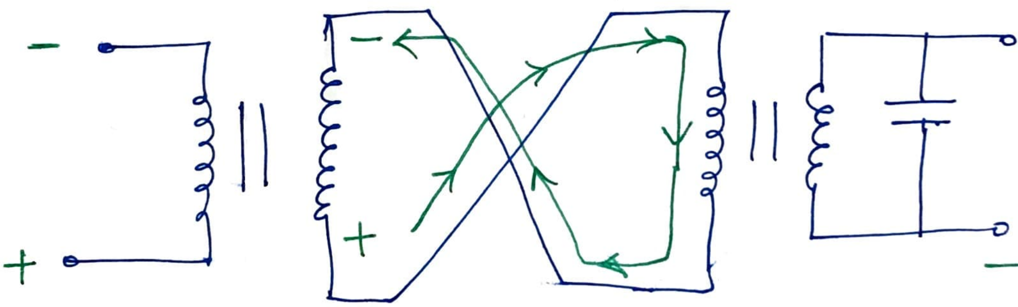
+ve cycle of Carrier



→ D1 & D2 FB as +ve cycle of carrier present.

→ –ve cycle of modulating signal there.

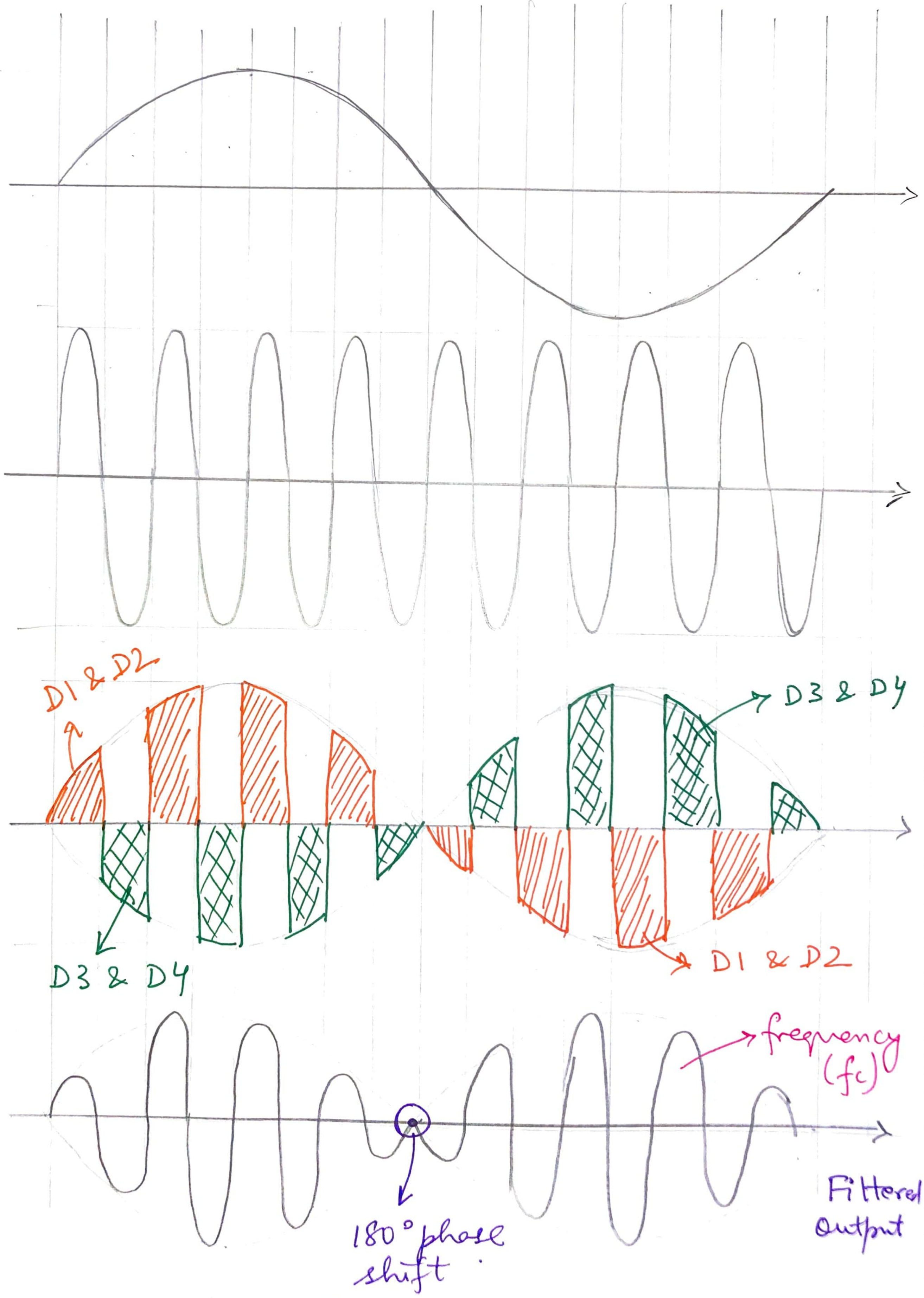
–ve cycle of carrier –



→ D3 & D4 FB as –ve cycle of carrier present

→ –ve cycle of modulating signal there.

→ Waveforms -


D1 & D2
D3 & D4
D3 & D4
D1 & D2
frequency (fc)
180° phase shift
Filtered Output

→ Diodes switch off and on at a high speed causing portions of modulating signal to be passed through diodes at different times.

→ DSB signal at primary of T_2 has steep rise and fall of waveform which is caused by rapid switching of diodes. Waveform contains harmonics of carrier because of switching action.

→ Hence at secondary of T_2, these high frequency harmonic content is filtered out leaving a DSB signal.

→ NOTE -

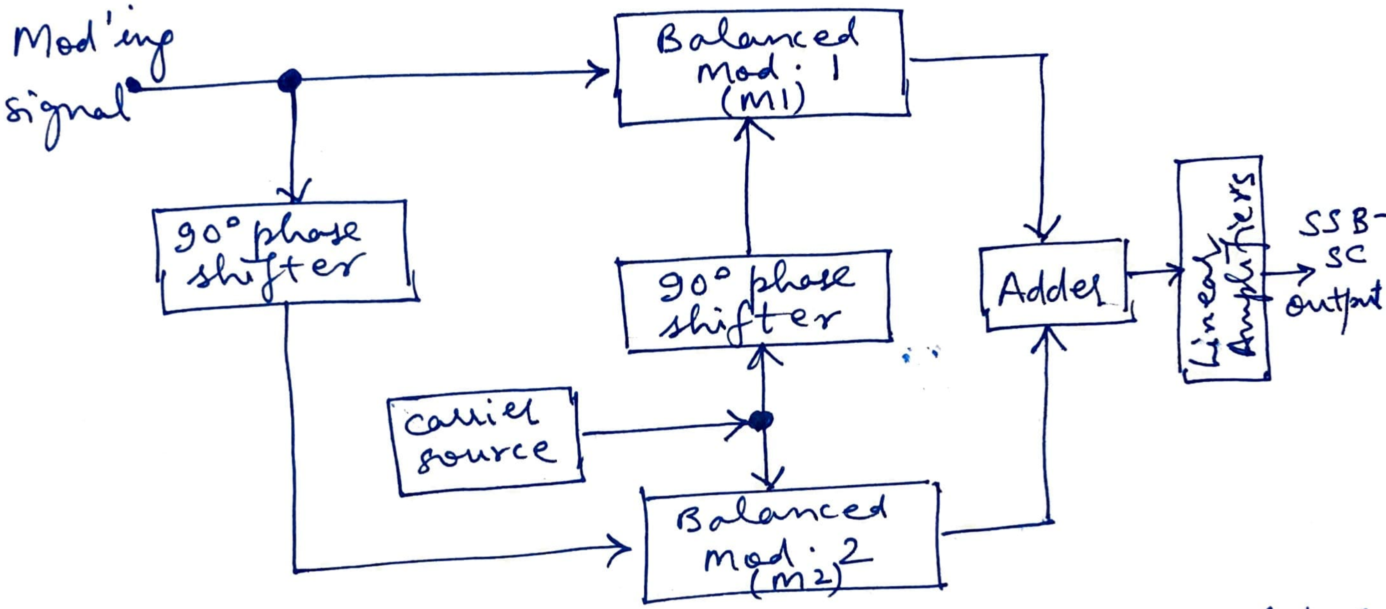
→ Output waveform is at carrier frequency even though the carrier is removed.

→ Envelope of output signal is not of the shape of modulating signal.

→ The phase reversal of signal is in the very centre of waveform.

→ GENERATION OF SSB-SC-AM USING PHASE-SHIFT METHOD –

For LSB Suppression –



→ This method uses two balanced modulators, M1 & M2 and two phase shifting (90°) networks.

→ Inputs to M1 are –
$\cos w_m t$ and $[\cos(w_c t + 90°)]$

→ Inputs to M2 are –
$[\cos(w_m t + 90°)]$ and $\cos w_c t$

→ Output of M_1 is –

$$= \{\cos[(w_c t + 90°) - w_m t] + \cos[(w_c t + 90°) + w_m t]\}$$

$$= \underbrace{\cos(w_c t - w_m t + 90°)}_{LSB} + \underbrace{\cos(w_c t + w_m t + 90°)}_{USB}$$

→ output of M2 is –

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

$= \underbrace{\cos(\omega_c t - \omega_m t - 90°)}_{LSB} + \underbrace{\cos(\omega_c t + \omega_m t + 90°)}_{USB}$

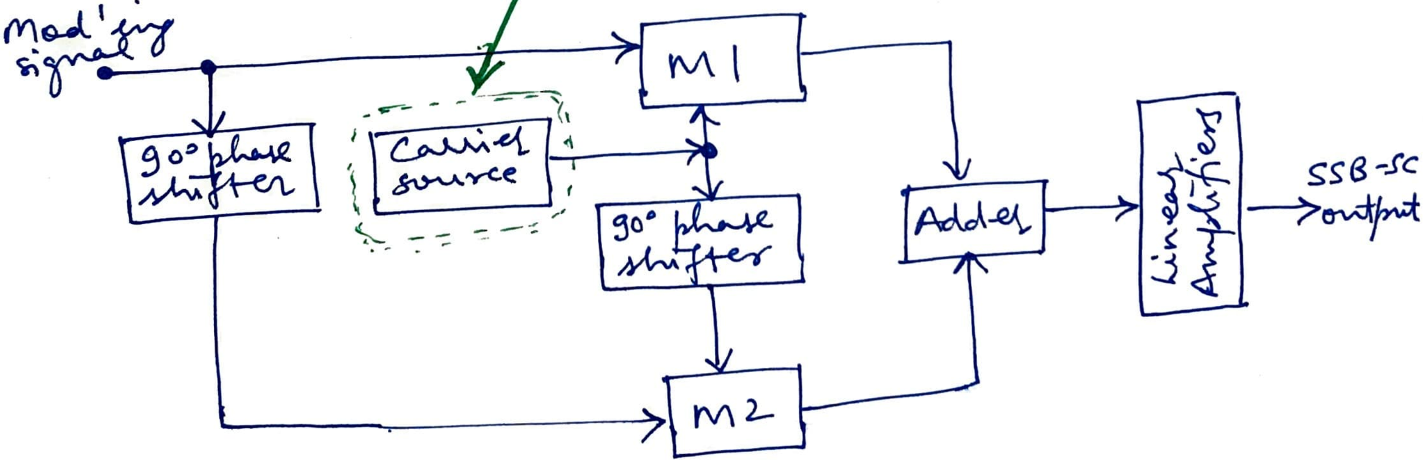
→ output of adder = output of M1 + output of M2

$= 2\cos(\omega_c t + \omega_m t + 90°)$

[∵ $\cos(\theta + 90°)$ and $\cos(\theta - 90°)$ are 180° out of phase.
⇒ LSBs are 180° out of phase.
∴ They cancel out]

→ For USB suppression –

→ Change position of carrier source.



