The Communication Process

"Communication is the process of establishing connection (or link) between two points for Information exchange."

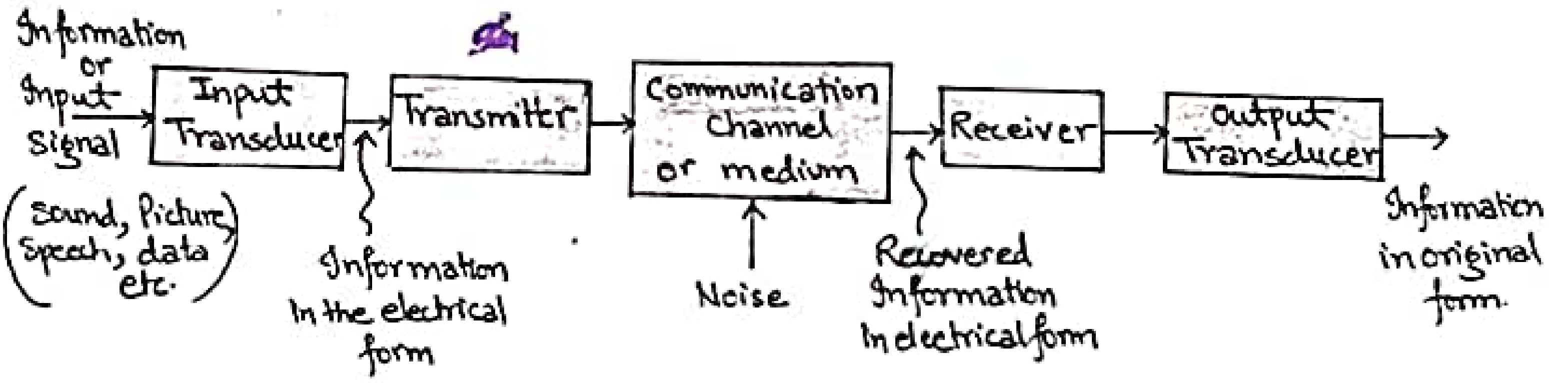
For communication to take place, three essential things must be required. i.e.,

1) Sender or Transmitter :- It send Information. For example TV transmitting station, Radio transmitting station (since, they transmit Information)

2) Receiver : It receives Information. For example TV sets & Radio. (They give Information from transmitter)

3) Communication Channel : This is the path through which the signal propagates from transmitter to receiver.

ELEMENTS OF COMMUNICATION SYSTEMS



The elements of communication systems are as follows:-

1) Information
2) Transmitter
3) Communication channel or medium
4) Noise
5) Receiver

Information: The communication systems communicate messages. The message comes from the information sources. It may contain human voice, picture, data, music & their combination

Input Transducer: Ex. Microphones, TV camera etc.

Transmitter: The transmitter is a collection of electronic circuits designed to convert the information into a signal suitable for transmission over a given communication medium.

Communication Channel: The communication channel is the medium by which the electronic signal is transmitted from one place to another. Ex: conducting wire, coaxial cable, optical fibre cable or free space.

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Depending on the type of communication medium

Communication System

- Wire Communication or Line communication

  Ex: Telegraphy , Telephony

  (Actually two physical wires or conductors are run between the transmitter & receiver).

- Wireless Communication or Radio communication.

  Ex: Radio or TV broadcasting, Satellite communication

  (No physical wire between transmission & Receiver to carry the signal)

  (Using transmitting antenna)

Noise: Noise is random, undesirable electrical energy that enters the communication system via the medium and Interfers with the transmitted message. Some noise is also produced in the receiver.

Ex: noise produce in nature
1) Lighting during rainy season
2) Due to radiations produced by the sun or other stars.

noise produced by electric ignition systems of cars, electric motors, fluorescent lights etc.

Receivers: A receiver is a collection of electronic circuits, designed to convert the signal back to the original Information.

Consists of Amplifiers, detector, mixer, oscillator, transducers and

Natural

Ex: noise produce in nature

1) lighting during rainy season
2) Due to radiations produced by the sun or other stars.

Man made

noise produced by electric ignition systems of cars, electric motors, fluorescent lights etc.

Receivers : A receiver is a collection of electronic circuits, designed to convert the signal back to the original Information.

Consists of Amplifiers, detector, mixer, oscillator, transducers and so on.

Output Transducer : Convert the electrical signal back to original form. i.e. sound or TV picture etc.

Ex: Loud speakers, Picture tubes, computer monitor etc.

MODULATION TECHNIQUES

In the modulation process, two signals are used namely

$\boxed{\text{Low frequency}}$ m(t) ; The modulating signal / baseband / message signal.

$\boxed{\text{High frequency}}$ c(t) ; The carrier signal (sinusoidal signal)

"In the modulation process some parameter of the carrier wave (such as Amplitude, Frequency or Phase) is varied in accordance with the modulating signal."

Ex: Amplitude Modulation (AM)
Frequency Modulation (FM)
Phase Modulation (PM)

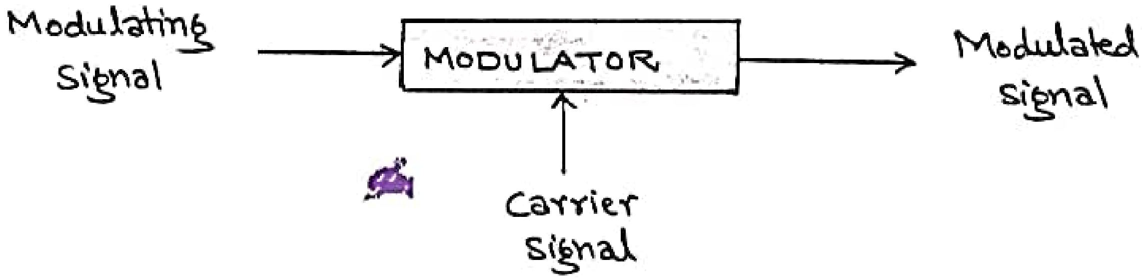
Note: After modulation process we get Modulated Signal.

- This modulated signal is then transmitted by the transmitter.
  The receiver will "Demodulate" the received modulated signal & get the original information signal back. Thus, demodulation is exactly opposite the modulation.

or

- In the modulation process, the baseband signal (such as video etc) modifies another higher-frequency signal called the carrier. The carrier is usually a sinusoidal wave that is higher in frequency than the highest baseband signal frequency.

"The baseband signal modifies the amplitude or frequency or phase of the carrier in the modulation process."



In the process of modulation, the carrier wave actually act as a carrier which carries the information signal (modulating signal) from the transmitter to receiver.

* Similar to a situation in which a person travels in his car or on his bike from one place to another.

"The person can be viewed as the modulating signal & the car or bike as a carrier."

NEED FOR MODULATION

NEED FOR MODULATION

Since, the baseband signals are incompatible for direct transmission over the medium and therefore we have to use modulation technique for the communication of baseband signal.

The advantage of Using modulation technique are given below.

★ 1) Reduce the height of antenna.

2) Avoid mixing of signals.

3) Increase the range of communication.

4) Improves quality of reception.

REDUCE THE HEIGHT OF ANTENNA

The minimum height of antenna is given as $\frac{\lambda}{4}$.

Here, $\boxed{\lambda = \frac{c}{f}}$ i.e. wavelength $= \frac{\text{Velocity of light}}{\text{frequency}}$.

Note: For Low frequency ≈ wavelength is very high

≈ So, Antenna Height is also very Large

Ex: Consider baseband signal with $f = 15KHz$.

$$\text{Height of antenna} = \frac{\lambda}{4} = \frac{c}{f \times 4} = \frac{3 \times 10^8}{15 \times 10^3 \times 4} = 5000 \text{ meters}$$

Also, If $f = 1MHz$

$$\text{Height of antenna} = \frac{\lambda}{4} = \frac{c}{f \times 4} = \frac{3 \times 10^8}{1 \times 10^6 \times 4} = 75 \text{ meters.}$$

FREQUENCY TRANSLATION IN THE MODULATION PROCESS

Base band or modulating Signal	$\xrightarrow[\text{Translated into}]{\text{Due to Modulation}}$	High frequency range called **Bandwidth**

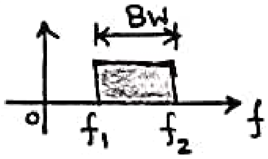
Low frequency signal
(20Hz to 20KHz)

BANDWIDTH: Is defined as the frequency range over which an Information signal is transmitted.

For Ex: The range of music signal is 20Hz to 15KHz.

$\therefore BW = f_2 - f_1$

$BW = 15000 - 20 = 14980\,Hz.$

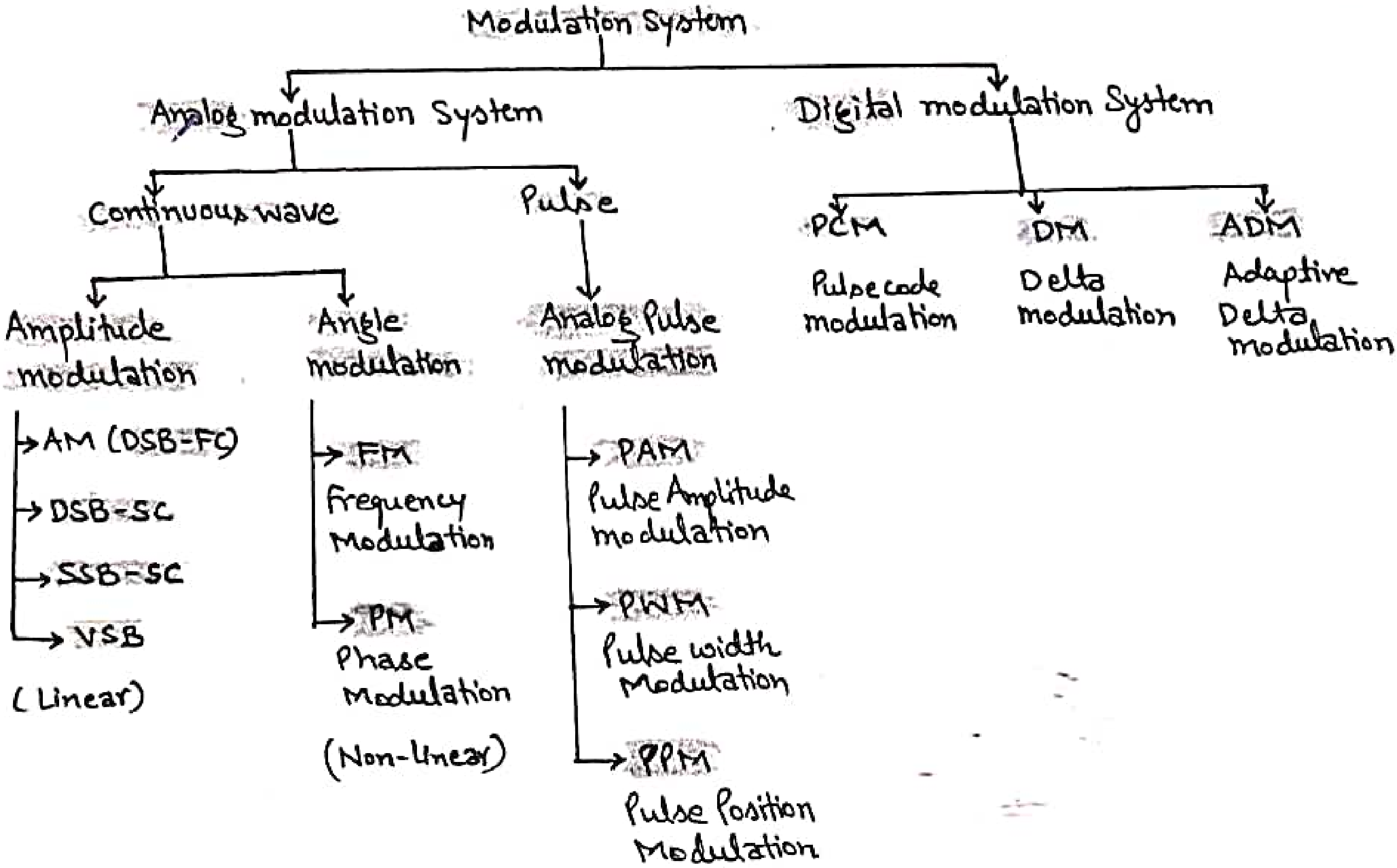


The bandwidth of different signals are as listed in Table.

Type of Signal	Range of frequency in Hz	Bandwidth in Hz.
Voice signal (speech) for telephony	300 – 3400	3100
Music signal	20–1500	14,980
TV signal (Picture)	0–5 MHz	5 MHz
Digital data	* 300 – 3400 (If its using the telephone line for its transmission)	3100

* Actually the required bandwidth in the data transmission depends on the rate at which the data is being transmitted.

Note: The BW increase with increase in the rate of data transmission.


Modulation system
Analog modulation System
Digital modulation System
Continuous wave
Pulse
PCM
Pulse code modulation
DM
Delta modulation
ADM
Adaptive Delta modulation
Amplitude modulation
Angle modulation
Analog Pulse modulation
AM (DSB-FC)
DSB-SC
SSB-SC
VSB
(Linear)
FM
Frequency Modulation
PM
Phase Modulation
(Non-Linear)
PAM
Pulse Amplitude modulation
PWM
Pulse width Modulation
PPM
Pulse Position Modulation

→ SSB-SC
→ VSB
(Linear)

Modulation
→ PM
Phase Modulation
(Non-Linear)

modulation
→ PWM
Pulse width Modulation
→ PPM
Pulse Position Modulation

Amplitude Modulation (AM) (Linear)

"Amplitude of the carrier is varied according to instantaneous magnitude of modulating signal."

- DSB-SC (Double sideband suppressed carrier)
- SSB-SC (Single sideband suppressed carrier)
- VSB (Vestigial sideband)

AMPLITUDE MODULATION (AM)

"Amplitude modulation is the process of changing the amplitude of a high frequency carrier signal in proportion with the instantaneous value of modulating signal (Information)."

Consider,

$m(t) = A_m \cos \omega_m t = A_m \cos(2\pi f_m t)$ → Contain Information → Message / Modulating / Baseband Signal

$c(t) = A_c \cos \omega_c t = A_c \cos(2\pi f_c t)$ → carrier signal of High frequency → Contain no Information.

$$\boxed{f_c >> f_m}$$

Note: Typically, the carrier amplitude A_c & the message signal $m(t)$ are measured in volts.

are measured in volts.

So, the AM signal is obtained by adding a large carrier c(t) to the modulating signal.

$$\boxed{S_{AM}(t) = \underbrace{\left[A_c + m(t)\right]}_{\text{Envelop of AM wave}} \cos(2\pi f_c t)} \quad —(1)$$

$$\boxed{S_{AM}(t) = A_c\left[1 + \frac{1}{A_c}m(t)\right]\cos(2\pi f_c t)}$$

$$\boxed{S_{AM}(t) = A_c\left[1 + K_a m(t)\right]\cos(2\pi f_c t)} \quad —(2)$$

where, $\boxed{K_a = \frac{1}{A_c}}$ → Constant called Amplitude sensitivity of the modulator.

→ measured in $volt^{-1}$.

→ Responsible for the generation of the modulated signal $S_{AM}(t)$.

From eq^n (1)

$$S_{AM}(t) = \left[A_c + m(t)\right]\cos(2\pi f_c t)$$

$$= \underbrace{A_c \cos(2\pi f_c t)}_{\text{carrier}} + \underbrace{m(t)\cos(2\pi f_c t)}_{\text{sidebands}}$$

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

$$= A_c\left[1 + \frac{A_m}{A_c}\cos(2\pi f_m t)\right]\cos(2\pi f_c t)$$

$\Downarrow$

μ = modulation factor (dimension less Constant)

$$\boxed{\mu = \frac{A_m}{A_c}}$$

→ modulation Index / factor / depth of modulation

→ Degree of modulation.