FREQUENCY MODULATION

→ Here, frequency of carrier varies in accordance with info signal.

→ Amplitude of carrier remain constant.

→ **Advantages –**

- Better noise immunity
- Improved system fidelity
- More efficient use of power.

→ **Disadvantages –**

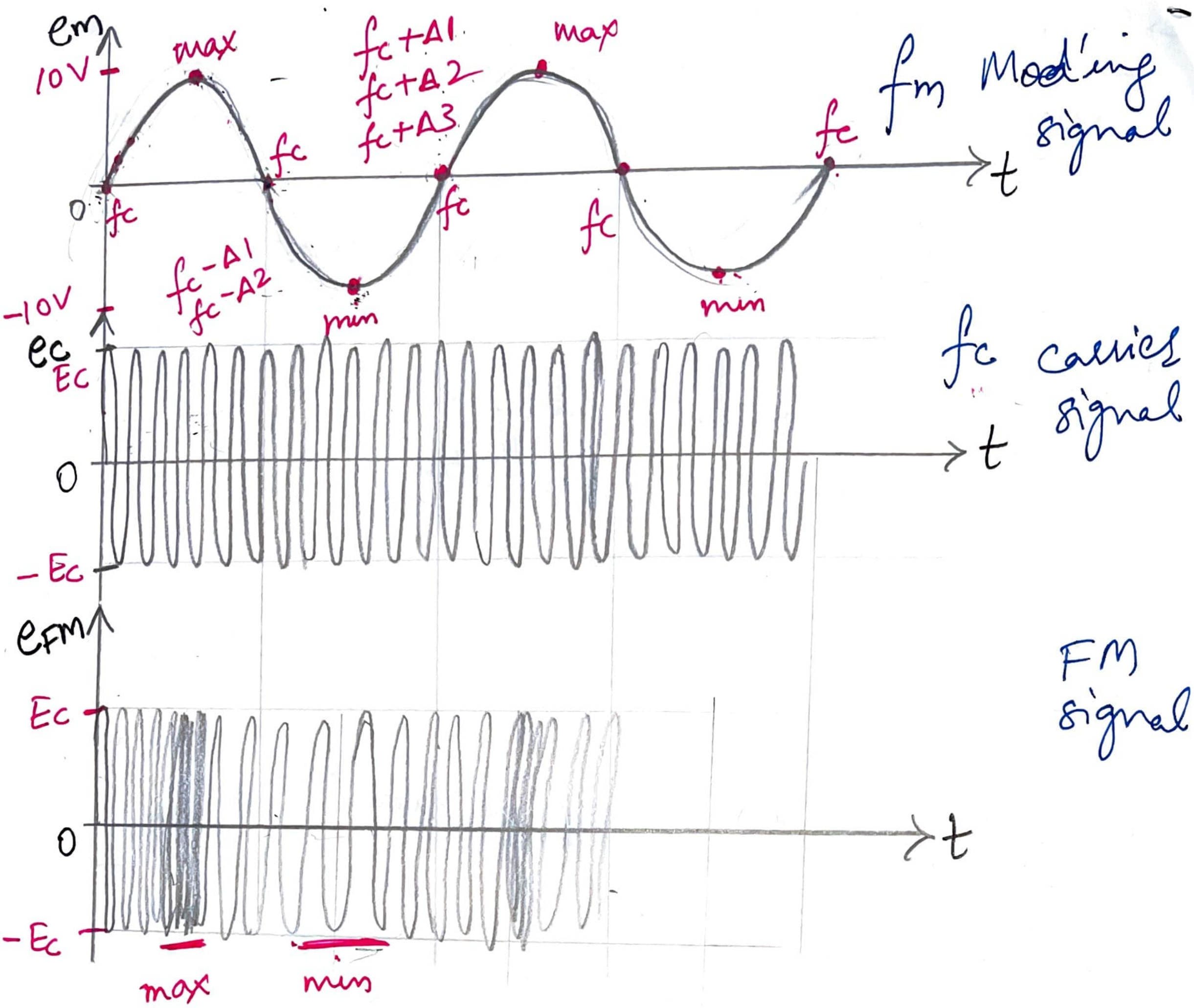
- Increased BW.
- Use of more complex circuits.

→ **Applications –**

- Radio Broadcasting.
- TV sound transmission
- Cellular radio.
- Microwave communication
- Satellite communication

→ **Definition of FM –**

→ In FM, the instantaneous frequency of the carrier is varied in proportion to the amplitude variation of modulating signal; i.e. information is conveyed via frequency changes.



→ ══

$f_c = 100 \cdot kHz$

$f_c + f_1$

$f_c + f_2$

$f_c + f_3$

⋮

$f_c + f_{10}$

$f_1 = 1\,kHz$

$f_2 = 2\,kHz$

⋮

$f_{10} = \underline{10\,kHz}$

$f_{max} = 100 + 10\,kHz = 110\,kHz$

$f_{min} = 100 - 10\,kHz = 90\,kHz$

$f_1 = 0.5\,kHz$

$f_2 = 1\,kHz$

⋮

$f_{10} = 5\,kHz$

$f_{max} = 105\,kHz$

$f_{min} = 95\,kHz$

Max. dev.	
10kHz	5kHz
δ	δ

→ The amount by which carrier frequency varies from its unmodulated value is called deviation (δ)

i.e. $f_{\substack{max \\ min}} = f_c \pm \delta$

→ $\delta \propto$ instantaneous value of modulating voltage

→ The rate at which frequency variation takes place = modulating frequency (f_m)

→ MATHEMATICAL REPRESENTATION OF FM –

→ Two important terminology –

I. Modulation Index –

$$m_f = \frac{\text{frequency deviation}}{\text{mod' ing frequency}} = \frac{\delta}{f_m}$$

Typical values = 5 - 2500 ($m_f >> 1$)

→ It decides BW of FM wave, i.e. decides number of sidebands having significant amplitudes

II. Deviation Ratio –

In FM Broadcasting, max. value of deviation is limited to 75 KHz

Also, max. mod'ing frequency limited to 15 KHz.

→ Modulation index corresponding to max. deviation & max. mod'ing frequency is called deviation ratio

i.e. Deviation Ratio $= \dfrac{\text{Max. deviation}}{\text{Max. mod'ing frequency}}$

→ MATHEMATICAL EXPRESSION –

→ We know that unmodulated carrier,

$$e_c = E_c \sin w_c t$$

In FM, frequency f of FM wave varies in accordance with modulating voltage.

$$f = f_c + K_{fc} E_m \cos w_m t$$

→ Max. freq deviation corresponds to values of $\cos w_m t = \pm 1$

∴ corresponding value of –

$$f = f_c + K f_c E_m \rightarrow \text{max. deviation}$$

where, K_{fc} → frequency sensitivity

→ We know, FM wave is a sine wave, amplitude of which is constant and angular velocity is a function of w_c & w_m

$$e_{FM} = E_c \sin [F(w_c, w_m)]$$

$$e_{FM} = E_c \sin \theta$$

Here, $\theta = F[w_c, w_m]$

Expln

$5 \sin \theta \quad | \quad \theta = wt$

→ $E_c \sin \theta$ is a rotating vector.

If E_c is rotating at a constant velocity, w, then $\theta = wt$

→ But, in FM, this velocity is not constant, it is changing continuously.

→ We know,

$$f = f_c + k f_c E_m \cos w_m t$$

$$\Rightarrow w = w_c + k w_c E_m \cos w_m t$$

$$w = w_c [1 + k E_m \cos w_m t]$$

→ $$\theta = \int w \cdot dt = \int w_c [1 + k E_m \cos w_m t] \cdot dt$$

$$= w_c \left[t + \frac{k E_m}{w_m} \sin w_m t \right]$$

$$= w_c t + \frac{k E_m w_c}{w_m} \sin w_m t$$

$$= w_c t + \underbrace{\frac{k E_m f_c}{f_m}}_{\delta} \sin w_m t$$

$$\theta = w_c t + \frac{\delta}{f_m} \sin w_m t$$

$$\theta = w_c t + m_f \sin w_m t$$

$$\therefore e_{FM} = E_c \sin \theta$$

$$\boxed{e_{FM} = E_c \sin [w_c t + m_f \sin w_m t]}$$

→ Frequency Spectrum of FM wave –

→ Expression of FM wave is not simple.

→ It is complex since it is a sine of a sine function.

→ Using Bessel's function, eqn for FM can be –

carrier

$$e_{FM} = E_c \{ J_0(m_f) \sin w_c t$$
$$+ \underbrace{J_1(m_f)}_{\text{ampl}} [\sin(w_c + w_m)t - \sin(w_c - w_m)t]$$
$$+ \underbrace{J_2(m_f)}_{\text{ampl}} [\sin(w_c + 2w_m)t + \sin(w_c - 2w_m)t]$$
$$+ \underbrace{J_3(m_f)}_{\text{ampl}} [\sin(w_c + 3w_m)t \mp \sin(w_c - 3w_m)t]$$
$$+ \dots \}$$

= carrier + ∞ S.Bs.

→ Observations –

→ FM wave consists of carrier and infinite sidebands.

→ Amplitude of carrier and sideband is dependent of J coefficients.

→ Values of these coefficients are given in a standard table or graph.

mf	Order of Function						
	J_0	J_1	J_2	J_3	J_4	J_5	....
0.00	1.0	–	–	–	–	–	
0.25	0.98	0.12	–	–	–	–	
0.50	0.97	0.24	0.03	–	–	–	
1.0	0.77	0.44	0.11	0.02	–	–	

→ J coeff. are dependent of mf.
mf det. how many SB have significant amplitude.

→ –ve J coeff. ⇒ 180° phase shift for that SB.

→ Carrier component does not remain constant.
As J_0 (mf) varies ⇒ amplitude of carrier varies.