$\boxed{\;A_c\;}$ ⟶ Degree of modulation.

$$S_{AM}(t) = A_c\left[1 + \mu \cos(2\pi f_m t)\right] \cos(2\pi f_c t)$$

$$= A_c \cos(2\pi f_c t) + A_c \mu \cos(2\pi f_m t) \cos(2\pi f_c t)$$

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

or
$$S_{AM}(t) = \underbrace{A_c \cos \omega_c t}_{\text{Carrier}} + \frac{1}{2} A_c \mu \Big[\underbrace{\underbrace{\cos(\omega_c + \omega_m)t}_{\text{USB}} + \underbrace{\cos(\omega_c - \omega_m)t}_{\text{LSB}}}_{\text{DSB}}\Big] \quad \text{--- (4)}$$

AM-DSB|FC

or

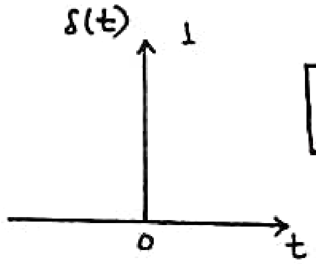
AM

{Time domain description of AM wave}

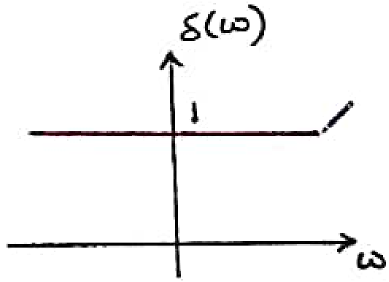
$\because \omega_c \gg \omega_m$

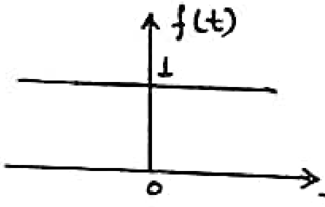
$\because \omega_c = 2\pi f_c t \quad \& \quad \omega_m = 2\pi f_m t$

$\because 2\cos A \cos B = \cos(A+B) + \cos(A-B)$

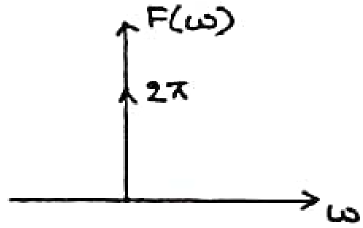


$\boxed{\mathcal{F}[\delta(t)] = 1}$





$\boxed{\mathcal{F}[1] = 2\pi\,\delta(\omega)}$



Since, $\mathcal{F}[f(t)] = F(\omega)$

$$\mathcal{F}[f(t-T)] = F(\omega)\, e^{-j\omega T}$$

or $\boxed{\mathcal{F}[f(t \pm T)] = F(\omega)\, e^{\pm j\omega T}}$ ..... Time Shifting property.

Also $\boxed{\mathcal{F}[f(t)\, e^{\pm j\omega_0 t}] = F(\omega \mp \omega_0)}$ ... Frequency Shifting In

Also $\boxed{\mathcal{F}\left[f(t)\, e^{\pm j\omega_0 t}\right] = F(\omega \mp \omega_0)}$ -- Frequency Shifting in frequency domain.

$$\mathcal{F}\left[e^{j\omega_0 t}\right] = \mathcal{F}\left[\underbrace{f(t)}_{=1} e^{j\omega_0 t}\right]$$

$\because \mathcal{F}[1] = 2\pi\delta(\omega)$

Also,

$\mathcal{F}[A] = A\, 2\pi\delta(\omega)$

$$\boxed{\mathcal{F}\left[e^{j\omega_0 t}\right] = 2\pi\delta(\omega - \omega_0)}$$

Also

$$\boxed{\mathcal{F}\left[e^{j2\pi f_0 t}\right] = \delta(f - f_0)}$$

&

$$\boxed{\mathcal{F}\left[e^{-j2\pi f_0 t}\right] = \delta(f + f_0)}$$

$$\mathcal{F}[\cos\omega_0 t] = \mathcal{F}\left[\frac{e^{j\omega_0 t} + e^{-j\omega_0 t}}{2}\right]$$

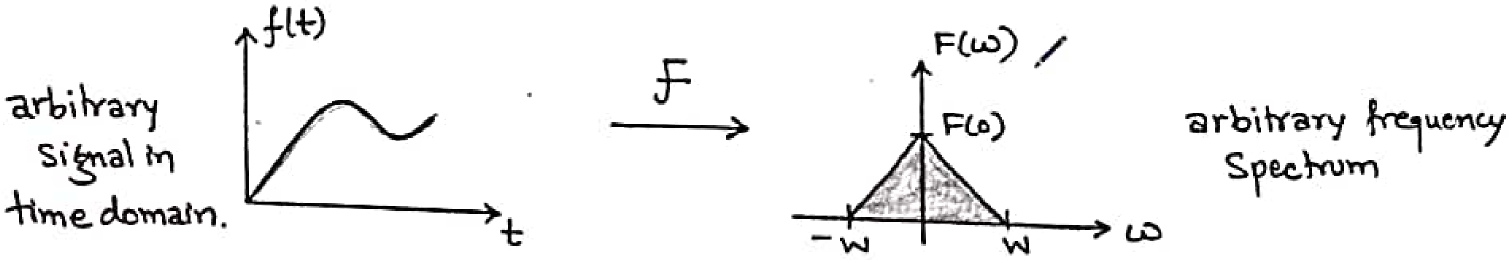
$$= \frac{1}{2}\left[2\pi\,\delta(\omega-\omega_0) + 2\pi\,\delta(\omega+\omega_0)\right]$$

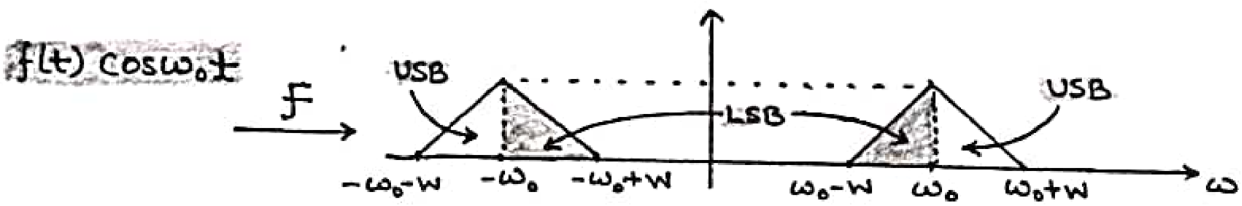
$$\boxed{\mathcal{F}[\cos\omega_0 t] = \pi\left[\delta(\omega+\omega_0) + \delta(\omega-\omega_0)\right]}$$

$$\mathcal{F}[f(t)\cos\omega_0 t] = \mathcal{F}\left[f(t)\cdot\frac{1}{2}\left(e^{j\omega_0 t} + e^{-j\omega_0 t}\right)\right]$$

$$\boxed{\mathcal{F}[f(t)\cos\omega_0 t] = \frac{1}{2}\left[F(\omega-\omega_0) + F(\omega+\omega_0)\right]}$$ Frequency Shifting.

→ <u>Modulation Theorem</u>





Note: Modulation simply represents translation of the frequency components from one value to another therefore this represents shifting of the frequency spectrum from origin to $\pm\omega_0$.

Existance of -ve Frequencies :- These frequency exists since the fourier spectrum of any signal is always an even function of ω.

- The -ve frequencies physically do not exist but these frequencies may be made +ve by the modulator or by translating the frequency component to any other value.

FREQUENCY DOMAIN DESCRIPTION (FREQUENCY SPECTRUM) OF AM WAVE.

The frequency spectrum of AM wave can be obtained by taking the Fourier transform of the AM wave (in time domain).

Note:

$$\text{F.T.}\left[e^{j2\pi f_c t}\right] = \delta(f-f_c)$$

$$\text{F.T.}\left[e^{-j2\pi f_c t}\right] = \delta(f+f_c)$$

$$\text{F.T.}\left[e^{j2\pi f_c t}\, m(t)\right] = M(f-f_c)$$

$$\text{F.T.}\left[e^{-j2\pi f_c t}\, m(t)\right] = M(f+f_c)$$

$$\cos\omega_c t \xleftrightarrow{\text{F.T.}} \pi\left[\delta(\omega+\omega_c) + \delta(\omega-\omega_c)\right]$$

$$m(t) \xleftrightarrow{\text{F.T.}} M(f)$$

$$A_c \cos\omega_c t \xleftrightarrow{\text{F.T.}} \frac{A_c}{2}\left[\delta(f+f_c) + \delta(f-f_c)\right]$$

The AM wave is given as

The AM wave is given as

$$S_{AM}(t) = A_c\left[1 + K_a m(t)\right]\cos\omega_c t$$

$$\Big\downarrow \text{F.T.}$$

$$S_{AM}(f) = \text{F.T.}\left[A_c\left\{1 + K_a m(t)\right\}\cos\omega_c t\right]$$

$$= \text{F.T.}\left[A_c\cos 2\pi f_c t + A_c K_a m(t)\cos 2\pi f_c t\right]$$

$$= A_c\ \text{F.T.}\left[\cos 2\pi f_c t\right] + A_c K_a\ \text{F.T.}\left[m(t)\cos 2\pi f_c t\right]$$

$$= A_c\ \text{F.T.}\left[\frac{e^{j2\pi f_c t} + e^{-j2\pi f_c t}}{2}\right] + A_c K_a\ \text{F.T.}\left[m(t)\left(\frac{e^{j2\pi f_c t} + e^{-j2\pi f_c t}}{2}\right)\right]$$

$$= \frac{A_c}{2}\text{F.T.}\left(e^{j2\pi f_c t}\right) + \frac{A_c}{2}\text{F.T.}\left(e^{-j2\pi f_c t}\right) + \frac{A_c K_a}{2}\text{F.T.}\left[m(t)\, e^{j2\pi f_c t}\right]$$

$$+ \frac{A_c K_a}{2}\text{F.T.}\left[m(t)\, e^{-j2\pi f_c t}\right]$$

$$= A_c \text{ F.T.}\left[\cos 2\pi f_c t\right] + A_c K_a \text{ F.T.}\left[m(t) \cos 2\pi f_c t\right]$$

$$= A_c \text{ F.T.}\left[\frac{e^{j2\pi f_c t} + e^{-j2\pi f_c t}}{2}\right] + A_c K_a \text{ F.T.}\left[m(t)\left(\frac{e^{j2\pi f_c t} + e^{-j2\pi f_c t}}{2}\right)\right]$$

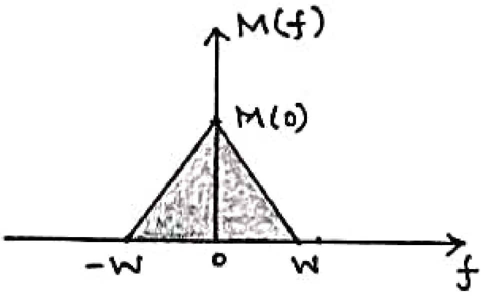
$$= \frac{A_c}{2} \text{ F.T.}\left(e^{j2\pi f_c t}\right) + \frac{A_c}{2} \text{ F.T.}\left(e^{-j2\pi f_c t}\right) + \frac{A_c K_a}{2} \text{ F.T.}\left[m(t)\, e^{j2\pi f_c t}\right] + \frac{A_c K_a}{2} \text{ F.T.}\left[m(t)\, e^{-j2\pi f_c t}\right]$$

$$S_{AM}(f) = \frac{A_c}{2}\delta(f-f_c) + \frac{A_c}{2}\delta(f+f_c) + \frac{K_a A_c}{2} M(f-f_c) + \frac{K_a A_c}{2} M(f+f_c)$$

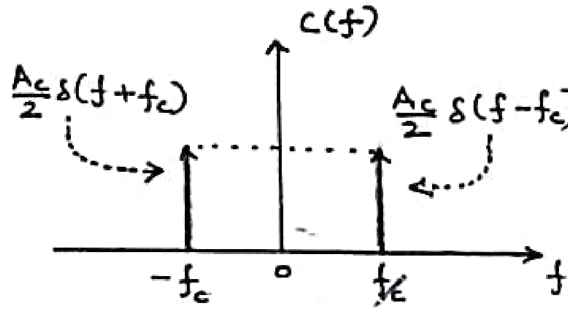
Two Impulse function occuring at f_c & $-f_c$

original spectrum $M(f)$ shifted in frequency domain by f_c & $-f_c$.

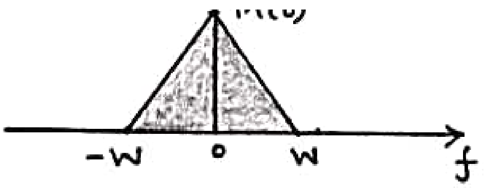
$$S_{AM}(f) = \underbrace{\frac{A_c}{2}\delta(f-f_c) + \frac{A_c}{2}\delta(f+f_c)}_{\text{Two impulse function occuring at } f_c \text{ \& } -f_c} + \underbrace{\frac{K_a A_c}{2} M(f-f_c) + \frac{K_a A_c}{2} M(f+f_c)}_{\text{original spectrum } M(f) \text{ shifted in frequency domain by } f_c \text{ \& } -f_c}$$



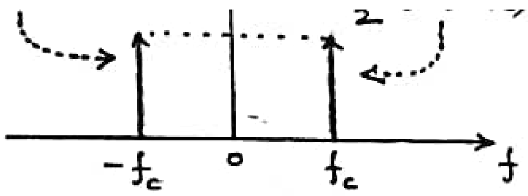
a) Frequency Spectrum of baseband Signal m(t)



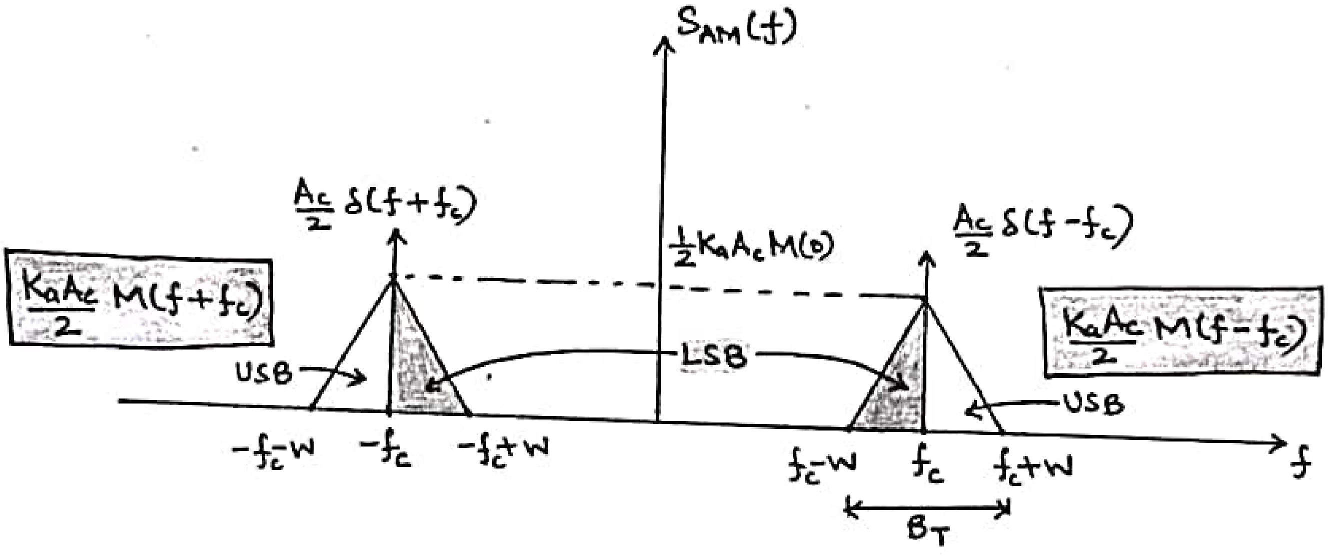
b) Frequency Spectrum of Carrier Signal c(t)