→ But... amplitude of FM wave will remain constant for a given mf.

∴ If E_c is the amplitude of FM wave for a given m_f (It will remain constant)

∴ Total power transmitted will also remain constant.

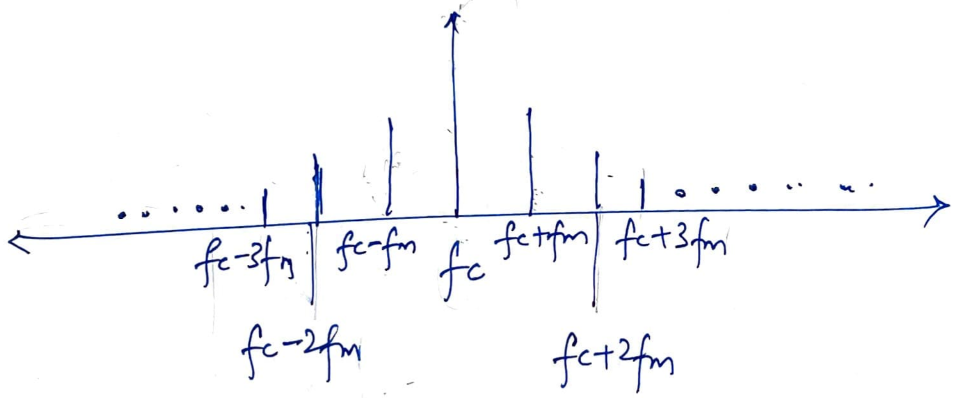
$$P_t = \frac{\left(E_c/\sqrt{2}\right)^2}{R} = \frac{E_c^2}{2R}$$

→ <u>Bandwidth</u>

<u>Freq. Spectrum</u>

Theoretically, ∞ SBs.

⇒ BW is ∞



More m_f ⇒ more significant SB

⇒ more BW.

(As ampl. of mod'ing signal varies, freq changes)

No. of SBs produced & their ampl. will change

So,

$$BW = 2f_m \times \text{No. of significant SBs}$$

→ Practically, we use CARSON'S RULE

$$BW = 2\left[\delta + f_{m(max)}\right]$$

gives correct result, when $m_f > 6$

If $m_f < 1$, then $BW = 2f_m$

NUMERICALS

Q1. An FM wave is represented by –

$$e_{FM} = 10 \sin\left[5\times10^{8} t + 4 \sin 1250 t\right]$$

Find – (a) Carrier and modulating frequency

(b) modulation index

(c) max. deviation

(d) Power dissipated by this FM wave across $5\,\Omega$ resistor.

Soln: We know –

$$e_{FM} = E_c \sin\left[w_c t + m_f \sin w_m t\right]$$

(a) $E_c = 10\ V$ $\quad w_c = 5\times10^{8}$ $\quad m_f = 4$ $\quad R = 5\,\Omega$

$w_m = 1250$

$$f_c = \frac{w_c}{2\pi} = 79.57\ MHz$$

$$f_m = \frac{w_m}{2\pi} = 199\ Hz$$

(b) $m_f = 4$

(c) Max. deviation, $\delta_{max} = m_f \times f_m$

$$= 4\times199 = 796\ Hz$$

(d) Power dissipated by FM wave,

$$P = \frac{E_c^{2}}{2R} = \frac{10^2}{2\times5} = 10\ W$$

Q2: A sinusoidal modulating signal of amplitu… 5V and frequency of 2kHz is applied to an FM generator which has a frequency sensitivity of 40 Hz/V. Calculate frequency deviation, modulation and BW.

Soln: $E_m = 5V$ $\quad f_m = 2kHz$

Frequency sensitivity $= K_{fc} = 40\,Hz/V$

$\therefore \delta = K_{fc} E_m = 40 \times 5 = 200\,Hz$

$$m_f = \frac{\delta}{f_m} = \frac{200}{2000} = 0.1$$

$\because m_f < 1$

$BW = 2f_m = 2 \times 2000 = 4\,kHz$

Q3: In an FM system, if max. value of deviation is 75 kHz and the max. modulating frequency is 10 kHz. Calculate deviation ratio and BW using Carson's rule.

Soln: $$\text{Deviation Ratio} = \frac{\text{max. dev}}{\text{max. } f_m} = \frac{75\,kHz}{10\,kHz} = 7.5$$

$BW = 2\left[\delta_{max} + \text{max } f_m\right] = 2\left[75+10\right] = 170\,kHz$

Q4. A 20 MHz carrier is modulated by a 400 Hz modulating signal. The carrier voltage is 5 V and max. deviation is 10 KHz. Write down the mathematical expression for FM wave. If modulating frequency is increased to 2 kHz, keeping everything else constant, write down the new expression for FM.

Soln: $f_c = 20\ MHz$ $\qquad f_m = 400\ Hz$

$\omega_c = 2\pi f_c = 1.25 \times 10^8\ rad/sec$

$\omega_m = 2\pi f_m = 2513\ rad/sec$

$\delta = 10\ KHz$ $\qquad E_c = 5\ V$

$$m_f = \frac{\delta}{f_m} = \frac{10\ KHz}{400\ Hz} = 25$$

$$e_{fm} = E_c \sin[\omega_c t + m_f \sin \omega_m t]$$

$$= 5 \sin[1.25 \times 10^8 t + 25 \sin 2513 t]$$

Now, $f_m = 2\ kHz \Rightarrow \omega_m = 2\pi f_m = 12566.3\ rad/sec$

$$m_{f_{new}} = \frac{\delta}{f_m} = \frac{10\ KHz}{2\ KHz} = 5$$

$$e_{fm_{new}} = E_c \sin[1.25 \times 10^8 t + 5 \sin 12566.3 t]$$

[redacted]

→ Pre-emphasis and De-emphasis -

→ Pre-emphasis -

→ In FM, noise has a greater effect on higher modulating frequencies.

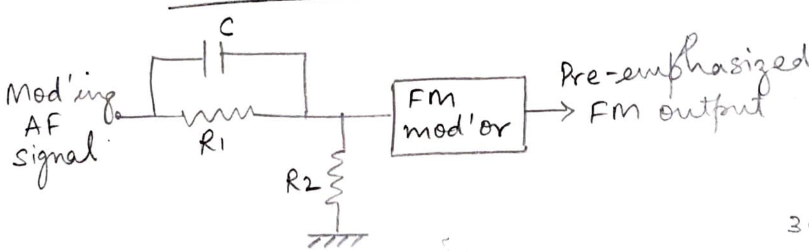
→ This effect can be reduced by increasing the value of mod. index (m_f) for higher modulating freq (f_m).

→ This can be done by increasing dev." δ " & δ can be increased by increasing amplitude of modulating signal at higher modulating frequencies.

→ Thus, if we boost the amplitude of higher frequency modulating signals artificially then it will be possible to improve the noise immunity at higher modulating frequencies.

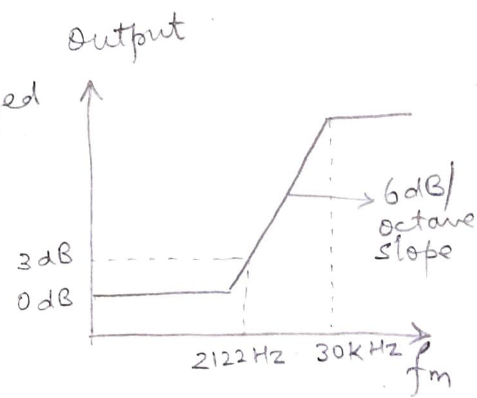
→ The artificial boosting of higher modulating frequencies is called as pre-emphasis.

Pre-emphasis Circuit



Pre-emphasis ckt. is basically a HPF.

Pre-emphasis char.



→ Mod'ing AF signal is passed through a high pass RC filter, before applying ~~to~~ it to FM modulator.

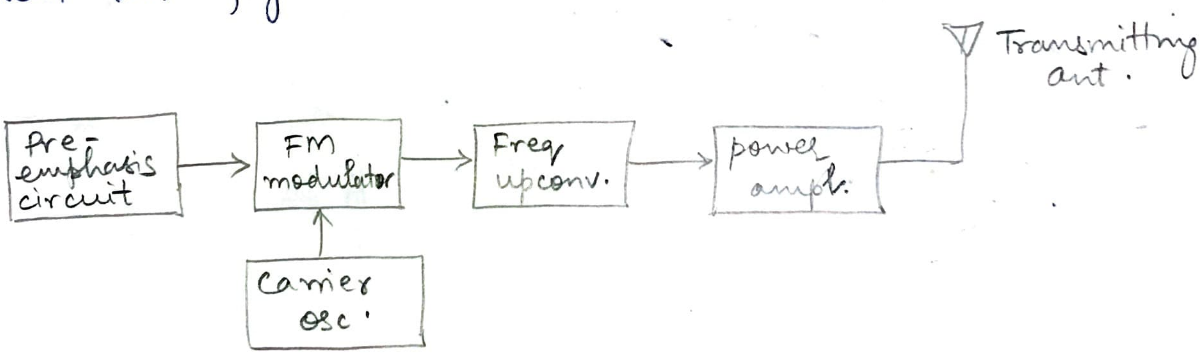
→ As fm inc, reactance of C dec. and mod'ing voltage applied to FM modulator goes on increasing.

→ Amt. of pre-emphasis in US FM Xmission and sound Xmission in TV is standardized at 75 μsec.

→ Pre-emphasis circuit is basically a HPF.

→ Pre-emphasis is carried out at Tx.

→ Thus, pre-emphasis ckt. is used at Tx as shown in fig. below –



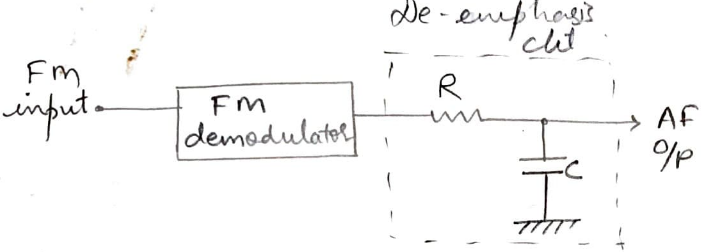
→ De-emphasis –

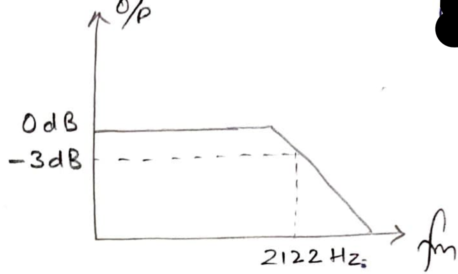
→ The artificial boosting given to higher modulating frequencies in the process of pre-emphasis is nullified or compensated at Rx by a process called de-emphasis.

→ The artificially boosted high freq. signals are brought to their original amplitude using de-emphasis ckt.

→ The 75 μsec de-emphasis ckt. is standard.

[redacted]





→ It is a LPF.

→ 75 μsec de-emphasis corresponds to a freq response curve that is 3dB down at a freq whose RC time constant is 75 μsec.

$$\text{ie. } f = \frac{1}{2\pi RC} = \frac{1}{2\pi \times 75 \times 10^{-6}} = 2122 \text{ HZ}$$

→ The demodulated FM is applied to de-emphasis ckt. With inc. in fm, reactance of C goes on dec. and o/p of de-emphasis ckt. will also reduce.

[redacted]

GENERATION OF FM WAVES

→ Two basic methods of generating FM waves –

I. Direct Methods

II. Indirect methods

→ Classification

- Direct
  - Reactance mod
  - Varactor diode mod
- Indirect
  - Armstrong method

→ Direct FM –

→ Inst. freq of carrier changed in ∝ message signal.

→ For this, VCO used.

→ VCO implemented using a sine osc. with a tuned ckt. having a high value of Q.

→ freq. of this osc. changed by incremental variation in reactive components involved in the tuned ckt.

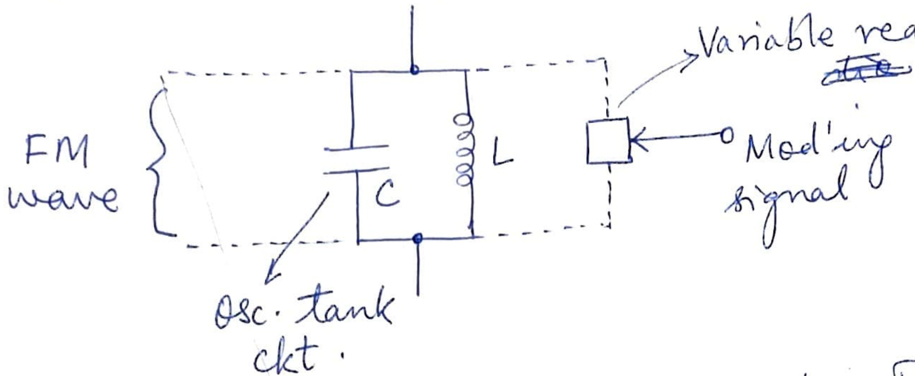
→ If L or C of a tuned ckt. of an osc. is changed in acc. with ampl. of mod'ing signal, ~~then~~ & then FM obtained across the tuned ckt.

→ A 2- or 3- terminal device is placed across the tuned ckt. The reactance of the device is varied ∝ mod'ing signal voltage.

→ This will vary the freq of the ~~s~~ osc. to produce FM.

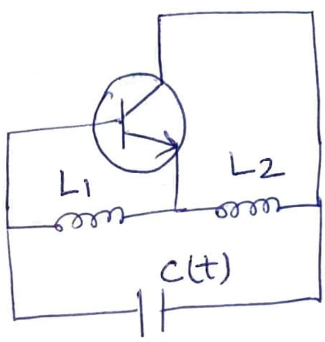
→ Devices used are FET, Transistor or Varactor diode.

→ Eg. Using Hartley osc. alongwith a varactor diode –



→ Varactor diode is rev. biased. Its C dep. on rev. V applied across it. This C is shown as C(t).

→ freq. of osc. of Hartley osc,



$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)\,C(t)}}$$

where,

$$C(t) = C + C_{varactor}$$

ie. $C(t)$ → effective C of fixed tuned ckt C (C) and varactor diode C ($C_{varactor}$).

→ Let the relation between mod'ing voltage $x(t) = 0$ and $C(t)$ be repr. as –

$$C(t) = C - k_c\, x(t)$$

C → total C when $x(t)$ and k_c is sensitivity of varactor capacitance to change in voltage.

→ Subs. expr. for $C(t)$,

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)(C-k_c x(t))}}$$

$$= \frac{1}{2\pi\sqrt{(L_1+L_2)C - (L_1+L_2)k_c x(t)}}$$

$$= \frac{1}{2\pi\sqrt{(L_1+L_2)C}\left[1 - \frac{k_c x(t)}{C}\right]^{1/2}}$$

[redacted]

→ But, $f_o = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$ which is osc. freq in absence of mod'ing signal [ie. $x(t) = 0$].

$$\therefore f_i(t) = f_o\left[1 - \frac{k_c}{C}x(t)\right]^{-1/2}$$

→ If max. change in C corresp. to mod'ing wave is assumed to be small as compared to unmod. C, then

$$f_i(t) = f_o\left[1 + \frac{k_c}{2C}x(t)\right]$$

$$\therefore f_i(t) = f_o + \frac{f_o k_c}{2C} \cdot x(t).$$

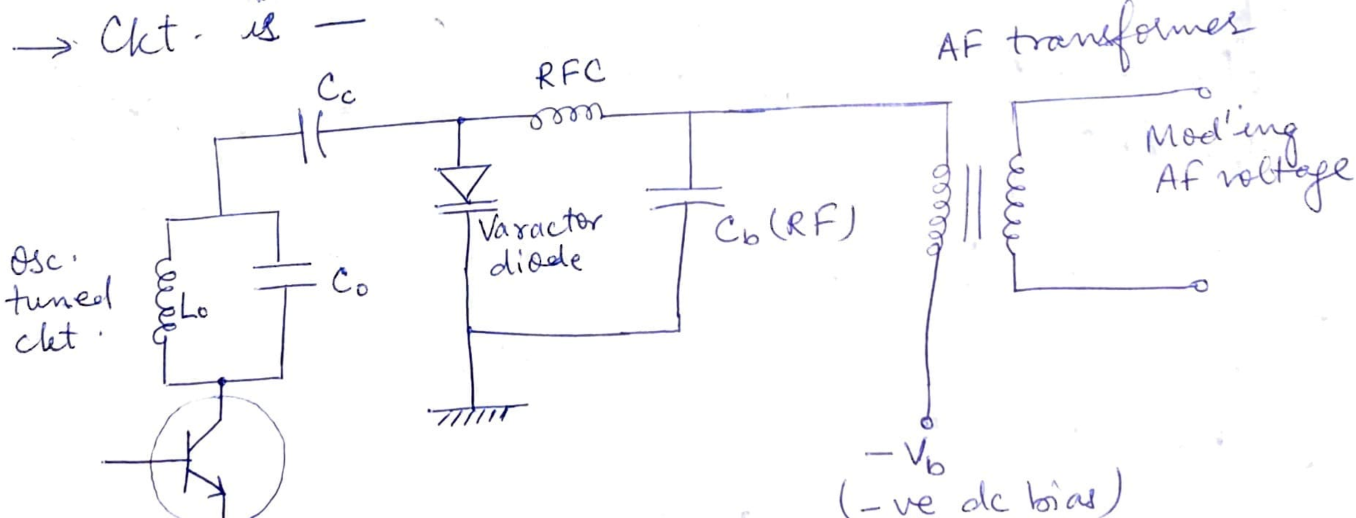
Let, $\frac{f_o k_c}{2C} = K_f$.

$$\therefore f_i(t) = f_o + k_f\, x(t)$$

where, k_f → freq. sensitivity of modulator.

→ Varactor Diode Modulator –

→ Ckt. is –



→ Varactor diode is a SC diode whose junc. C varies linearly with applied bias. must be RB.

→ Operation –

→ Varactor diode RB by –ve dc source, $-V_b$.

→ Mod'ing AF V, appears in series with $-V_b$.

→ ∴ V applied across VD varies ∝ mod'ing V.

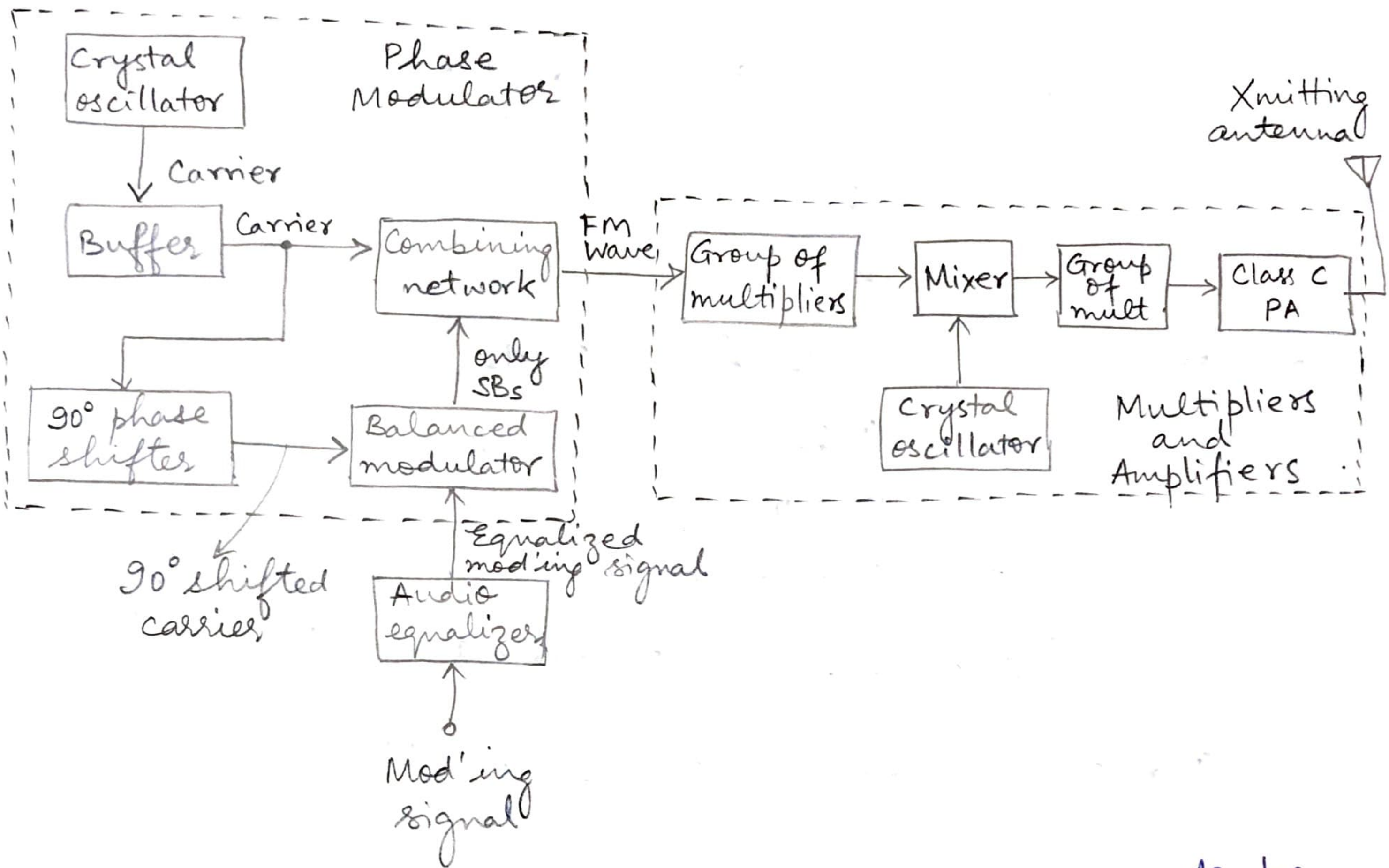
→ This will vary junc. C of VD. VD appears in ||
with osc. tuned ckt.