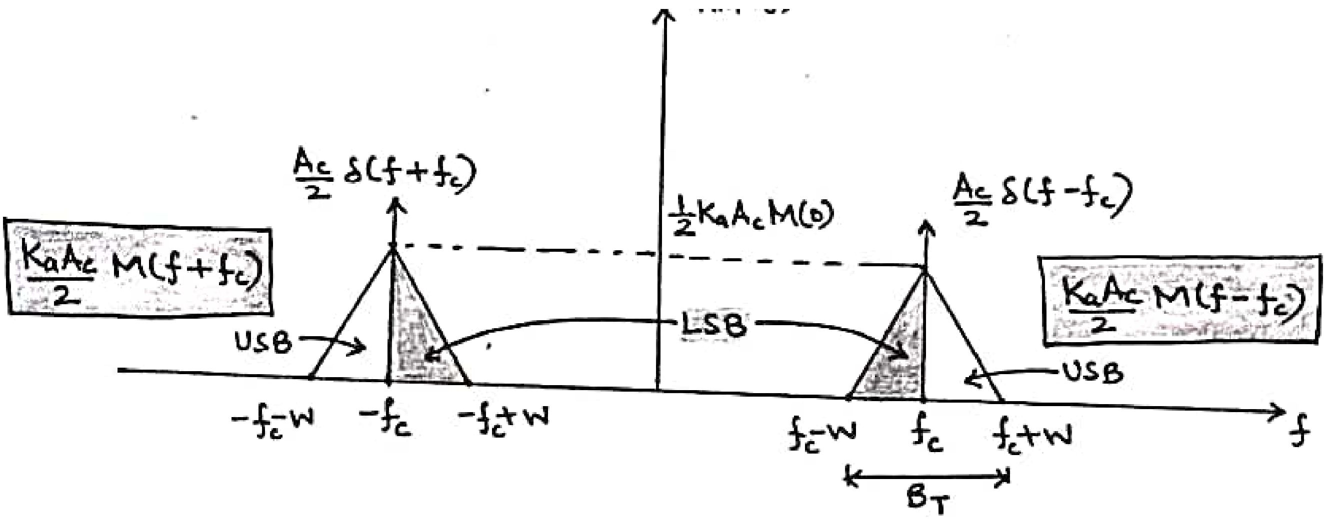
a) Frequency Spectrum of baseband Signal m(t)



b) Frequency Spectrum of Carrier Signal c(t)



c) Spectrum of AM wave



c) Spectrum of AM wave

Note: Bandwidth or Transmission Bandwidth $= 2W$, (for AM i.e. DSB/FC)

i.e $\boxed{B_T = 2W}$

- For +ve frequencies, the highest frequency component of the AM wave equals (ω_c+W or f_c+W), and the lowest frequency component equals (ω_c-W or f_c-W). The difference between these two frequencies define the transmission bandwidth B_T for the AM wave.

SINGLE TONE AMPLITUDE MODULATION

AM in which the modulation or baseband signal consists of only one frequency component or single tone i.e; modulation is done by a single frequency or tone.

This type of Amplitude modulation is known as single tone Amplitude modulation.

Let, message signal ; $m(t) = \underbrace{A_m}_{\text{Amplitude of modulating wave}} \cos(2\pi \underbrace{f_m}_{\text{Frequency of modulating wave}} t)$

Carrier Signal ; $c(t) = A_c \cos(2\pi f_c t)$

General Expression for AM signal is

$$s(t) = [1 + k\, m(t)]\, c(t)$$

Carrier signal ; $c(t) = A_c \cos(2\pi f_c t)$

General Expression for AM signal is

$$S_{AM}(t) = [1 + K_a m(t)] \, c(t)$$

$$= A_c \left[1 + \underbrace{K_a A_m}_{\mu} \cos(2\pi f_m t) \right] \cos(2\pi f_c t)$$

μ = maximum deviation.

$$\boxed{\begin{aligned} \because K_a &= \frac{1}{A_c} \\ \mu &= \frac{A_m}{A_c} \end{aligned}}$$

$$\therefore S_{AM}(t) = A_c \cos \omega_c t + \mu A_c \cos \omega_c t \cos \omega_m t$$

$$S_{AM}(t) = \underbrace{A_c \cos \omega_c t}_{\text{carrier}} + \frac{\mu A_c}{2} \left[\underbrace{\cos(\omega_c + \omega_m)t}_{\text{USB}} + \underbrace{\cos(\omega_c - \omega_m)t}_{\text{LSB}} \right]$$

Frequency Component	Amplitude	Power
ω_c (Carrier)	A_c	$P_c \propto A_c^2$ Contain no Information
$\omega_c + \omega_m$ (USB)	$\frac{1}{2} A_c \mu$	$P_{USB} \propto \left(\frac{1}{2} A_c \mu\right)^2 = \frac{1}{4} A_c^2 \mu^2$ or $\frac{1}{4} P_c \mu^2$
$\omega_c - \omega_m$ (LSB)	$\frac{1}{2} A_c \mu$	$P_{LSB} = \frac{1}{4} P_c \mu^2$

Total transmitting power in AM signal

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

$$P_t = P_c + \frac{1}{4} P_c \mu^2 + \frac{1}{4} P_c \mu^2 = P_c + \frac{1}{2} P_c \mu^2$$

$\omega_c-\omega_m$ (LSB)	$\frac{1}{2}A_c\mu$	$P_{LSB}=\frac{1}{4}P_c\mu^2$

Total transmitting power in AM signal

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

$$P_t = P_c + \frac{1}{4}P_c\mu^2 + \frac{1}{4}P_c\mu^2 = P_c + \frac{1}{2}P_c\mu^2$$

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

$\because P = I^2R$

So, $I_t^2R = I_c^2R\left(1+\frac{\mu^2}{2}\right)$

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

Transmission Efficiency

Transmission efficiency of an AM wave is the ratio of the transmitted power which contains the information (i.e. the total sideband power) to the total transmitted power.

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

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

The percentage transmission efficiency :

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

Types of AM signals

$$S_{AM}(t) = A_c \cos \omega_c t + \frac{1}{2} A_c \mu \left[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t \right]$$

AM - DSB|FC

$$S_{AM}(t) = \frac{1}{2} A_c \mu \left[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t \right]$$

AM - DSB|SC

$$S_{AM}(t) = \frac{1}{2} A_c \mu \cos(\omega_c + \omega_m)t$$

$\downarrow$

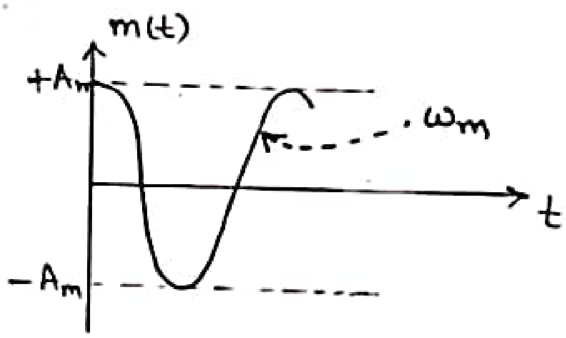
USB retained

AM-SSB|SC

$$S_{AM}(t) = A_c \cos \omega_c t + \frac{1}{2} A_c \mu \cos(\omega_c + \omega_m)t$$

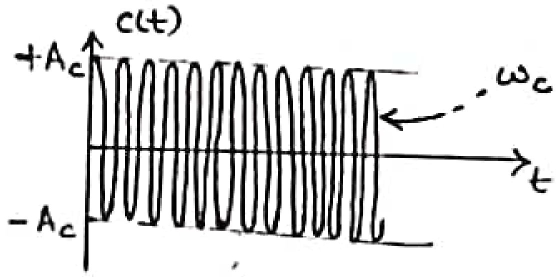
AM-SSB|FC

GRAPHICAL REPRESENTATION OF SINGLE TONE AM (DSB/FC) IN TIME DOMAIN



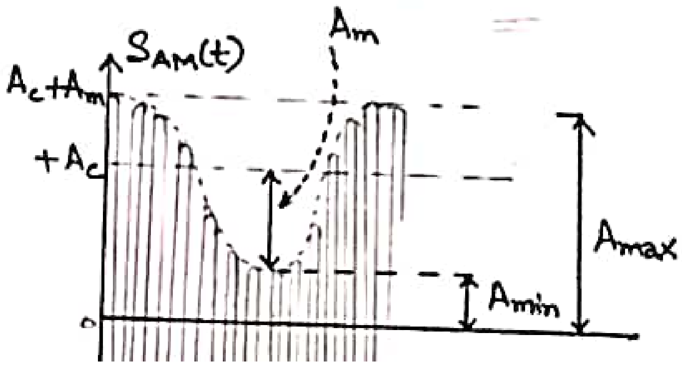
$$m(t) = A_m \cos \omega_m t$$

$$\boxed{\omega_m << \omega_c}$$



$$c(t) = A_c \cos \omega_c t$$

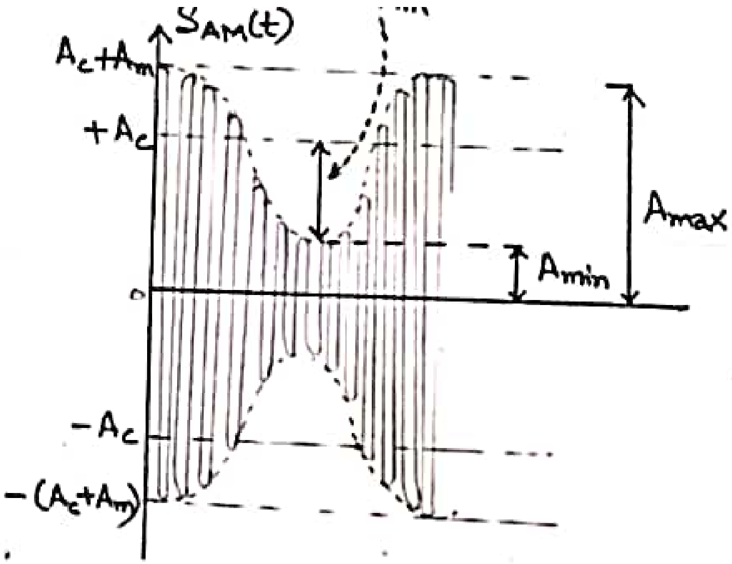
Case I : $0 < \mu < 1$



$$A_{max} = A_c + A_m$$

$$A_{min} = A_c - A_m$$

Case I: $0<\mu<1$



$$A_{max} = A_c + A_m$$

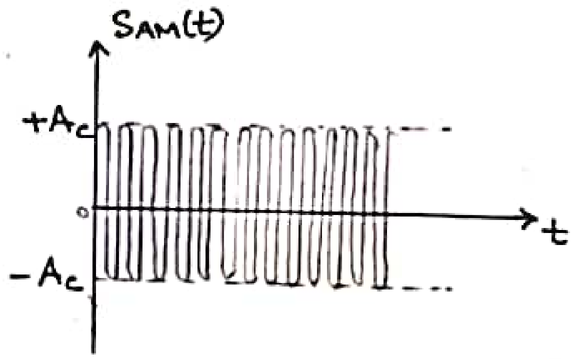
$$A_{min} = A_c - A_m$$

$$\mu = \frac{A_m}{A_c}$$

$$\boxed{\mu = \frac{A_{max}-A_{min}}{A_{max}+A_{min}}}$$

Case II $\mu = 0$; $\therefore A_m = 0$

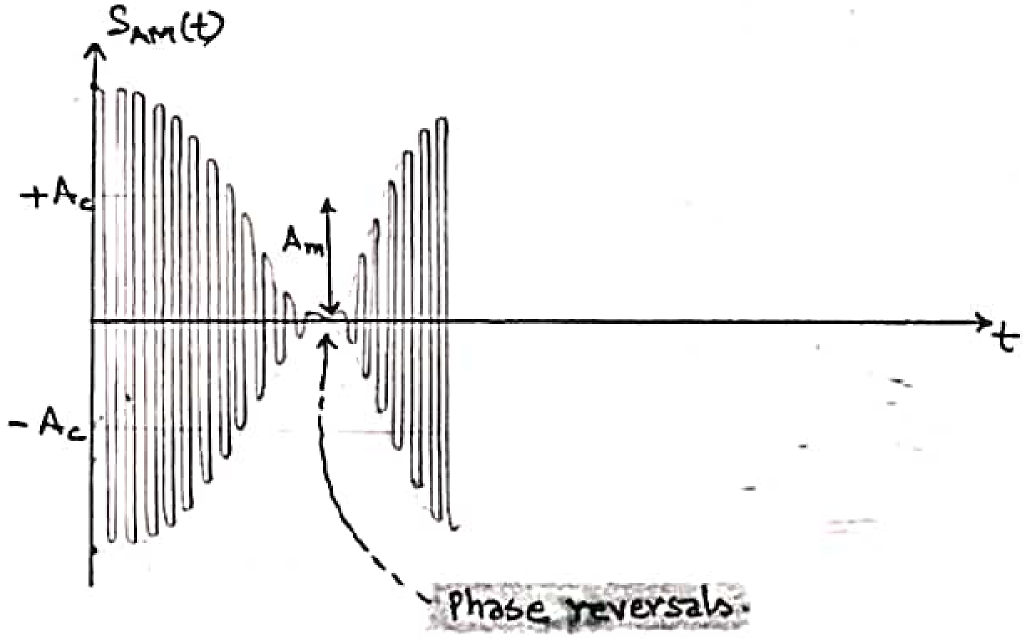
$\Rightarrow A_{max} = A_{min}$



Called Unmodulated Carrier

Case III : $\mu = 1$; $\mu = \frac{A_m}{A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$

$\therefore A_m = A_c$ and $A_{min} = 0$



POWER TRANSMITTED & POWER SAVING (%) FOR VARIOUS AM SIGNALS ($\mu = 1$)

i) **AM-DSB/FC**

$$P_t = P_c\left(1+\frac{\mu^2}{2}\right) = \frac{3}{2}P_c \quad \text{--- max power}$$

$$\boxed{P_t = \left(\frac{3}{2}\right)P_c} \quad \text{--- std. AM}$$

ii) **AM-DSB/SC**

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

$$\boxed{P_t = \left(\frac{1}{2}\right)P_c}$$

$\therefore$ Power Saving, $P_{saving} = P_c$ i.e suppress Carrier

$$\% \text{ Power Saving} = \frac{P_c}{P_t}\times 100 = \frac{P_c}{\left(\frac{3}{2}\right)P_c}\times 100\% \simeq 67\% \; (66.6\%)$$

$$\boxed{P_t = \left(\frac{1}{2}\right)P_c}$$

$\therefore$ Power Saving , $P_{saving} = P_c$ i.e suppress Carrier

$$\% \text{ Power Saving} = \frac{P_c}{P_t} \times 100 = \frac{P_c}{\left(\frac{3}{2}\right)P_c} \times 100\% \simeq 67\% \ (66.6\%)$$

iii) AM-SSB/FC

$$P_t = P_c\left(1 + \frac{\mu^2}{2}\right) = P_c + P_c\frac{\mu^2}{4} + \cancel{P_c\frac{\mu^2}{4}}$$

$$P_t = P_c\left(1 + \frac{\mu^2}{4}\right) = \left(\frac{5}{4}\right)P_c \qquad \because \mu = 1$$

$$P_{saving} = P_c\frac{\mu^2}{4} = \frac{1}{4}P_c$$

$$\% \text{ Saving} = \frac{1/4\, P_c}{3/2\, P_c} \times 100 = \frac{1}{4} \times \frac{2}{3} \times 100 \simeq 16\%$$

iv) **AM-SSB|SC**

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

$$P_t = \frac{1}{4} P_c \qquad \because \mu = 1$$

$$P_{saving} = P_c + \frac{1}{4} P_c = \left(\frac{5}{4}\right) P_c$$

$$\%\ \text{saving} = \frac{(5/4)\, P_c}{(3/2)\, P_c} \times 100 = \frac{5}{4} \times \frac{2}{3} \times 100 \simeq 83\%$$

Note: The transmitter power distributed to carrier frequency component is called as wastage of transmitter power in AM.

For effective distribution case $\boxed{\text{i.e. } \mu = 1}$, large % of transmitter power (66.6%) will be wasted in carrier transmission.

It correspond to biggest drawback of AM.

Multitone AM :

In practice more than one modulating signals will be present.

Let us assume that there are two modulating signals.

$$m_1(t) = A_{m_1} \cos \omega_{m_1} t$$

$$m_2(t) = A_{m_2} \cos \omega_{m_2} t$$

Total modulating signal : $m(t) = m_1(t) + m_2(t)$

Also carrier : $c(t) = A_c \cos \omega_c t$

$\therefore$ AM wave

$$S_{AM}(t) = A_c \left[1 + K_a m(t) \right] \cos 2\pi f_c t$$

$$= A_c \left[1 + \underbrace{K_a A_{m_1}}_{\mu_1} \cos \omega_{m_1} t + \underbrace{K_a A_{m_2}}_{\mu_2} \cos \omega_{m_2} t \right] \cos 2\pi f_c t$$

So

μ_1 μ_2

So,
$$S_{AM}(t) = A_c\left[1 + \mu_1 \cos \omega_{m1} t + \mu_2 \cos \omega_{m2} t\right] \cos 2\pi f_c t$$

Here, $\mu_1 = \frac{A_{m1}}{A_c} = K_a A_{m1}$

$\mu_2 = \frac{A_{m2}}{A_c} = K_a A_{m2}$

$$S_{AM}(t) = \underbrace{A_c \cos 2\pi f_c t}_{\text{Carrier}} + A_c \mu_1 \cos 2\pi f_{m1} t \cos 2\pi f_c t + A_c \mu_2 \cos 2\pi f_{m2} t \cdot \cos 2\pi f_c t$$

$$S_{AM}(t) = \underbrace{A_c \cos 2\pi f_c t}_{\text{carrier}} + \frac{A_c \mu_1}{2} \cos 2\pi \underbrace{(f_c + f_{m1})}_{\text{USB 1}} t + \frac{A_c \mu_1}{2} \cos 2\pi \underbrace{(f_c - f_{m1})}_{\text{LSB 1}} t$$
$$+ \frac{A_c \mu_2}{2} \cos 2\pi \underbrace{(f_c + f_{m2})}_{\text{USB 2}} t + \frac{A_c \mu_2}{2} \cos 2\pi \underbrace{(f_c - f_{m2})}_{\text{LSB 2}} t$$

Above equation shows that; AM wave along with carrier there are four sidebands components.

Two USB at $\rightarrow (f_c + f_{m1})$, $\rightarrow (f_c + f_{m2})$

Two LSB at $\rightarrow (f_c - f_{m1})$, $\rightarrow (f_c - f_{m2})$

$$BW = USB_2 - LSB_2$$
$$= (f_c + f_{m2}) - (f_c - f_{m2})$$
$$\boxed{BW = 2f_{m2}}$$

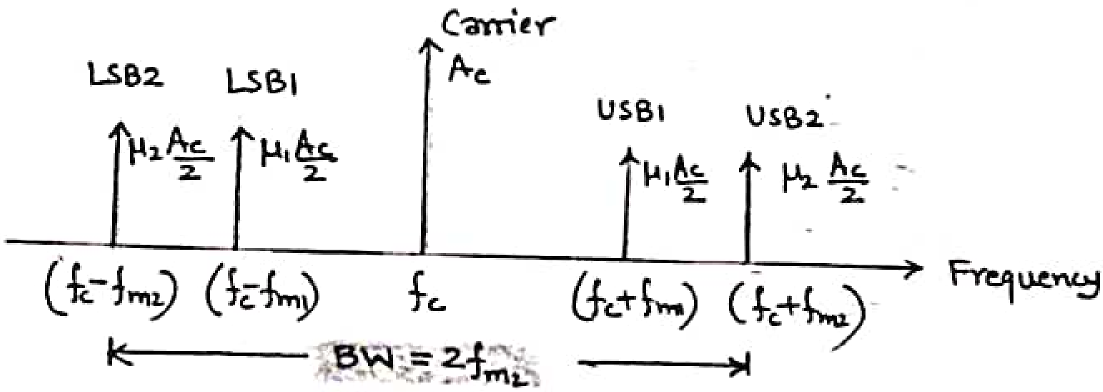


Fig: Frequency spectrum of AM with two modulating signals

Total Power in AM wave: $P_t = P_c + P_{USB1} + P_{USB2} + P_{LSB1} + P_{LSB2}$

$\longleftarrow BW = 2f_{m2} \longrightarrow$

Fig: Frequency spectrum of AM with two modulating signals

Total Power in AM wave: $P_t = P_c + P_{USB1} + P_{USB2} + P_{LSB1} + P_{LSB2}$

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

So,
$$P_t = P_c + \frac{\mu_1^2}{4} P_c + \frac{\mu_2^2}{4} P_c + \frac{\mu_1^2}{4} P_c + \frac{\mu_2^2}{4} P_c$$

$$P_t = P_c + \frac{\mu_1^2}{2} P_c + \frac{\mu_2^2}{2} P_c$$

$$\boxed{P_t = P_c\left[1 + \frac{\mu_1^2}{2} + \frac{\mu_2^2}{2}\right]}$$

Note: For 'n' number of modulating signals with modulation indexes $\mu_1, \mu_2, \dots, \mu_n$.

$$\boxed{P_t = P_c\left[1 + \frac{\mu_1^2}{2} + \frac{\mu_2^2}{2} + \dots + \frac{\mu_n^2}{2}\right]}$$

Effective modulation index (m_t)

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

Single tone / Single frequency

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

$$P_t = P_c\left[1+\frac{\mu_1^2}{2}+\frac{\mu_2^2}{2}\right]$$

Multitone / Two modulating frequency.

$$\boxed{P_t = P_c\left[1+\frac{\mu_1^2+\mu_2^2}{2}\right]}$$

Comparing both

$$\mu_t^2 = \mu_1^2+\mu_2^2$$

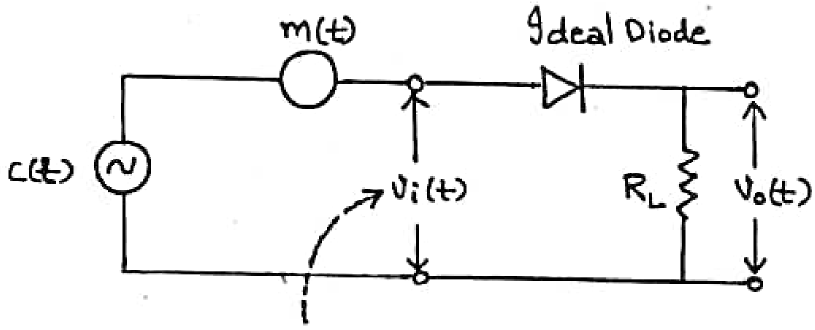
$$\boxed{\mu_t = \sqrt{\mu_1^2+\mu_2^2}}$$

GENERATION OF AM WAVE (DSB|FC)

- Device called <u>Switching modulator</u> or <u>Switching amplitude modulator.</u>

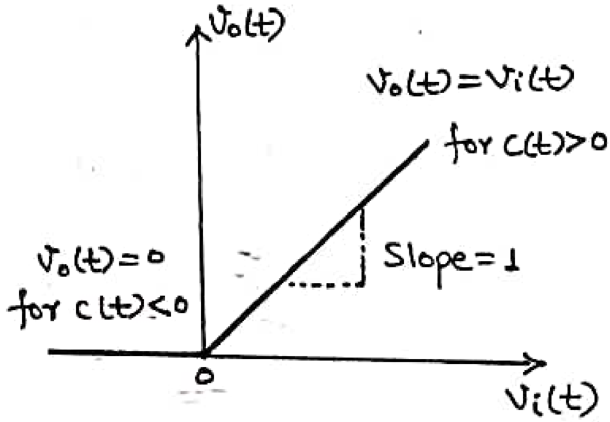
- A <u>non-linear element</u> (<u>Diode</u>) is used for its Implementation.

- Called <u>Low Power</u> modulator circuits.



$$v_i(t) = c(t) + m(t)$$

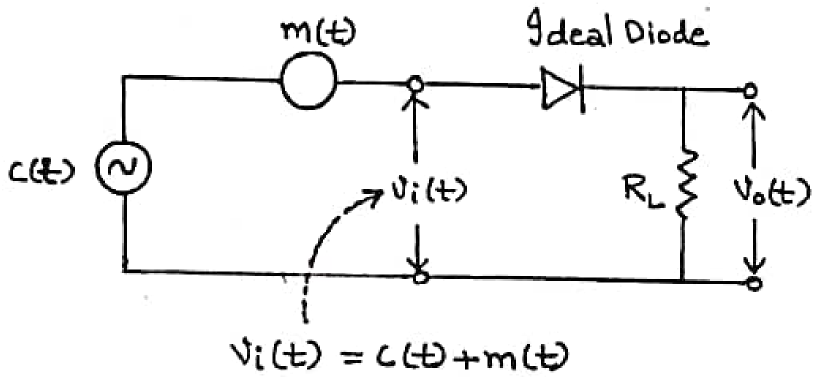
a) <u>Switching modulator</u>



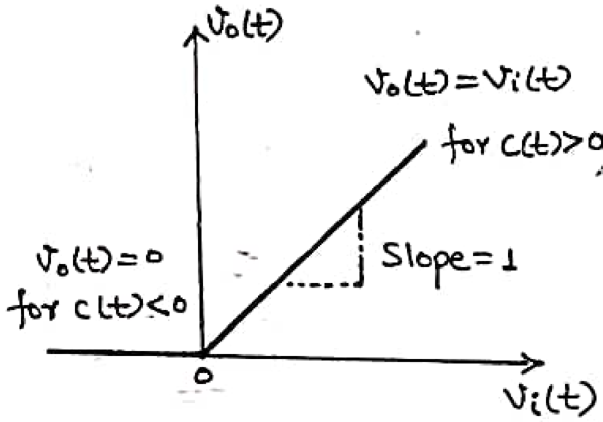
b) <u>Idealized input-output Characteristics.</u>

- Switching modulator consists of the following

* Called Low Power modulator circuits.



a) Switching modulator



b) Idealized input-output characteristics.

* Switching modulator consists of the following

1) An Ideal diode

2) A carrier source ; $c(t)$ & modulating signal ; $m(t)$

* In switching modulator, the carrier signal and modulating signal are connected in series with each other. so, the input voltage to the diode is given by:

* In switching modulator, the carrier signal and modulating signal are connected in series with each other. so, the input voltage to the diode is given by:

$$\boxed{\begin{aligned} v_i(t) &= c(t) + m(t) \\ v_i(t) &= A_c \cos \omega_c t + m(t) \end{aligned}}$$

* The diode has been assumed to be ideal, it means that it offer

→ zero resistance in the forward direction $[c(t) > 0]$

→ ∞ resistance in the reverse direction $[c(t) < 0]$

Note:- The status (ON or OFF) of the diode is depends upon the amplitude of carrier signal.

Here ; $\boxed{A_c >> A_m}$

amplitude of carrier signal.

Here ; $\boxed{A_c >> A_m}$

OPERATION : $v_o(t) = v_i(t)$ ---> +ve half cycle of c(t)

$v_o(t) = 0$ ---> −ve half cycle of c(t)

$$\boxed{v_o(t) \simeq \begin{cases} v_i(t) & \text{for } c(t) > 0 \\ 0 & \text{for } c(t) < 0 \end{cases}} \quad -①$$

---> means load voltage $v_o(t)$ varies periodically between the values $v_i(t)$ & zero .at the rate equal to carrier frequency f_c.

---> Mathematically expressed as follow:

$$v_o(t) = \left[A_c \cos(2\pi f_c t) + m(t)\right] g_p(t) \quad -②$$

where $g_p(t) \approx$ Periodic pulse train of duty cycle to one half &

→ means load voltage $v_o(t)$ varies periodically between the values $v_i(t)$ & zero at the rate equal to carrier frequency f_c.

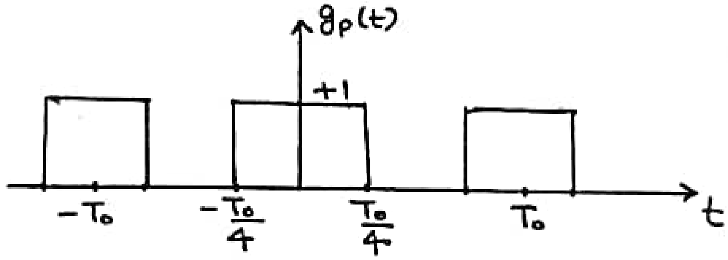
→ Mathematically expressed as follow:

$$v_o(t) = \left[A_c \cos(2\pi f_c t) + m(t)\right] g_p(t) \quad - ②$$

where $g_p(t)$ ≈ Periodic pulse train of duty cycle to one half & Period $T_o = \frac{1}{f_c}$.

Expressed in Fourier series

$$\boxed{g_p(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{(2n-1)} \cos\left[2\pi f_c t(2n-1)\right]} \quad ③$$



Substituting eqⁿ ③ in eqⁿ ② we get

substituting eq^n ③ in eq^n ② we get

$$v_o(t) = \left[A_c \cos(2\pi f_c t) + m(t)\right]\left\{\frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{(2n-1)}\cos\left[2\pi f_c t\,(2n-1)\right]\right\}$$

6

$$v_o(t) = \left[A_c \cos(2\pi f_c t) + m(t)\right]\left\{\frac{1}{2} + \frac{2}{\pi}\cos 2\pi f_c t + \underbrace{\text{odd harmonics}}_{\substack{\text{Eliminated} \\ \text{(Unwanted)}}}\right\}$$

$$= \frac{A_c}{2}\cos(2\pi f_c t) + \frac{2A_c}{\pi}\cos^2(2\pi f_c t) + \frac{m(t)}{2} + \frac{2}{\pi}m(t)\cos(2\pi f_c t)$$

$$v_o(t) = \underbrace{\frac{A_c}{2}\cos(2\pi f_c t) + \frac{2}{\pi}m(t)\cos(2\pi f_c t)}_{\text{AM wave}} + \underbrace{\frac{m(t)}{2}} + \underbrace{\frac{2A_c}{\pi}\cos^2(2\pi f_c t)}$$

$$v_o(t) = \left[A_c \cos(2\pi f_c t) + m(t)\right]\left\{\frac{1}{2} + \frac{2}{\pi}\cos 2\pi f_c t + \underbrace{\text{odd harmonics}}_{\substack{\text{Eliminated}\\ \text{(Unwanted)}}}\right\}$$

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$$v_o(t) = \underbrace{\frac{A_c}{2}\cos(2\pi f_c t) + \frac{2}{\pi}m(t)\cos(2\pi f_c t)}_{\text{AM wave}} + \underbrace{\underbrace{\frac{m(t)}{2}}_{\substack{\text{Modulating}\\ \text{Signal}}} + \underbrace{\frac{2A_c}{\pi}\cos^2(2\pi f_c t)}_{\substack{\text{second harmonic of}\\ \text{carrier.}}}}_{\text{Unwanted Terms}}$$

Removed from $v_o(t)$ by means of

$\boxed{\text{BPF}}$ ≈ with centre frequency f_c &

$BW = 2W$

$$v_o(t) = \underbrace{\frac{A_c}{2}\cos(2\pi f_c t) + \frac{2}{\pi} m(t)\cos(2\pi f_c t)}_{\text{AM wave}} + \underbrace{\underbrace{\frac{m(t)}{2}}_{\text{Modulating Signal}} + \underbrace{\frac{2A_c}{\pi}\cos^2(2\pi f_c t)}_{\text{Second harmonic of carrier.}}}_{\text{Unwanted Terms}}$$