→ ∴ Osc. freq will change with change in VD - C
and FM is produced.

→ RFC will connect dc & mod'ing signal to VD but
offers a very high impedance at high osc. freq.

→ ∴ Osc. ckt. isolated from dc bias & mod'ing
signal.

→ Indirect Method [Armstrong Method] of FM gen –



→ In direct method of gen. of FM, LC osc. to be used. Crystal osc. cannot be used.

→ LC osc. not stable for comm. or broadcast purpose.

→ ∴ Direct methods cannot be used for broadcast applns.

→ ∴ We use indirect method or Armstrong method of FM generation.

→ In this method, FM is obtained through PM.

→ Crystal osc. can be used, ∴ freq. stability v. high.

[redacted]

→ Uses PM to gen. FM

→ This method can be understood by dividing it into 4 parts as follows –

I. Generation of FM from phase modulator
II. Implementation of phase modulator
III. Combining I & II to obtain FM
IV. Use of freq. multipliers and amplifiers.

→ Part - I –

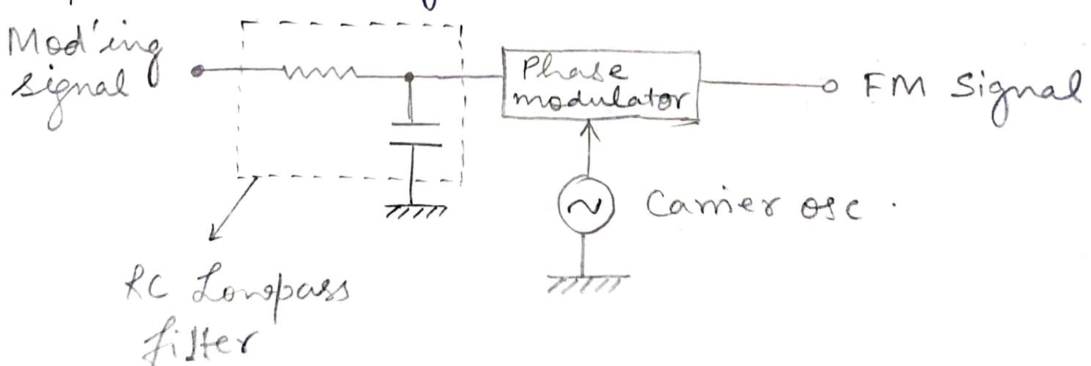
1) In PM, along with phase var, some freq var. also takes place.
Higher mod'ing voltages produce greater phase shift which in turn produces greater freq dev.

2) And higher mod'ing freq. produce a faster rate of change of mod'ing voltage, hence they also produce greater freq. dev.

3) Thus, in PM, carrier freq dev. is ∝ mod'ing voltage as well as mod'ing freq.

4) But, in FM, freq. dev. is only ∝ mod'ing voltage regardless of its freq.

5) To correct this problem, mod'ing signal is passed through a low pass RC filter (integrator)



Due to this hf mod'ing signals are attenuated but there is no change in amplitudes of lf mod'ing signals.

6) Filter output is then applied to a phase modulator alongwith carrier.

7) Hence, extra dev. in carrier fc due to higher mod'ing freq is compensated by reducing amplitude of hf mod'ing signals.

8) Hence, freq. dev. at output of phase modulator will be effectively $\propto$ only to mod'ing voltage and we obtain an FM wave at output of phase modulator.

→ Due to this arrangement, freq dev at O/P of phase modulator, corresponding to higher mod'ing freq. is reduced.
The result is FM produced by phase modulator.

9) Mathematical proof -
Consider expr. for PM wave -

$$e_{pm} = A \sin[w_c t + m_p \sin w_m t]$$

Let, $e_{pm} = A \sin \theta$
where, $\theta = [w_c t + m_p \sin w_m t]$

Instant. ang. freq of PM wave is defined as -

$$w_i = \frac{d\theta}{dt} = \frac{d}{dt}[w_c t + m_p \sin w_m t] = w_c + m_p \cos w_m t \times w_m$$

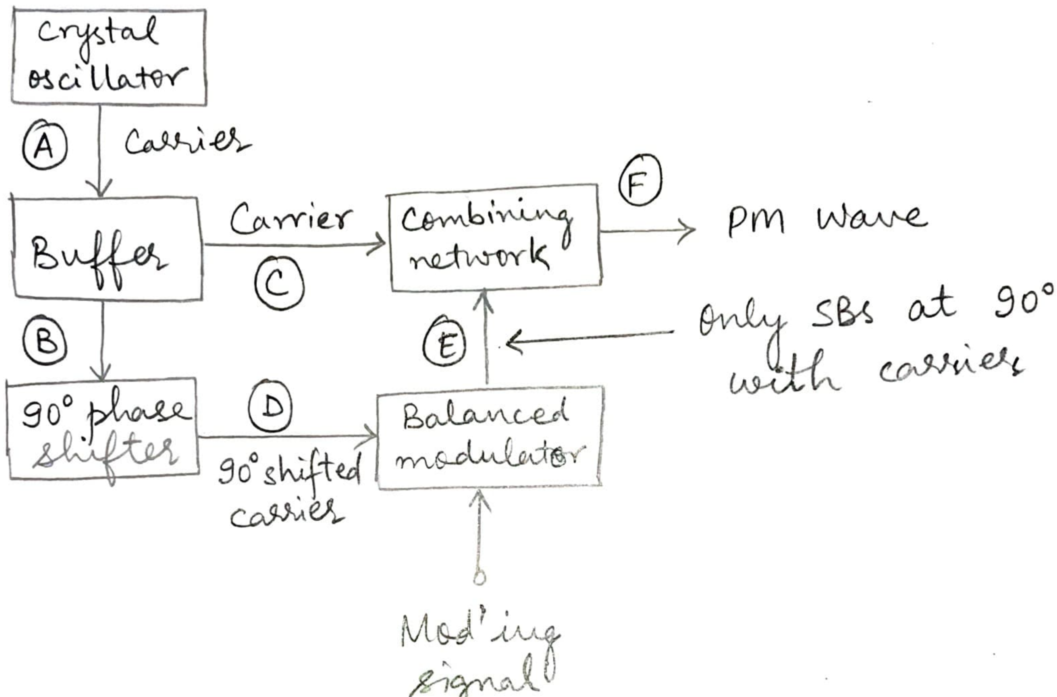
$$\therefore f_i = f_c + m_p f_m \cos w_m t$$

II term in RHS is freq dev., max. dev. given by-

$$\delta_{max} = f_m \times m_p$$

→ As $m_p \propto$ mod'ing voltage, f_i will vary in $\propto$ mod'ing voltage.
∴ Freq. mod. obtained using PM.

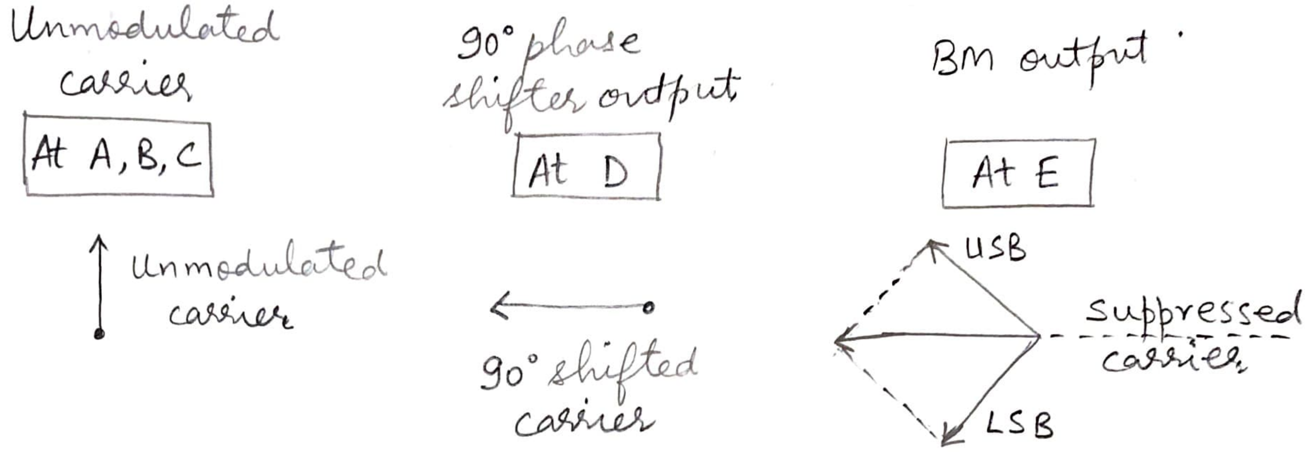
→ <u>Part - II</u> –

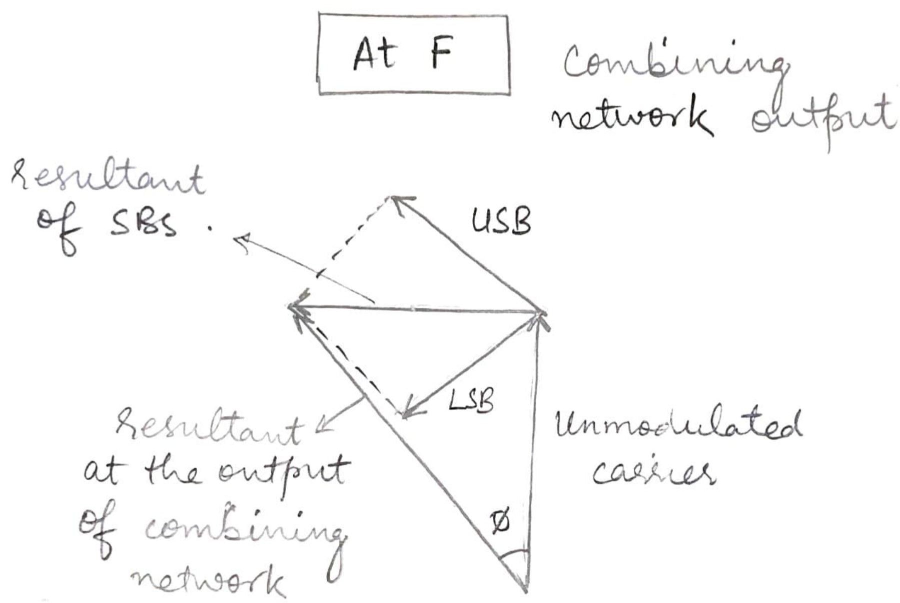


1) Crystal osc. produces a stable unmodulated carrier which is applied to "90° phase shifter" as well as "combining network" through a buffer.

2) 90° phase shifter produces a 90° phase shifted carrier.
It is applied to bal. mod. alongwith mod'ing signal.
Thus, the carrier used for modulation is 90° shifted wrt original carrier.

3) At output of BM, we get DSBSC signal.
The signal consists of only two SBs with their resultant in phase with the 90° shifted carrier.

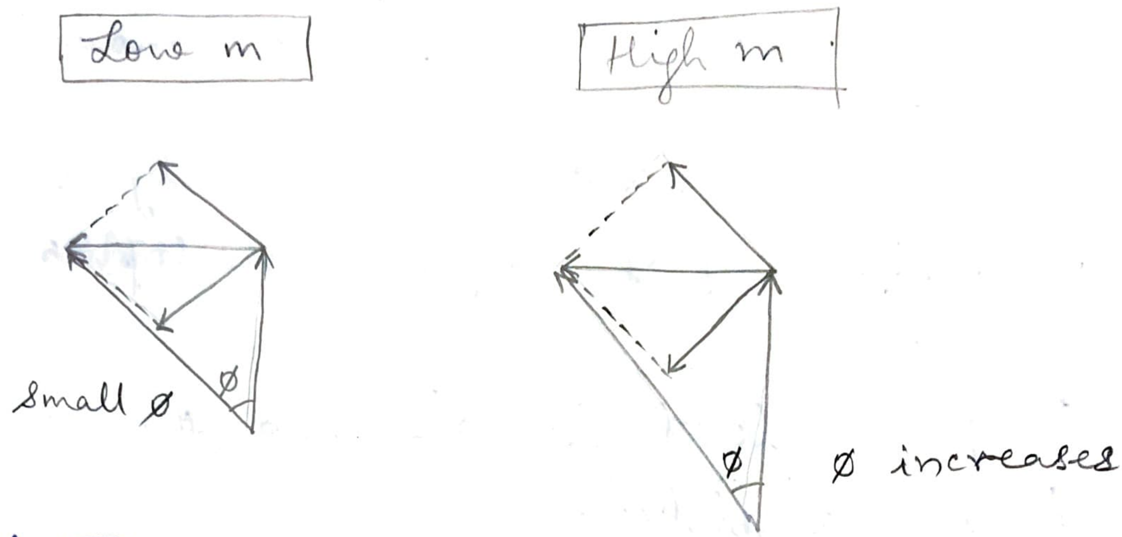




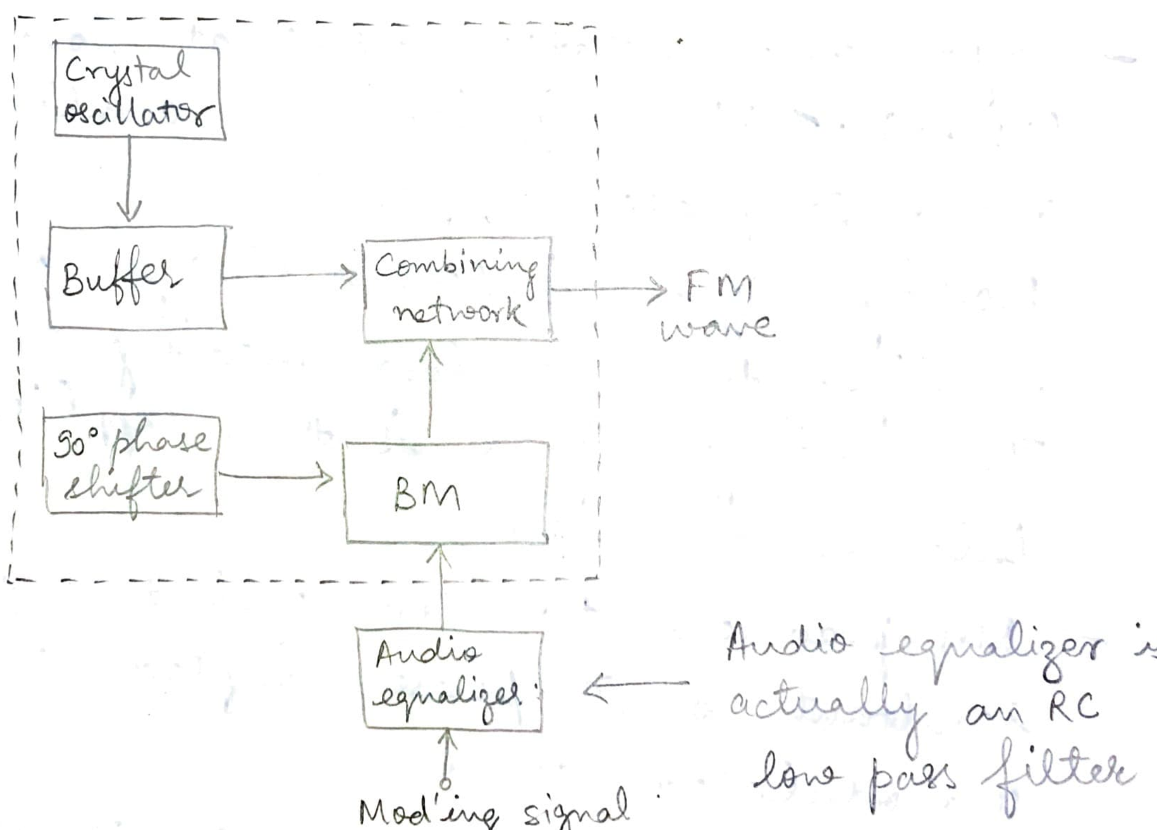
4) The two sidebands and their original carrier without any phase shift are applied to a combining network.
At the ~~out~~ output of a combining network, we get the resultant of vector addition of carrier and two sidebands.

5) Now, as m is increased, amplitude of SBs also inc. Hence, amplitude of their resultant increases. This will increase the angle "ø" made by the resultant with unmodulated carrier.
The angle "ø" decreases with reduction in m.

Thus, the resultant at output of combining network is phase modulated.



→ Part - III



→ Mod'ing signal passed through audio equalizing ckt. and applied to phase modulator ckt.

→ We get FM wave at output of combining network.

→ Part - IV

→ FM signal produced at output of phase modulator has a low carrier freq and low modulation index.
They are increased to an adequately high value with the help of frequency multipliers and mixer.
The power level is raised to the desired level by the amplifier.

→ SUMMARY —

- Crystal osc. generates carrier at low freq (1 MHz). This is applied to a combining N/w and a 90° phase shifter.
- Mod'ing signal is passed through an audio equalizer to boost low mod'ing freq. The mod'ing signal is then applied to a balanced modulator.
- BM produces two SBs such that their resultant is 90° phase shifted wrt unmodulated carrier.
- Un modulated carrier and 90° ~~phase~~ shifted SBs are added in the combining network.
- At the O/p of the combining N/w, we get an FM wave. This FM wave has a low carrier freq, f_c and low value of mod. index m_f.

[redacted]

- f_c and m_f are then raised by passing FM wave through first group of multipliers. Carrier freq. is then raised by using a mixer and then f_c and m_f both are raised to reqd. high values using second group of multipliers.
- FM signal with high f_c and high m_f is then passed through a class C - PA to raise power level of FM signal.

FM DEMODULATION

In FM demodulators, the intelligence to be recovered is not in amplitude variations; it is in the *variation of the instantaneous frequency* of the carrier, either above or below the centre frequency. The detecting device must be constructed so that its output amplitude will vary linearly according to the instantaneous frequency of the incoming signal.

Several types of FM detectors have been developed and are in use, we study two of the most common: (1) Phase-shift detector, (2) Ratio detector.

SLOPE DETECTION

To be able to understand the principles of operation for FM detectors, we need to first study the simplest form of frequency-modulation detector, the **SLOPE DETECTOR**. The slope detector is essentially a tank circuit which is tuned to a frequency either slightly above or below the FM carrier frequency. Figure 1 is a plot of voltage versus frequency for a tank circuit. The resonant frequency of the tank is the frequency at point 4. Components are selected so that the resonant frequency is higher than the frequency of the FM carrier signal at point 2. The entire frequency deviation for the FM signal falls on the lower slope of the bandpass curve between points 1 and 3. As the FM signal is applied to the tank circuit in Figure 2, the output amplitude of the signal varies as its frequency swings closer to, or further from, the resonant frequency of the tank. Frequency variations will still be present in this waveform, but it will also develop amplitude variations, as shown in Figure 2. This is because of the response of the tank circuit as it varies with the input frequency. This signal is then applied to the diode detector in Figure 3 and the detected waveform is the output. This circuit has the major disadvantage that any amplitude variations in the rf waveform will pass through the tank circuit and be detected. This disadvantage can be eliminated by placing a limiter circuit before the tank input. This circuit is basically the same as an AM detector with the tank tuned to a higher or lower frequency than the received carrier.

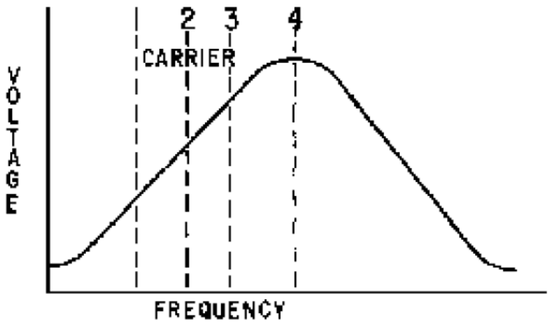


Figure 1 Slope detector - VOLTAGE VERSUS FREQUENCY PLOT

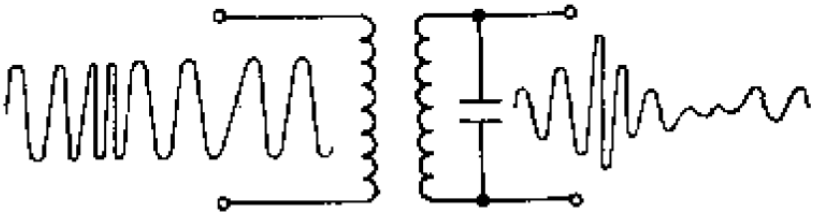


Figure 2 Slope detector - TANK CIRCUIT

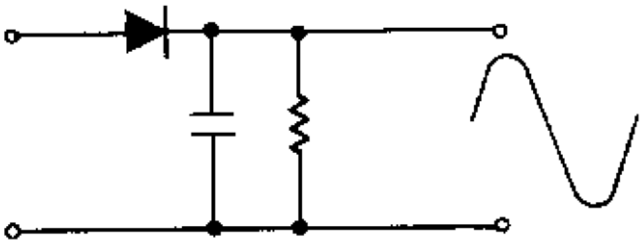


Figure 3 Slope detector - DIODE DETECTOR

FOSTER-SEELEY DISCRIMINATOR

The Foster-Seeley Discriminator is also known as the Phase-Shift Discriminator. It uses a double-tuned rf transformer to convert frequency variations in the received FM signal to amplitude variations. These amplitude variations are then rectified and filtered to provide a dc output voltage. This voltage varies in both amplitude and polarity as the input signal varies in frequency. A typical discriminator response curve is shown in Figure 4. The output voltage is 0 when the input frequency is equal to the carrier frequency (fr). When the input frequency rises above the centre frequency, the output increases in the positive direction. When the input frequency drops below the centre frequency, the output increases in the negative direction. The output of the Foster-Seeley discriminator is affected not only by the input frequency, but also to a certain extent by the input amplitude. Therefore, using limiter stages before the detector is necessary.