Unwanted Terms

Removed from $v_o(t)$ by means of

$\boxed{\text{BPF}}$ ≈ with centre frequency f_c & $BW = 2W$

So,

$$v_o(t) = \frac{A_c}{2}\cos(2\pi f_c t) + \frac{2}{\pi} m(t)\cos(2\pi f_c t)$$

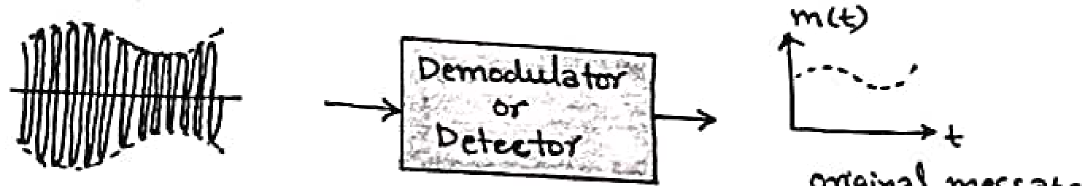
$$S_{AM}(t) = A_c\left[1 + K_a m(t)\right]\cos 2\pi f_c t$$

$$S_{AM}(t) = A_c \cos 2\pi f_c t + K_a m(t)\cos 2\pi f_c t$$

Similar to AM i.e. std. AM (DSB/FC)

DETECTION (DEMODULATION) OF AM WAVES (DSB|FC)

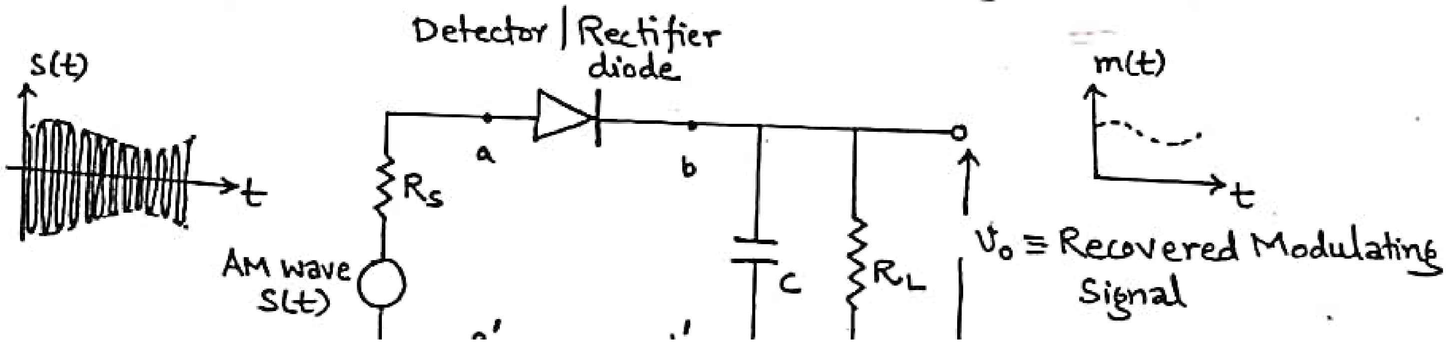
⊛ The process of detection or demodulation is the process of recovering the message signal, $m(t)$ from standard AM wave at the receiver side. [Exactly opposite to that of modulation].

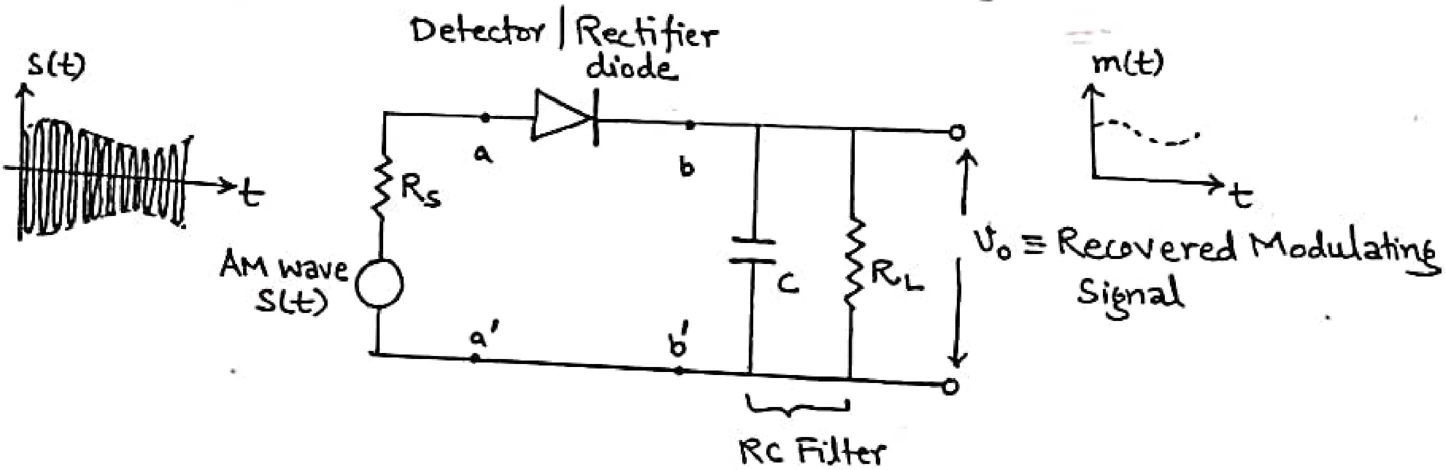


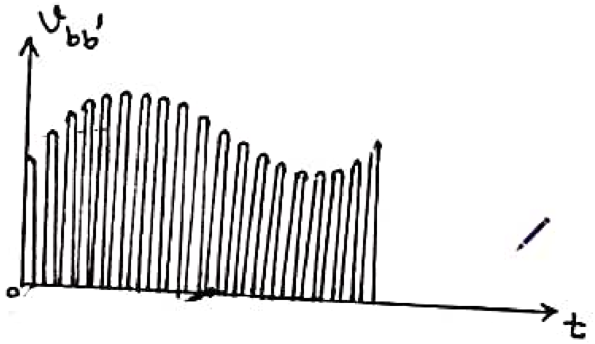
$S_{AM}(t)$, AM wave

original message signal.

ENVELOPE DETECTOR:





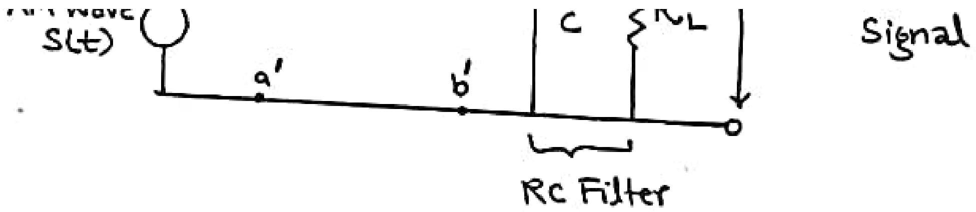


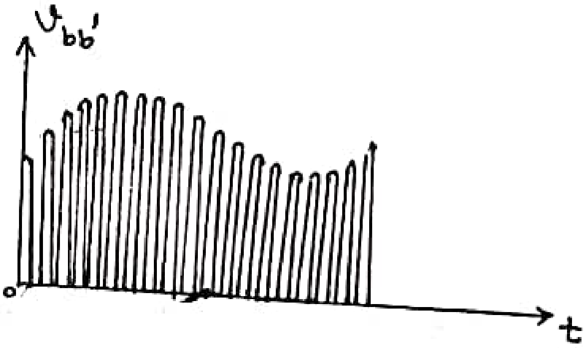
OPERATION :

- The standard AM wave is applied at the input of the detector.

In every $+\frac{1}{2}$ cycle of I/P $\longrightarrow$ Detector Diode ≈ FB $\longrightarrow$ Charge the filter Capacitor

C ↑ Peak value of I/P voltage.





OPERATION :

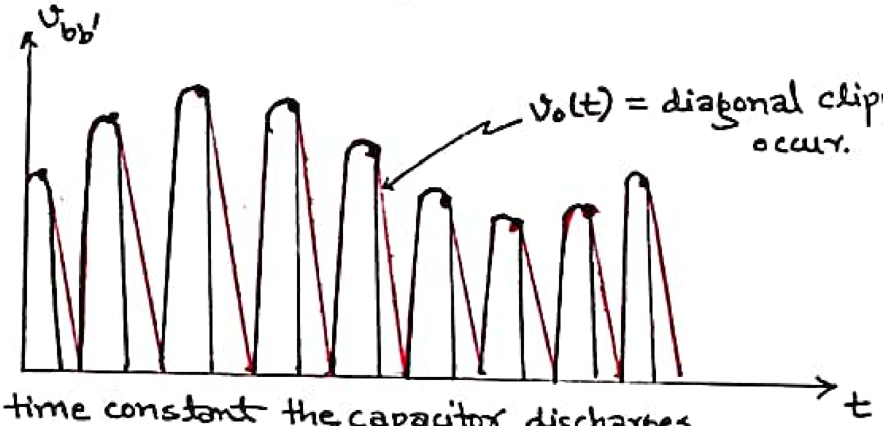
- The standard AM wave is applied at the input of the detector.

In every $+\frac{1}{2}$ cycle of I/P $\longrightarrow$ Detector Diode $\approx$ FB $\longrightarrow$ charge the filter capacitor C $\uparrow$ Peak value of I/P voltage.

- As soon as C $\uparrow$ charge to peak value $\longrightarrow$ Diode stop conducting $\longrightarrow$ Discharges across R_L Until next +ve $\frac{1}{2}$ cycle $\longrightarrow$ Process Repeats.

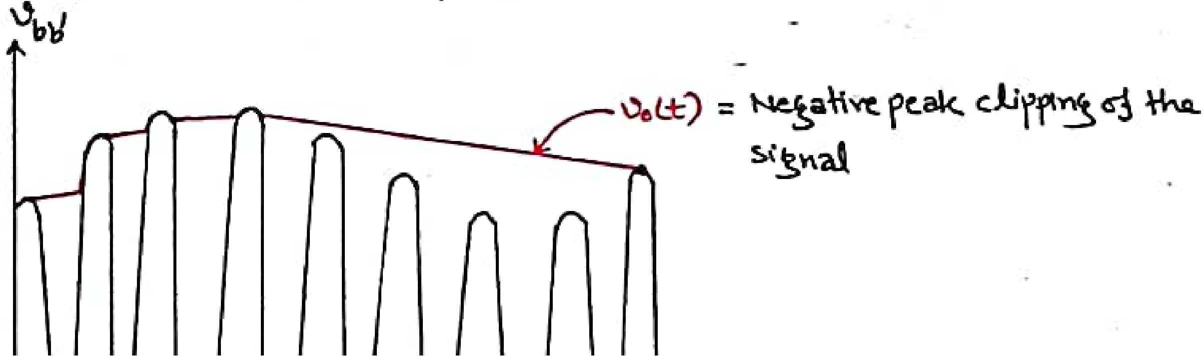
$\boxed{\text{Charging- discharging depends on RC time Constant}}$

Case I: RC Time constant is SMALL ;

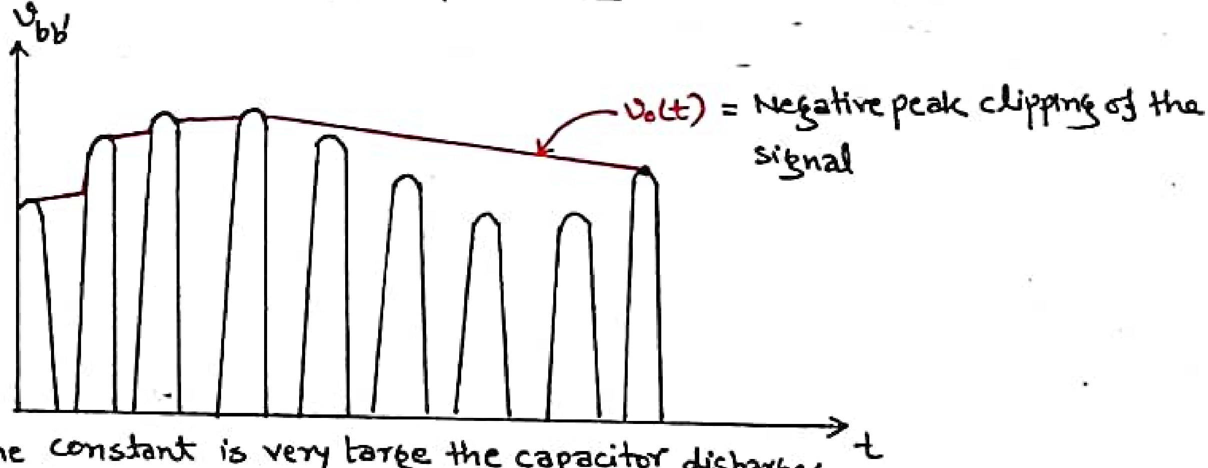


* For small RC time constant the capacitor discharges almost instantaneously and therefore diagonal clipping occur which is undesirable.

Case II : RC constant is very LARGE.

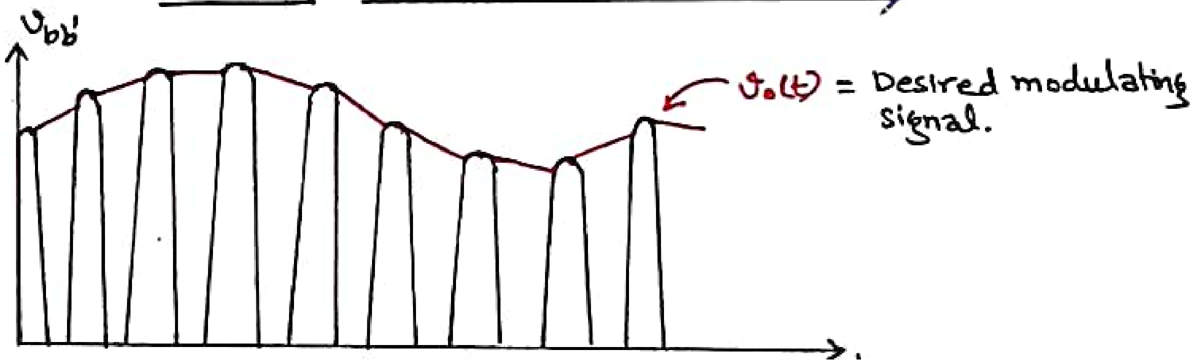


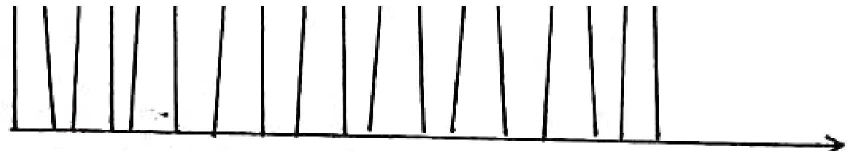
Case II : RC constant is very LARGE.



* When the time constant is very large the capacitor discharges very slowly. o/p voltage does not follow the envelope of the composite signal & -ve peak clipping of the signal occurs which is undesirable.

Case III : RC time constant is MEDIUM.





* When the time constant is very large the capacitor discharges very slowly. o/p voltage does not follow the envelope of the composite signal & -ve peak clipping of the signal occurs which is undesirable.

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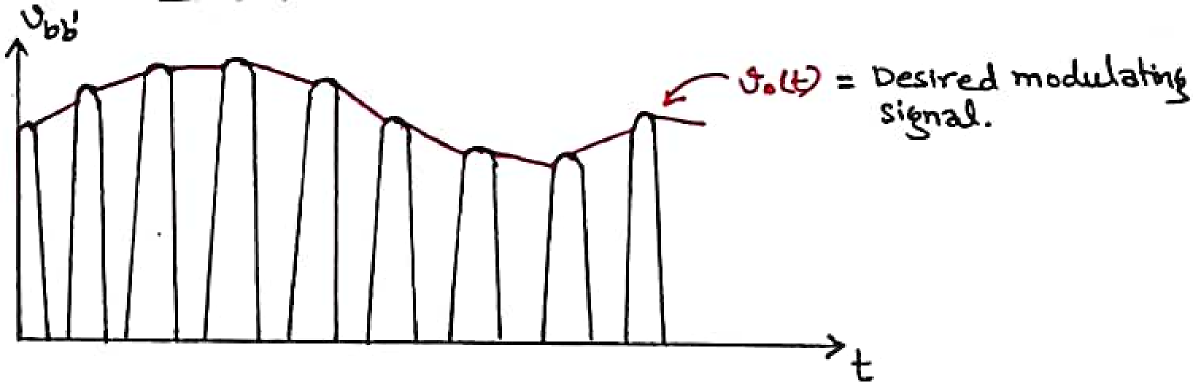

* When the RC time constant is MEDIUM then the output voltage follow very closely the envelope of composite signal and desired modulating signal is obtained.