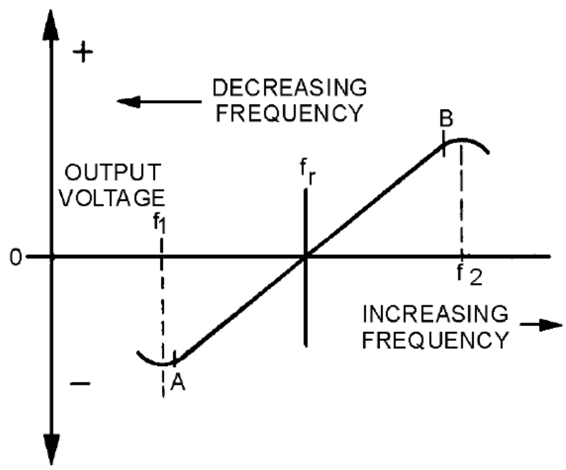


Figure 4 Discriminator response curve

Circuit Operation of a Foster-Seeley Discriminator

Figure 5 shows a typical Foster-Seeley discriminator. The collector circuit of the preceding limiter/ amplifier circuit (Q1) is shown. The limiter/amplifier circuit is a special amplifier circuit which limits the amplitude of the signal. This limiting keeps interfering noise low by removing excessive amplitude variations from signals. The collector circuit tank consists of C1 and L1. C2 and L2 form the secondary tank circuit. Both tank circuits are tuned to the centre frequency of the incoming FM signal. Choke L3 is the dc return path for diode rectifiers CR1 and CR2. R1 and R2 are not always necessary but are usually used when the back (reverse bias) resistance of the two diodes is different. Resistors R3 and R4 are the load resistors and are bypassed by C3 and C4 to remove rf. C5 is the output coupling capacitor.

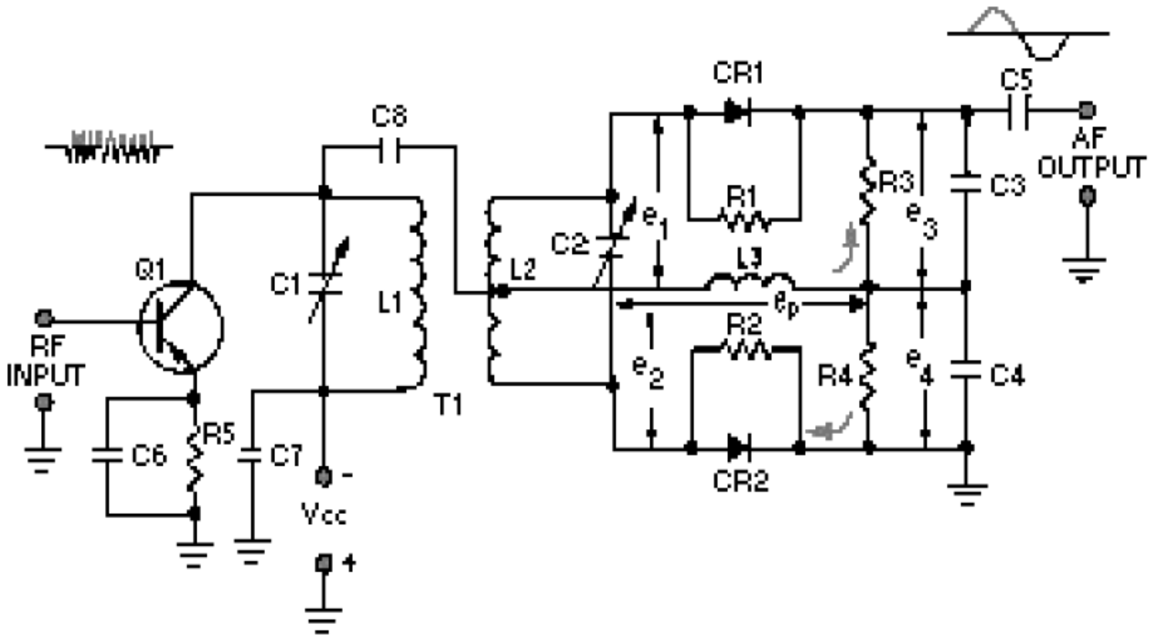


Figure 5 Foster-Seeley Discriminator

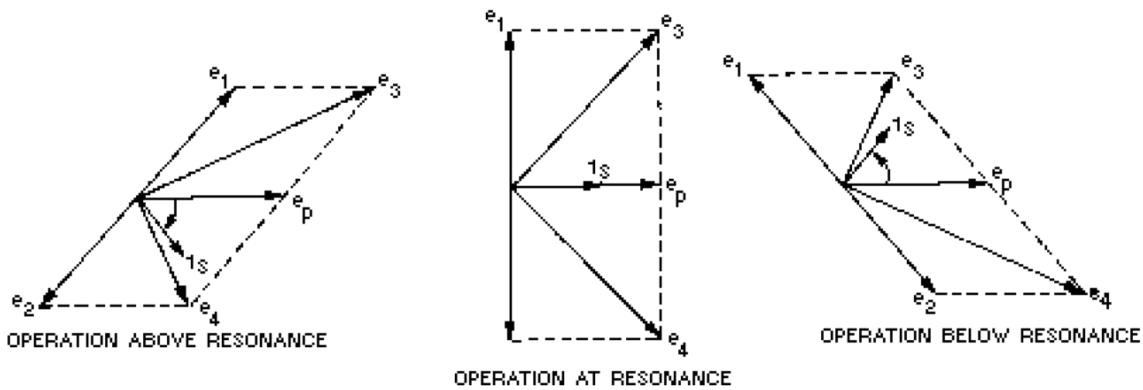


Figure 6 Vectors - Foster-Seeley Discriminator

CIRCUIT OPERATION AT RESONANCE

The operation of the Foster-Seeley discriminator can best be explained using vector diagrams [Figure 6] that show phase relationships between the voltages and currents in the circuit. Let's look at the phase relationships when the *input frequency is equal to the centre frequency* of the resonant tank circuit. The input signal applied to the primary tank circuit is shown as vector ep. Since coupling capacitor C8 has negligible reactance at the input frequency, rf choke L3 is effectively in parallel with the primary tank circuit. Also, because L3 is effectively in parallel with the primary tank circuit, input voltage ep also appears across L3. With voltage ep applied to the primary of T1, a voltage is induced in the secondary which causes current to flow in the secondary tank circuit. When the input frequency is equal to the centre frequency, the tank is at resonance and acts resistive. Current and voltage are in phase in a resistance circuit, as shown by is and ep. The current flowing in the tank causes voltage drops across each half of the balanced secondary winding of transformer T1. These voltage drops are of equal amplitude and opposite polarity with respect to the centre tap of the winding. Because the winding is inductive, the voltage across bit is 90 degrees out of phase with the current through it. Because of the centre-tap arrangement, the voltages at each end of the secondary winding of T1 are 180 degrees out of phase and are shown as e1 and e2 on the vector diagram.

The voltage applied to the anode of CR1 is the vector sum of voltages ep and e1, shown as e3 on the diagram. Likewise, the voltage applied to the anode of CR2 is the vector sum of voltages ep and e2, shown as e4 on the diagram. At resonance e3 and e4 are equal, as shown by vectors of the same length.

Equal anode voltages on diodes CR1 and CR2 produce equal currents and, with equal load resistors, equal and opposite voltages will be developed across R3 and R4. The output is taken across R3 and R4 and will be 0 at resonance since these voltages are equal and of appositive polarity.

The diodes conduct on opposite half cycles of the input waveform and produce a series of dc pulses at the rf rate. This rf ripple is filtered out by capacitors C3 and C4.

OPERATION ABOVE RESONANCE

A phase shift occurs when an *input frequency higher than the centre frequency* is applied to the discriminator circuit and the current and voltage phase relationships change. When a series-tuned circuit operates at a frequency above resonance, the inductive reactance of the coil increases and the capacitive reactance of the capacitor decreases. Above resonance the tank circuit acts like an inductor. Secondary current lags the primary tank voltage, ep. Notice that secondary voltages e1 and e2 are still 180 degrees out of phase with the current (i_S) that produces them. The change to a lagging secondary current rotates the vectors in a clockwise direction. This causes e_l to become more in phase with ep while e2 is shifted further out of phase with ep. The vector sum of ep and e2 is less than that of ep and e1. Above the centre frequency, diode CR1 conducts more than diode CR2. Because of this heavier conduction, the voltage developed across R3 is greater than the voltage developed across R4; the output voltage is positive.

OPERATION BELOW RESONANCE

When the *input frequency is lower than the centre frequency*, the current and voltage phase relationships change. When the tuned circuit is operated at a frequency lower than resonance, the capacitive reactance increases and the inductive reactance decreases. Below resonance the tank acts like a capacitor and the secondary current leads primary tank voltage ep. This change to a leading secondary current rotates the vectors in a *counter-clockwise* direction. From the vector diagram you should see that e2 is brought nearer in phase with ep, while e_l is shifted further out of phase with ep. The vector sum of ep and e2 is larger than that of e and e1. Diode CR2 conducts more than diode CR1 below the centre frequency. The voltage drop across R4 is larger than that across R3 and the output across both is negative.

Disadvantages

These voltage outputs can be plotted to show the response curve of the discriminator discussed earlier (Figure 5). When weak AM signals (too small in amplitude to reach the circuit limiting level) pass through the limiter stages, they can appear in the output. These unwanted amplitude variations will cause primary voltage ep [Figure 5] to fluctuate with the modulation and to induce a similar voltage in the secondary of T1. Since the diodes are connected as half-wave rectifiers, these small AM signals will be detected as they would be in a diode detector and will appear in the output. This unwanted AM interference is cancelled out in the ratio detector and is the main disadvantage of the Foster-Seeley circuit.

RATIO DETECTOR

The Ratio Detector uses a double-tuned transformer to convert the instantaneous frequency variations of the FM input signal to instantaneous amplitude variations. These amplitude variations are then rectified to provide a dc output voltage which varies in amplitude and polarity with the input signal frequency. This detector demodulates FM signals and suppresses amplitude noise without the need of limiter stages.