SELECTION OF THE RC TIME CONSTANT

Assume, diode $\approx$ Ideal

Presenting

$$\left[\begin{array}{lll} \text{resistance } r_f \text{ to current flow} & \rightarrow & \text{FB region} \\ \text{Infinite } (\infty) \text{ resistance} & \rightarrow & \text{RB region.} \end{array}\right]$$

⊛ The charging time Constant $\boxed{(r_f+R_s)C \ll \frac{1}{f_c} \text{ (Carrier period)}}$

so, Capacitor C charges rapidly & thereby follows the applied Voltage up to the +ve peak when the diode is conducting.

The discharging time constant $R_L C$ must be long enough to ensure that the Capacitor discharges slowly through load resistance R_L between +ve peaks of the Carrier wave, but not so long that the capacitor voltage will not discharge at the maximum rate of change of the modulating wave.

The discharging time constant R_LC must be long enough to ensure that the Capacitor discharges slowly through load resistance R_L between the peaks of the carrier wave, but not so long that the capacitor voltage will not discharge at the maximum rate of change of the modulating wave.

i.e. $$\boxed{\frac{1}{f_c} << R_LC << \frac{1}{W}}$$

Where. W = message bandwidth

LIMITATIONS & MODIFICATION OF AM-DSB/FC

Transmitted Power ← Two primary Communication resources → Channel Bandwidth

↓

Used Efficiently.

AM suffers from two major practical limitations:

1) AM is wasteful of transmitted power :- The transmission of the carrier wave represents a waste of power.

2) AM is wasteful of Channel bandwidth :- As far as the transmission of information is concerned, only one sideband is necessary, and

Used Efficiently.

AM suffers from two major practical limitations:

1) AM is wasteful of transmitted power :- The transmission of the carrier wave represents a waste of power.

2) AM is wasteful of Channel bandwidth :- As far as the transmission of information is concerned, only one sideband is necessary, and the communciation channel need only the same bandwidth as the message signal. [As AM requires transmission bandwidth equal to twice the message bandwidth $\approx$ wasteful of channel bandwidth].

twice the message bandwidth ≈ wasteful of channel bandwidth].

THREE modifications of AM to overcome above limitations.

1) Double sideband - suppressed Carrier (DSB-SC) modulation:

"Transmitted power is saved through suppression of the carrier wave."
but channel bandwidth, $B_T = 2W$ i.e. twice of message bandwidth.

2) Single sideband (SSB) modulation:

"Transmitted power is saved through suppression of one of the sideband"
(USB or LSB).

* SSB is the optimum form of continuous-wave modulation as it requires the minimum transmitted power and minimum channel bandwidth.
* Practical disadvantage: 1) Increase Complexity
  2) Limited applicability.

the minimum transmitted power and minimum channel bandwidth.

- Practical disadvantage: 1) Increase Complexity
  2) Limited applicability.

(.2)

3) Vestigial sideband (VSB) modulation:

"One sideband is passed almost completely and just a trace, or vestige, of the other sideband is retained."

- The required channel bandwidth is slightly in excess of the message bandwidth by an amount equal to the width of the vestigial sideband.

- Well suited for the transmission of wideband signal such as TV signals, that contain significant components at extremely low frequencies.

DOUBLE SIDEBAND SUPPRESSED CARRIER (DSB-SC) MODULATION

- Carrier is completely independent of modulating signal $m(t)$, which means that the transmission of carrier wave represents a wastage of power.

- Efficiency of transmission can be improved by suppressing the carrier from modulated wave. This results in double sideband suppressed carrier (DSB-SC) modulation.

- The DSB-SC modulation is obtained by taking the product of carrier $c(t)$ and the modulating signal $m(t)$ as follows:

$$\boxed{S(t) = C(t)\, m(t)} \quad \text{----AM/DSB-SC}$$

(DSB-SC) modulation.

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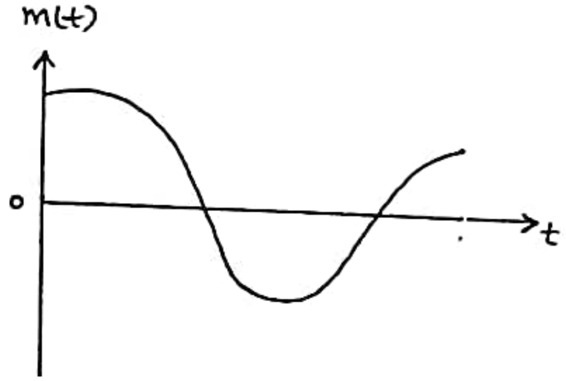
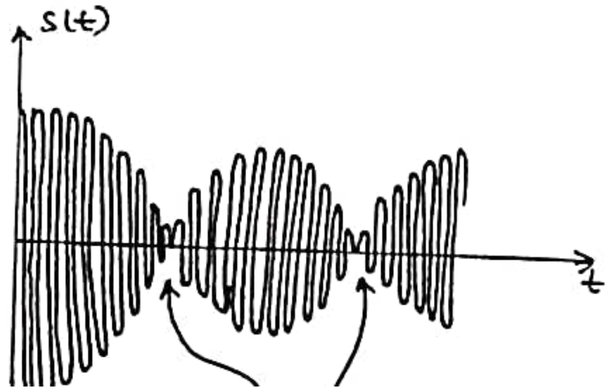
$$\boxed{S(t) = C(t)\, m(t)} \quad \text{----AM/DSB-SC}$$

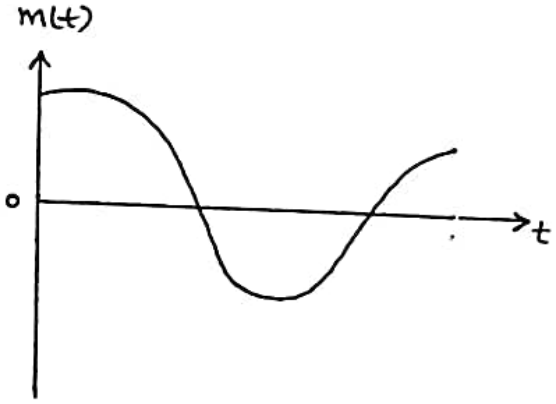
where $c(t) = A_c \cos\omega_c t$

$$\boxed{S(t) = A_c\, m(t) \cos\omega_c t}$$

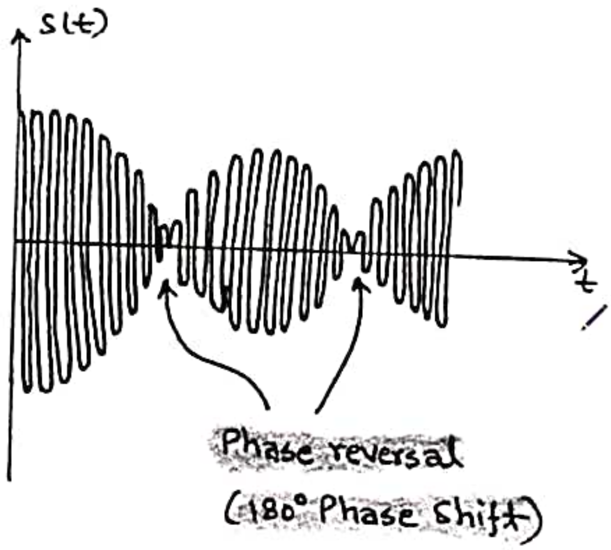




$$\boxed{s(t) = A_c\, m(t) \cos \omega_c t}$$



a) Base band signal



b) DSB-SC modulated wave

* The modulated wave undergoes a phase reversal whenever the modulating signal m(t) crosses zero.

FREQUENCY DOMAIN DESCRIPTION OF DSB-SC

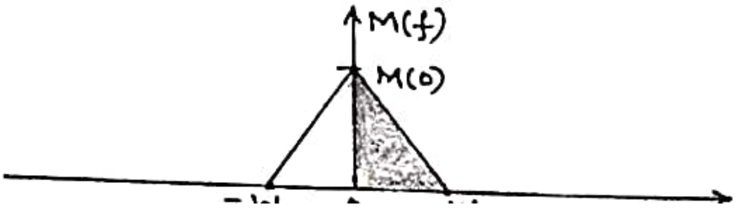
$s(t) = m(t)\,c(t) = A_c\, m(t) \cos(2\pi f_c t)$ ... Time domain.

$\Big\downarrow$ F.T.

$$F.T.\left[s(t)\right] = F.T.\left[A_c\, m(t)\cos(2\pi f_c t)\right] = A_c\, F.T.\left[m(t)\left\{\frac{e^{j2\pi f_c t} + e^{-j2\pi f_c t}}{2}\right\}\right]$$

$$S(f) = \frac{A_c}{2}\left\{F.T.\left[m(t)\,e^{j2\pi f_c t}\right] + F.T.\left[m(t)\,e^{-j2\pi f_c t}\right]\right\}$$

$$S(f) = \frac{A_c}{2}\left\{M(f-f_c) + M(f+f_c)\right\}$$



where

$M(f) \approx$ F.T. of $m(t)$

limited to the Interval $(-W \leq f \leq W)$

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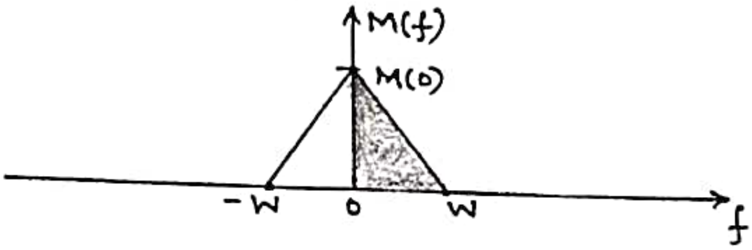

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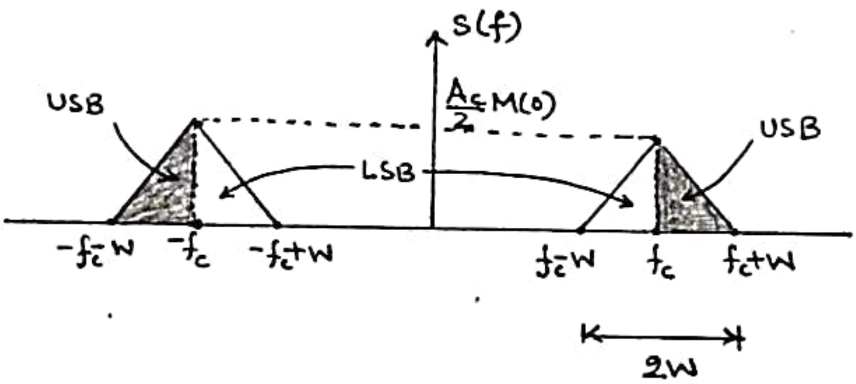
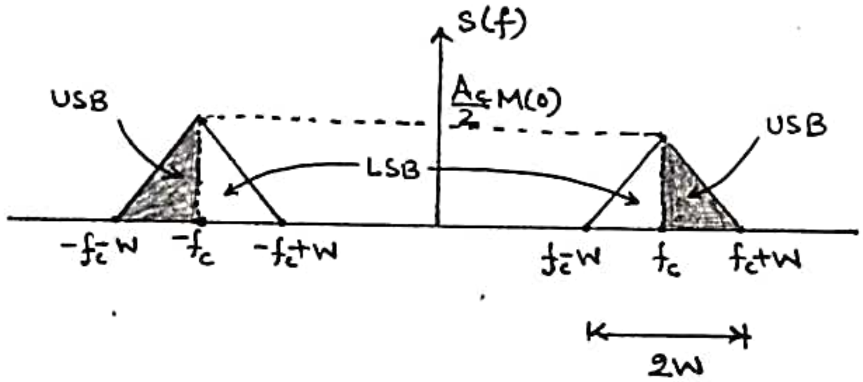
Assume arbitrary spectrum.



Transmission Bandwidth: $B_T = (f_c+W) - (f_c-W) = 2W$ (Hz)

J

→ Assume arbitrary spectrum.



Transmission Bandwidth: $B_T = (f_c+W) - (f_c-W) = \underline{2W}$ (Hz)

i.e. $\boxed{B_T = 2W}$

Note: The transmission bandwidth of DSB-SC is same as that of the standard AM (DSB-FC).

GENERATION OF DSB-SC WAVES (PRODUCT MODULATOR)

"RING MODULATOR is the most useful product modulator, also called chopper modulator.

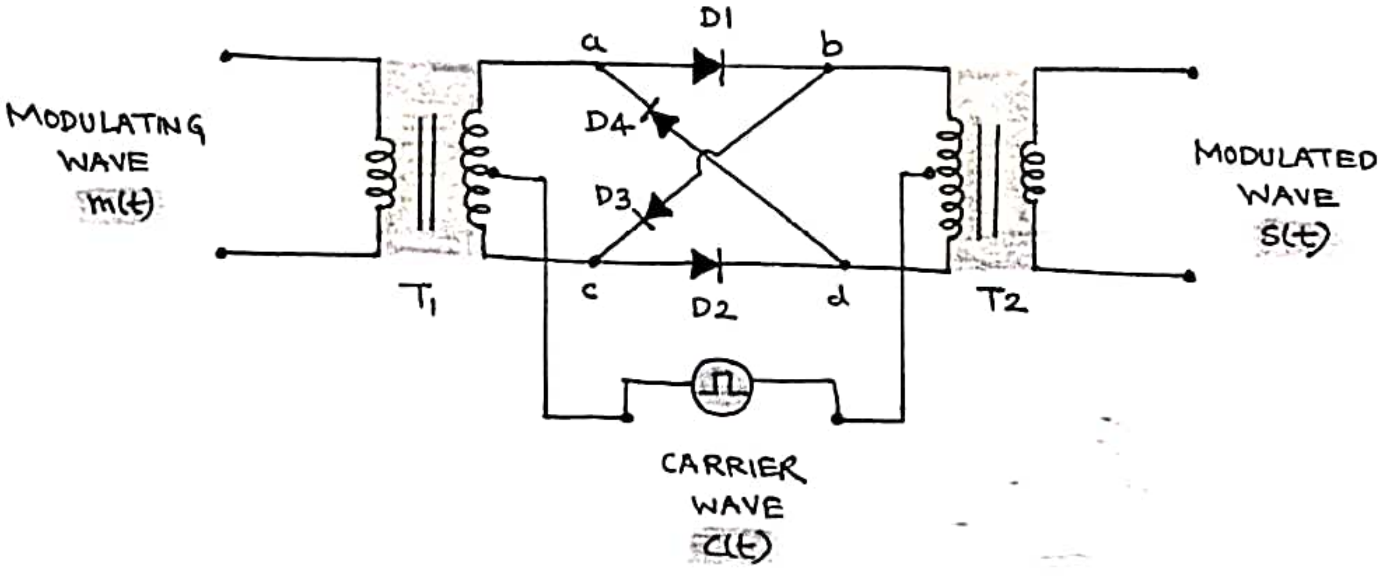


Fig: RING MODULATOR

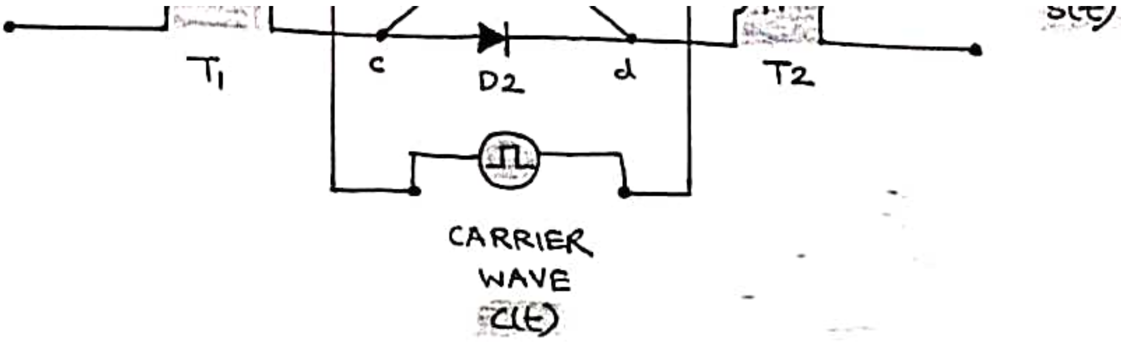


Fig: RING MODULATOR

⊛ The diodes are controlled by SQUARE WAVE carrier c(t) of frequency f_c applied across a centre tapped transformer.

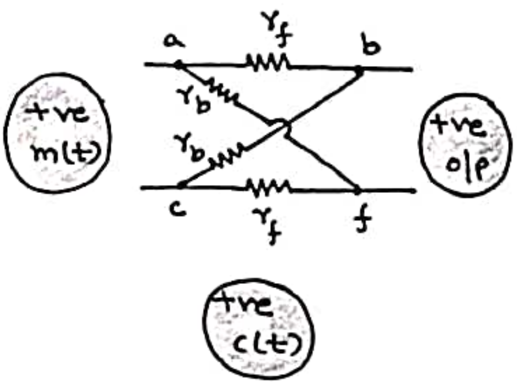
Note: When $m(t) = 0$; then output $s(t) = m(t)\,c(t) = 0$ ✓

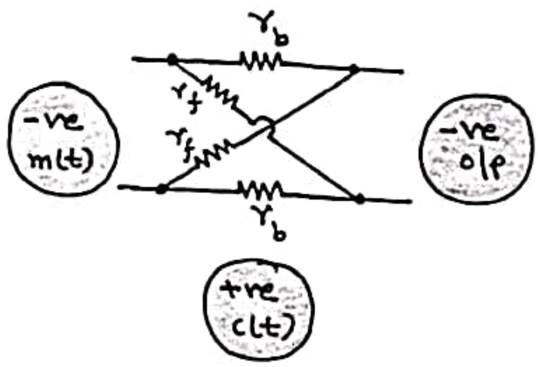
$m(t) \neq 0$; " " $s(t) = m(t)\,c(t)$

+ve half cycle of m(t).	-ve half cycle of m(t).
Case I. +ve half cycle of c(t)	Case I.

$m(t) \neq 0$; " " $s(t) = m(t)\, c(t)$

+ve half cycle of m(t).	-ve half cycle of m(t)
Case I +ve half cycle of c(t) $D_1 D_2 \approx$ Switch ON, $D_3 D_4 \approx$ Switch OFF } o/p $T_2 \approx$ +ve	**Case I** +ve half cycle of c(t) $D_1 D_2 \approx$ switch OFF, $D_3 D_4 \approx$ Switch ON } o/p $T_2 \approx$ -ve
Case II -ve half cycle of c(t) $D_1 D_2 \approx$ Switch OFF, $D_3 D_4 \approx$ Switch ON } o/p $T_2 \approx$ -ve	**Case II** -ve half cycle of c(t) $D_1 D_2 \approx$ switch ON, $D_3 D_4 \approx$ switch OFF } o/p $T_2 \approx$ +ve





m(t)	c(t)	s(t)
+	+	+
−	+	−
+	−	−
−	−	+

* The square wave carrier can be represented in Fourier Series as:

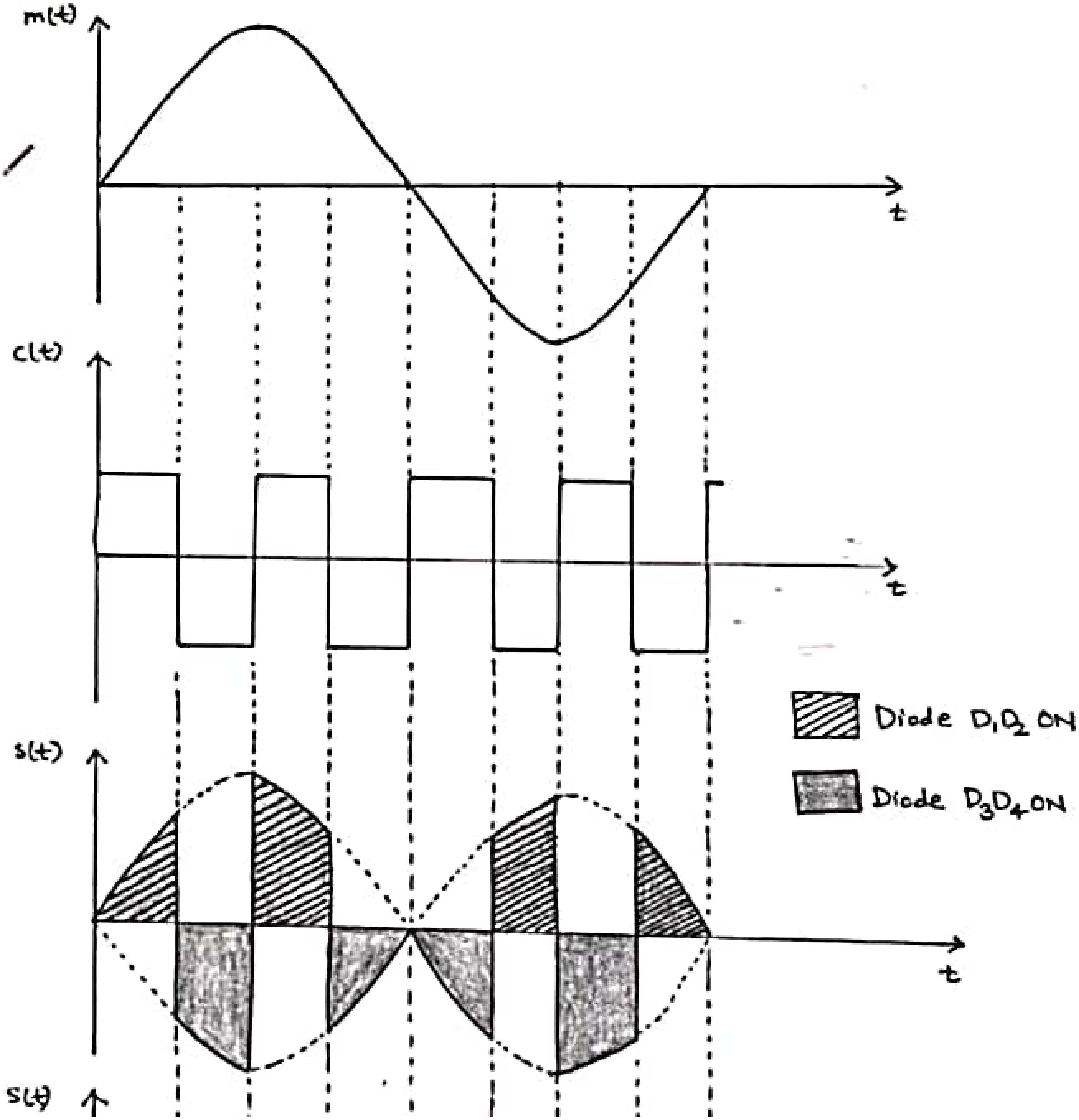
$$\boxed{c(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos\left[2\pi f_c t(2n-1)\right]}$$

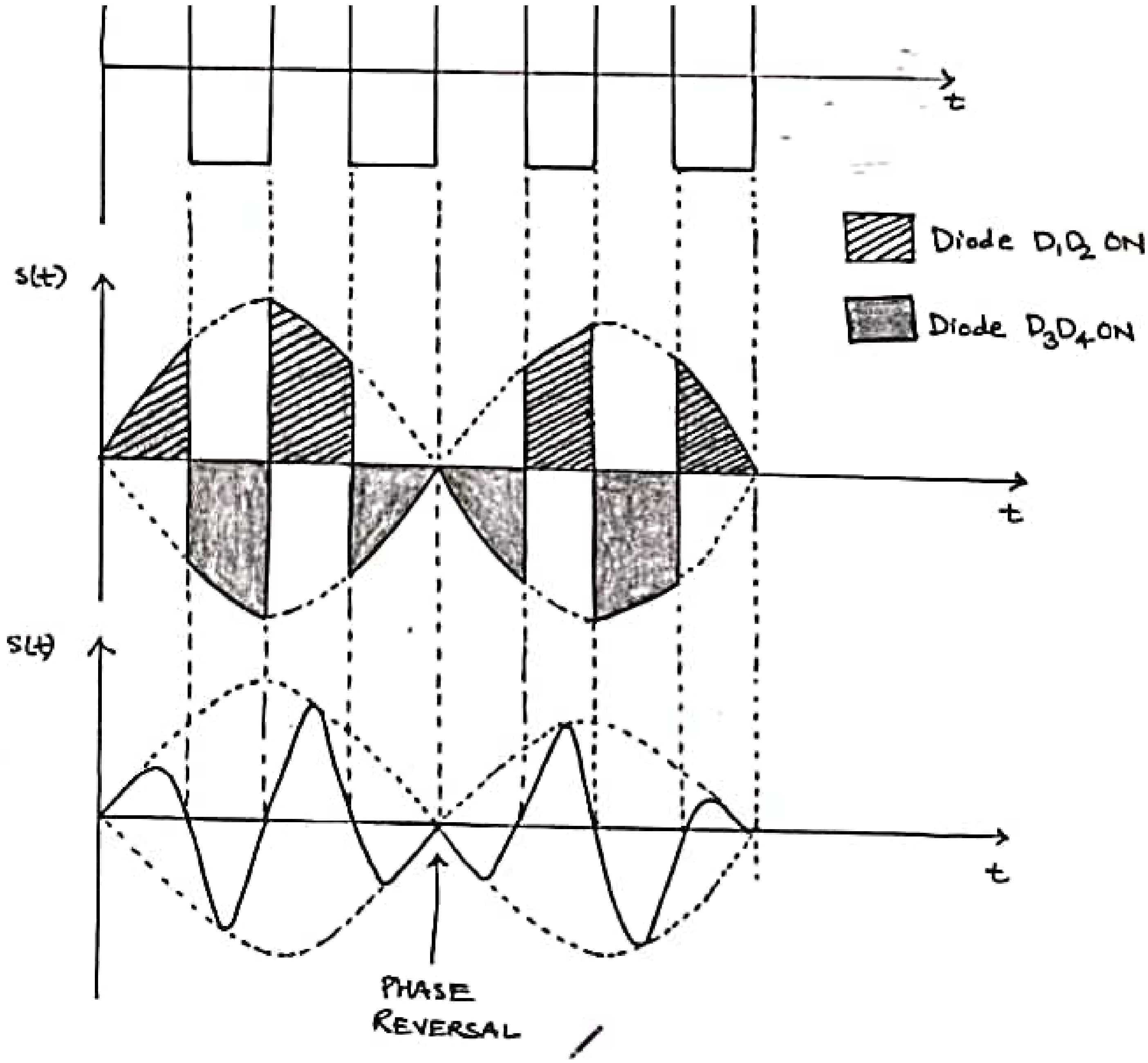
The ring modulator output is therefore

$$s(t) = m(t)\, c(t)$$

$$s(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos\left[2\pi f_c t\,(2n-1)\right] m(t)$$

* The ring modulator is sometimes referred to as the double-balanced modulator, because it is balanced w.r.t both the baseband signal; $m(t)$ & square wave carrier; $c(t)$.


m(t)
t
c(t)
t
s(t)
t
Diode D_1D_2 ON
Diode D_3D_4 ON
s(t)



t
Diode D_1D_2 ON
Diode D_3D_4 ON
s(t)
t
s(t)
t
PHASE
REVERSAL

DEMODULATION (Detection) of DSB-SC SIGNALS

"COHERENT or SYNCHRONOUS DEMODULATION"

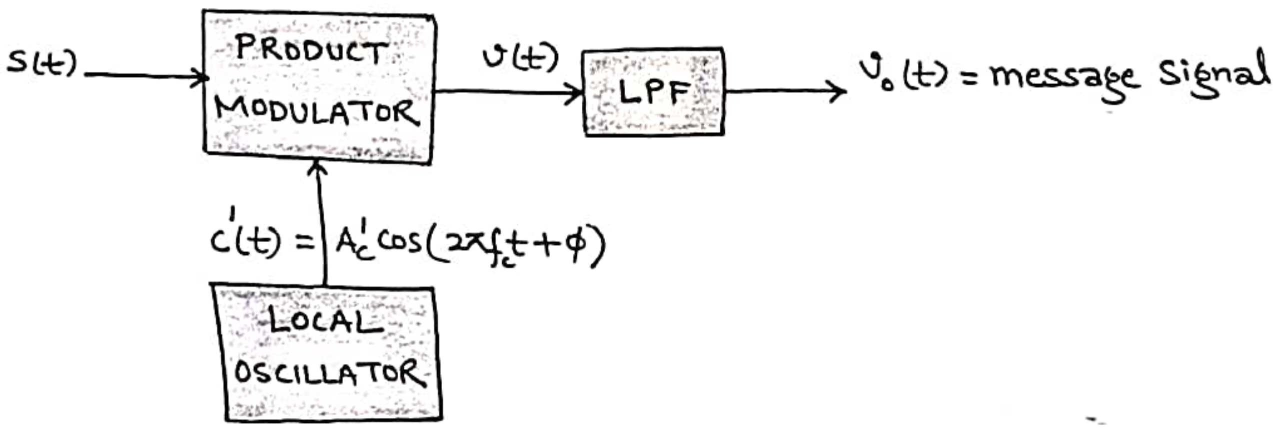


Fig: COHERENT DETECTION of DSB-SC modulated wave.

* The baseband signal $m(t)$ can be uniquely recovered from a DSB-SC wave $s(t)$ by first multiplying $s(t)$ with a locally generated sinusoidal wave and then pass through L.P.F.

Note :- It is assumed that the local oscillator signal is exactly coherent or synchronized, in both frequency & phase with the carrier wave $c(t)$ used in the product modulator to generate $s(t)$.

Special case :- A local oscillator signal having same frequency but arbitrary phase difference ϕ, measured w.r.t $c(t)$.

Thus, denoting the local oscillator signal by $A_c' \cos(2\pi f_c t + \phi)$.

Thus, denoting the local oscillator signal by $A_c' \cos(2\pi f_c t + \phi)$.

* The L.P.F is used for eliminating all the unwanted frequency component i.e. (high frequency component) from the output of product modulator.

The DSB-SC wave is given by:

$$s(t) = c(t)\, m(t) = A_c\, m(t) \cos(2\pi f_c t)$$

The product modulator o/p:

$$v(t) = c'(t)\, s(t)$$

$$v(t) = c'(t)\, s(t)$$

$$v(t) = \underbrace{A_c' \cos(2\pi f_c t + \phi)}_{c'(t)}\ \underbrace{A_c \cos(2\pi f_c t)\, m(t)}_{s(t) = c(t)m(t)}$$

$$v(t) = A_c A_c' \underbrace{\cos(2\pi f_c t + \phi) \cos(2\pi f_c t)}_{\cos A \cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]} m(t)$$

$$v(t) = \underbrace{\frac{1}{2} A_c A_c' \cos(4\pi f_c t + \phi)\, m(t)}_{\text{Unwanted term}} + \underbrace{\underbrace{\frac{1}{2} A_c A_c' \cos\phi}_{\text{constant}}\, m(t)}_{\text{Proportional to } m(t)}$$

Removed by

$$v(t) = \underbrace{\frac{1}{2}A_cA_c' \cos(4\pi f_c t + \phi)\, m(t)}_{\text{Unwanted term}} + \underbrace{\underbrace{\frac{1}{2}A_cA_c' \cos\phi}_{\text{constant}}\, m(t)}_{\text{Proportional to } m(t)}$$

Unwanted term $\xrightarrow{\text{Removed by}}$ $\boxed{\text{LPF}}$

Proportional to $m(t)$ $\xrightarrow{\text{Allow by}}$ $\boxed{\text{LPF}}$

Note:- The cut-off frequency of this filter is greater than W but less than $(2f_c - W)$. Thus the output of filter, we get

$$\boxed{v_o(t) = \frac{1}{2}A_cA_c' \cos\phi\, m(t)}$$

Note:- The cut-off frequency of this filter is greater than W but less than $(2f_c - W)$. Thus the output of filter, we get

$$\boxed{v_o(t) = \frac{1}{2} A_c A_c' \cos\phi \; m(t)}$$

$v_o(t) \propto m(t)$ when phase error is constant.