Circuit Operation

Figure 7 shows a typical ratio detector. The input tank capacitor (C1) and the primary of transformer T1 (L1) are tuned to the centre frequency of the FM signal to be demodulated. The secondary winding of T1 (L2) and capacitor C2 also form a tank circuit tuned to the centre frequency. Tertiary (third) winding L3 provides additional inductive coupling which reduces the loading effect of the secondary on the primary circuit. Diodes CR1 and CR2 rectify the signal from the secondary tank.
Capacitor C5 and resistors R1 and R2 set the operating level of the detector. Capacitors C3 and C4 determine the amplitude and polarity of the output. Resistor R3 limits the peak diode current and furnishes a dc return path for the rectified signal. The output of the detector is taken from the common connection between C3 and C4. Resistor RL is the load resistor. R5, C6, and C7 form a low-pass filter to the output.

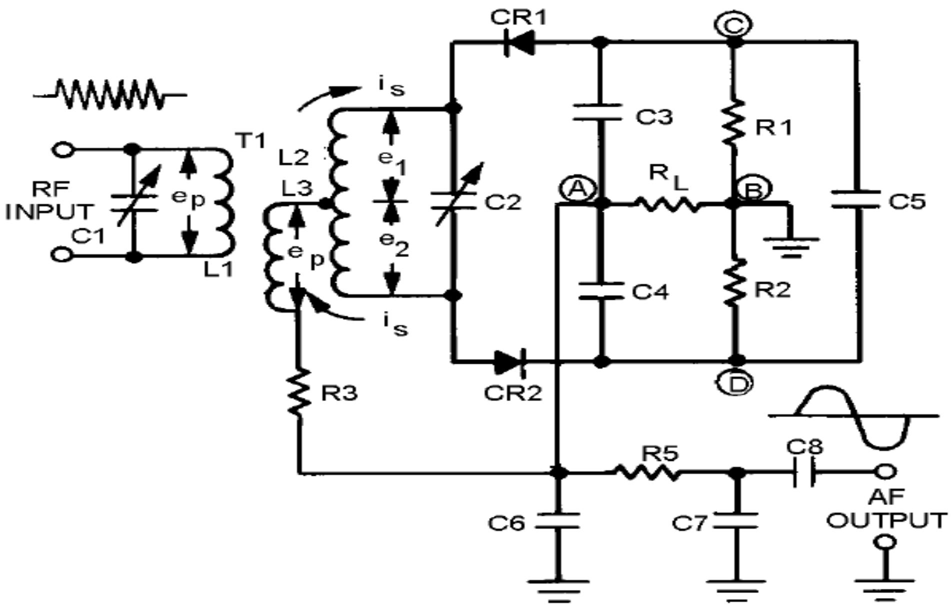


Figure 7 - Ratio detector

This circuit operates on the same principles of phase shifting as did the Foster-Seeley discriminator. In that discussion, vector diagrams were used to illustrate the voltage amplitudes and polarities for conditions at resonance, above resonance, and below resonance. The same vector diagrams apply to the ratio detector but will not be discussed here. Instead, you will study the resulting current flows and polarities on simplified schematic diagrams of the detector circuit.

OPERATION AT RESONANCE

When the input voltage ep is applied to the primary in Figure 7, it also appears across L3 because, by inductive coupling, it is effectively connected in parallel with the primary tank circuit. At the same time, a voltage is induced in the secondary winding and causes current to flow around the secondary tank circuit. At resonance the tank acts like a resistive circuit; that is, the tank current is in phase with the primary voltage e_p. The current flowing in the tank circuit causes voltages e_1 and e_2 to be developed in the secondary winding of T1. These voltages are of equal magnitude and of opposite polarity with respect to the centre tap of the winding. Since the winding is inductive, the voltage drop across it is 90 degrees out of phase with the current through it.

Figure 8 is a simplified schematic diagram of a ratio detector at resonance. The voltage applied to the cathode of CR1 is the vector sum of e_1 and e_p. Likewise, the voltage applied to the anode of CR2 is the vector sum of e_2 and e_p. No phase shift occurs at resonance and both voltages are equal. Both diodes conduct equally. This equal current flow causes the same voltage drop across both R1 and R2. C3 and C4 will charge to equal voltages with opposite polarities. Let's assume that the voltages across C3 and C4 are equal in amplitude (5 volts) and of opposite polarity and the total charge across C5 is 10 volts. R1 and R2 will each have 5 volts dropped across them because they are of equal values. The output is taken between points A and B. To find the output voltage, you algebraically add the voltages between points A and B (loop ACB or ADB). Point A to point D is −5 volts. Point D to point B is +5 volts. Their algebraic sum is 0 volts and the output voltage is 0 at resonance. If the voltages on branch ACB were figured, the same output would be found because the circuit branches are in parallel.

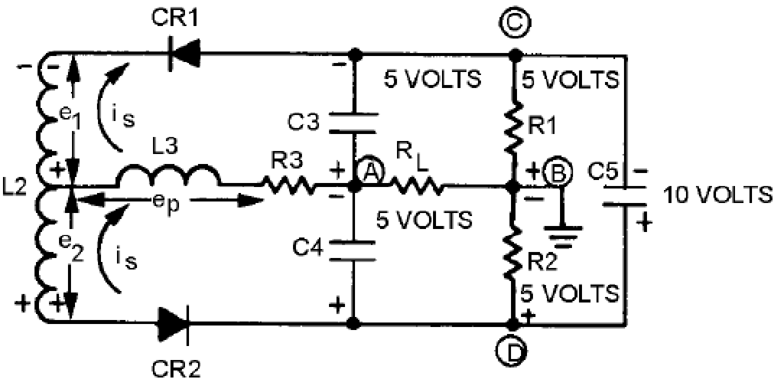


Figure 8 Current flow and polarities at resonance

When the input signal reverses polarity, the secondary voltage across L2 also reverses. The diodes will be reverse biased and no current will flow. Meanwhile, C5 retains most of its charge because of the long time constant offered in combination with R1 and R2. This slow discharge helps to maintain the output.

OPERATION ABOVE RESONANCE

When a tuned circuit (Figure 9) operates at a frequency higher than resonance, the tank is inductive. The secondary current i lags the primary voltage e_p. Secondary voltage e_1 is nearer in phase with primary voltage e, while e_2 is shifted further out of phase with e_p. The vector sum of e_1 and e_p is larger than that of e_2 and e_p. Therefore, the voltage applied to the cathode of CR1 is greater than the voltage applied to the anode of CR2 above resonance.

Assume that the voltages developed above resonance are such that the higher voltage on the cathode of CR1 causes C3 to charge to 8 volts. The lower voltage on the anode of CR2 causes C4 to charge to 2 volts. Capacitor C5 remains charged to the sum of these two voltages, 10 volts. Again, by adding the voltages in loop ACB or ADB between points A and B, you can find the output voltage. Point A to point D equals -2 volts. Point D to point B equals +5 volts. Their algebraic sum, and the output, equals +3 volts when tuned above resonance. During the negative half cycle of the input signal, the diodes are reverse biased and C5 helps maintain a constant output.

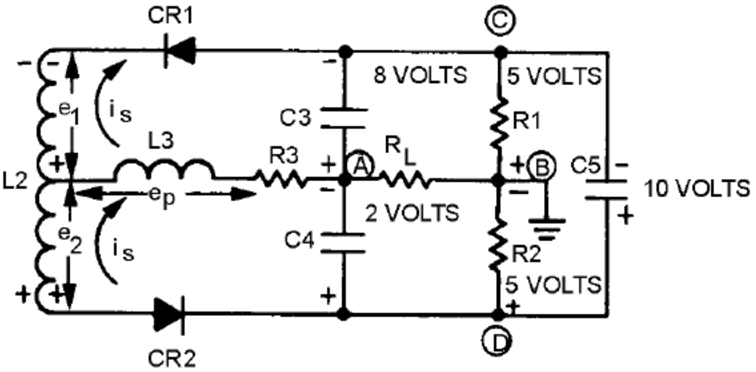


Figure 9 Current flow and polarities above resonance

OPERATION BELOW RESONANCE

When a tuned circuit operates below resonance (Figure 10), it is capacitive. Secondary current is leads the primary voltage e_p and secondary voltage e_2 is nearer in phase with primary voltage e_p. The vector sum of e_2 and e_p is larger than the sum of e_1 and e_p. The voltage applied to the anode of CR2 becomes greater than the voltage applied to the cathode of CR1 below resonance.

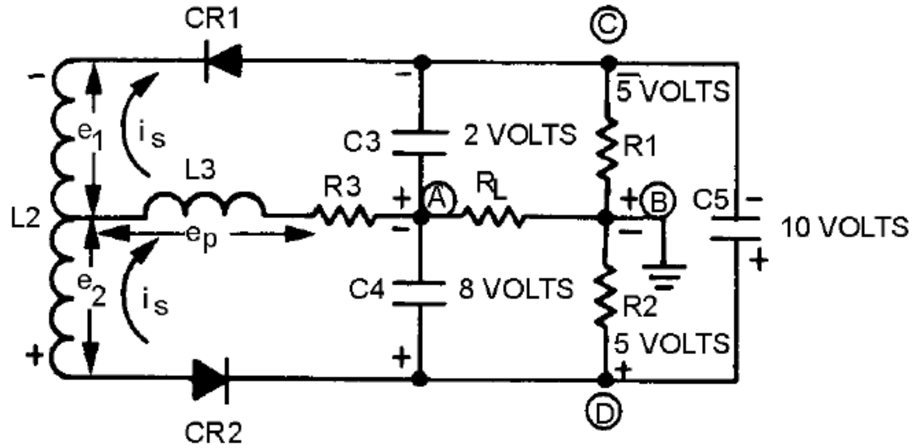


Figure 10 Current flow and polarities below resonance

Assume that the voltages developed below resonance are such that the higher voltage on the anode of CR2 causes C4 to charge to 8 volts. The lower voltage on the cathode of CR1 causes C3 to charge to 2 volts. Capacitor C5 remains charged to the sum of these two voltages, 10 volts. The output voltage equals −8 volts plus +5 volts, or −3 volts, when tuned below resonance. During the negative half cycle of the input signal, the diodes are reverse biased and C5 helps maintain a constant output.

Advantage of a Ratio Detector

The ratio detector is not affected by amplitude variations on the FM wave. The output of the detector adjusts itself automatically to the average amplitude of the input signal. C5 charges to the sum of the voltages across R1 and R2 and, because of its time constant, tends to filter out any noise impulses. Before C5 can charge or discharge to the higher or lower potential, the noise disappears. The difference in charge across C5 is so slight that it is not discernible in the output. Ratio detectors can operate with as little as 100 millivolts of input. This is much lower than that required for limiter saturation and less gain is required from preceding stages.

Reference: https://www-elec.inaoep.mx/~rogerio/DemodulationGeneral.pdf