QUADRATURE NULL EFFECT :

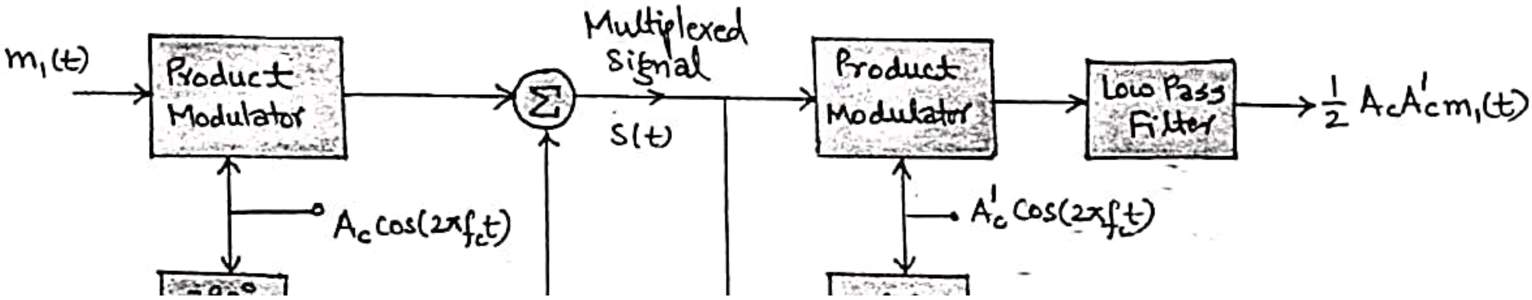
- The amplitude of the demodulated signal $v_o(t)$ is maximum when $\phi = 0$ & minimum when $\phi = \pm\frac{\pi}{2}$ i.e. 0

So, when $\phi = \pm\frac{\pi}{2}$ represents Quadrature Null effect of the coherent detector.

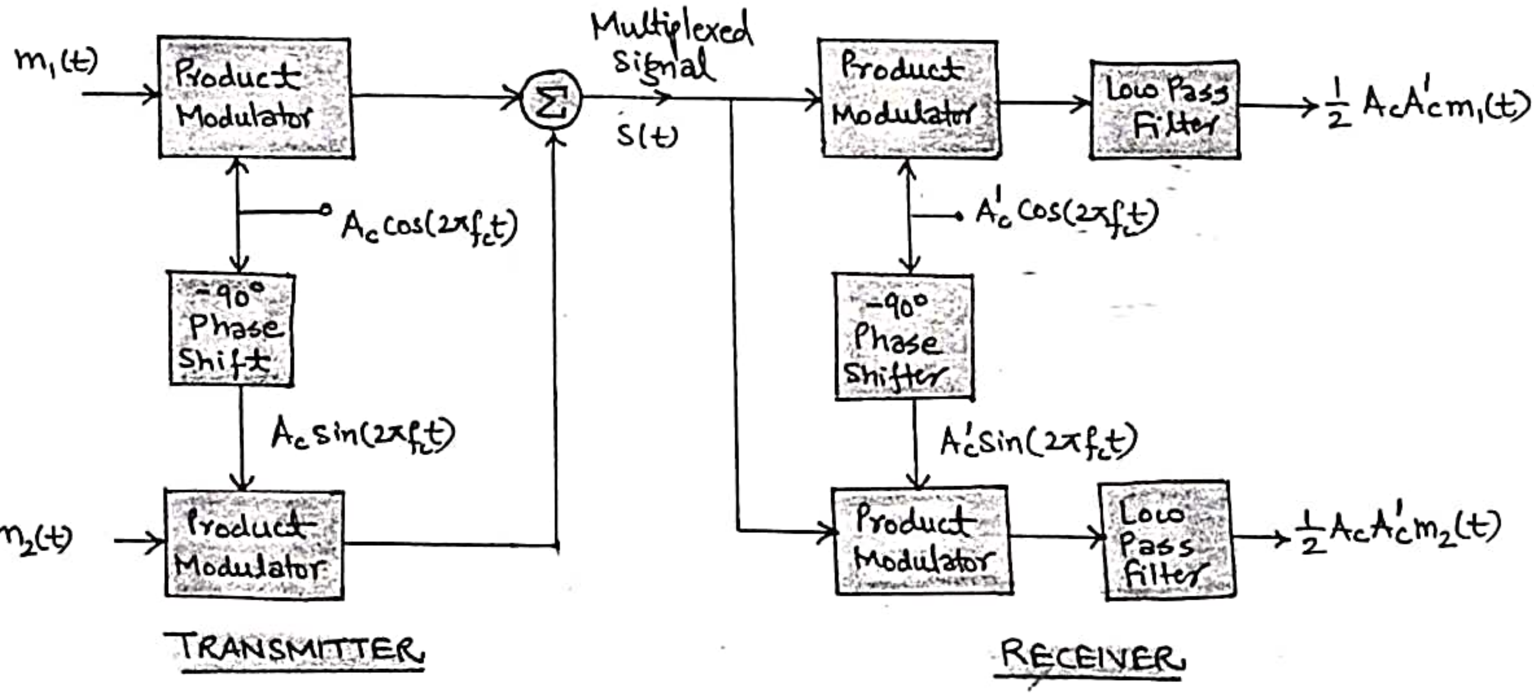
QUADRATURE - CARRIER MULTIPLEXING.

- The quadrature null effect of the coherent detector may also be used in the construction of Quadrature-carrier multiplexing or Quadrature-amplitude modulation (QAM).

- This technique enable two DSB-SC modulated wave (using two independent message signal, $m_1(t)$ & $m_2(t)$) to occupy the same channel bandwidth, so called a bandwidth-conservation scheme.



message signal, $m_1(t)$ & $m_2(t)$) to occupy the same channel bandwidth, so called a <u>bandwidth - conservation scheme</u>.



TRANSMITTER

1) Two separate product modulators supplied with two carrier waves of same frequency but different in phase by $-90°$.

$$\boxed{s(t) = A_c m_1(t)\cos(2\pi f_c t) + A_c m_2(t)\sin(2\pi f_c t)}$$

(Multiplexed band-pass signal)

$A_c m_1(t) \longrightarrow$ Inphase Component
$A_c m_2(t) \longrightarrow$ Quadrature ,,

2) $s(t)$ occupy a channel bandwidth of $2W$ centred on carrier frequency f_c where W is the message bandwidth.

RECEIVER

1) Multiplexed signal $s(t)$ applied simultaneously to two separate coherent detectors, supplied with two local carriers of same frequency but differing in phase by $-90°$.

2) o/p of Top detector $= \frac{1}{2} A_c A_c' m_1(t)$

o/p of Bottom detector $= \frac{1}{2} A_c A_c' m_2(t)$

Note: To operate satisfactorily.

Maintain correct phase & frequency relationships between the oscillator used to generate the carriers in the transmitter & the corresponding local oscillator used in the receiver.

SINGLE - SIDEBAND MODULATION (SSB)

Transmitted Signal ; DSB-SC → USB, LSB } Information contained is Identical.

So, [carrier + one of sidband ≈ Suppressed] → SSB or SSB-SC
→ Lower SSB or LSSB
Upper SSB (USSB)

one of sidband → No Information is Lost

Theory : Consider $m(t) = A_m \cos(2\pi f_m t)$

$c(t) = A_c \cos(2\pi f_c t)$

DSB-SC

$$S_{DSB}(t) = c(t)\, m(t)$$

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

Theory: Consider $m(t) = A_m \cos(2\pi f_m t)$

$c(t) = A_c \cos(2\pi f_c t)$

DSB-SC

$$S_{DSB}(t) = c(t)\,m(t)$$

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

$$= \frac{1}{2} A_c A_m \cos\left[2\pi(f_c + f_m)t\right] + \frac{1}{2} A_c A_m \cos\left[2\pi(f_c - f_m)t\right]$$

Two side frequencies $\rightarrow$ $f_c + f_m$ ----- Upper side frequency

$\rightarrow$ $f_c - f_m$ ---- Lower side frequency

$$S_{USSB}(t) = \frac{1}{2} A_c A_m \cos\left[2\pi(f_c + f_m)t\right] \quad \text{-----} \quad \cos(A+B) = \cos A \cos B - \sin A \sin B$$

$$= \frac{1}{2} A_c A_m \cos(2\pi f_c t)\cos(2\pi f_m t) - \frac{1}{2} A_c A_m \sin(2\pi f_c t)\sin(2\pi f_m t)$$

$$S_{LSSB}(t) = \frac{1}{2} A_c A_m \cos\left[2\pi(f_c - f_m)t\right] \quad \text{-----} \quad \cos(A-B) = \cos A \cos B + \sin A \sin B$$

$$S_{LSSB}(t) = \frac{1}{2} A_c A_m \cos[2\pi(f_c - f_m)t] \quad \text{----} \quad \cos(A-B) = \cos A \cos B + \sin A \sin B$$

$$= \frac{1}{2} A_c A_m \cos(2\pi f_c t)\cos(2\pi f_m t) + \frac{1}{2} A_c A_m \sin(2\pi f_c t)\sin(2\pi f_m t)$$

USSB

$$\boxed{S_{SSB}(t) = \frac{1}{2} A_c A_m \cos(2\pi f_c t)\cos(2\pi f_m t) \mp \frac{1}{2} A_c A_m \sin(2\pi f_c t)\sin(2\pi f_m t)}$$

LSSB

General SSB

---

(12)

Now Consider a periodic message signal, defined by Fourier series

$$\left.\begin{aligned} m(t) &= \sum_n a_n \cos(2\pi f_m t) \\ \text{Also} \quad \hat{m}(t) &= \sum_n a_n \sin(2\pi f_m t) \end{aligned}\right\} \text{mixture of sinusoidal waves with harmonically related frequencies.}$$

Note: Carrier $c(t)$ is common to all the sinusoidal component of $m(t)$ or $\hat{m}(t)$.

$$\ldots - \sum_n a_n \sin(2\pi f_m t) \Big]$$

Note: Carrier $c(t)$ is common to all the sinusoidal component of $m(t)$ or $\hat{m}(t)$.

SSB :
$$S_{SSB}(t) = \frac{1}{2}A_cA_m\cos(2\pi f_c t)\cos(2\pi f_m t) \mp \frac{1}{2}A_cA_m\sin(2\pi f_c t)\sin(2\pi f_m t)$$

$$S_{SSB}(t) = \frac{1}{2}A_c\cos(2\pi f_c t)\sum_n a_n\cos(2\pi f_m t) \mp \frac{1}{2}A_c\sin(2\pi f_c t)\sum_n a_n\sin(2\pi f_m t)$$

$$\boxed{S_{SSB}(t) = \frac{A_c}{2}m(t)\cos(2\pi f_c t) \underset{\text{LSSB}}{\overset{\text{USSB}}{\mp}} \frac{A_c}{2}\hat{m}(t)\sin(2\pi f_c t)}$$

Note: Periodic signal $\hat{m}(t)$ can be derived from the periodic modulating signal $m(t)$ simply by shifting the phase of each cosine term in $m(t)$ by $-90°$; by a method called <u>HILBERT TRANSFORM</u>.

HILBERT TRANSFORMER is a <u>wide-band phase-shifter</u> whose frequency response is characterized in two parts:

HILBERT TRANSFORMER is a wide-band phase shifter whose frequency response is characterized in two parts:

1) The magnitude response is unity for all frequencies, both +ve and −ve.

2) The phase response is +90° for −ve frequencies & −90° for +ve frequencies

---

* Hilbert transform of m(t) denoted by $\hat{m}(t)$

Thus, $\hat{m}(t) = m(t) * \frac{1}{\pi t} = \frac{1}{\pi}\int_{-\infty}^{\infty} m(\tau)\, \frac{1}{(t-\tau)}\, d\tau$ or $\boxed{\frac{1}{\pi}\int_{-\infty}^{\infty} \frac{m(\tau)}{t-\tau}\, d\tau}$

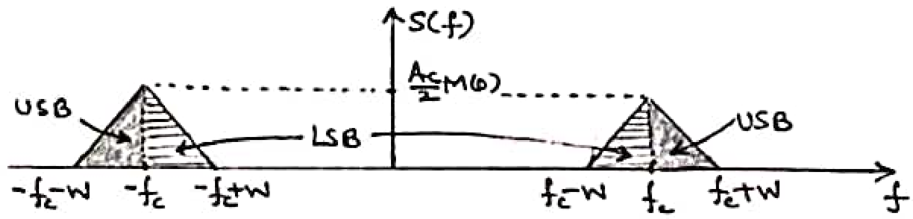
$$m(t) \longrightarrow \boxed{\begin{array}{c}\text{Phase Shifter} \\ -\frac{\pi}{2}\ \text{rad}\end{array}} \longrightarrow \hat{m}(t)$$

$$\text{H.T.}\left[A_m \cos(2\pi f_m t)\right] = A_m \sin(2\pi f_m t)$$

FREQUENCY DOMAIN DESCRIPTION

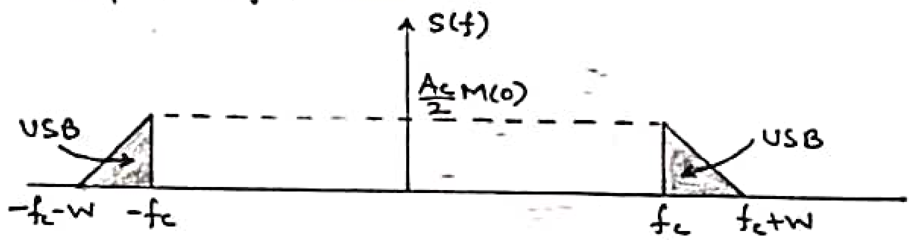
FREQUENCY DOMAIN DESCRIPTION

a) Spectrum of m(t)

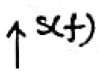


b) Spectrum of DSB-SC

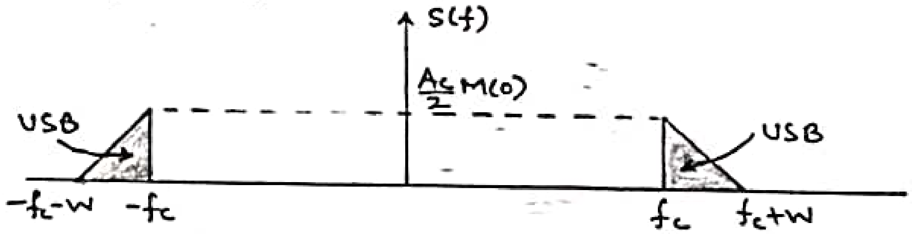
$$S_{USSB} = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) - \hat{m}(t)\sin(2\pi f_c t)\right]$$



c) Spectrum of USSB

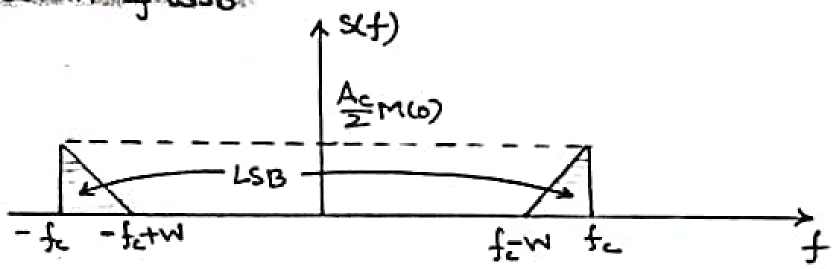


$$S_{USSB} = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) - \hat{m}(t)\sin(2\pi f_c t)\right]$$



c) Spectrum of USSB

$$S_{LSSB} = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) + \hat{m}(t)\sin(2\pi f_c t)\right]$$



d) Spectrum of LSSB

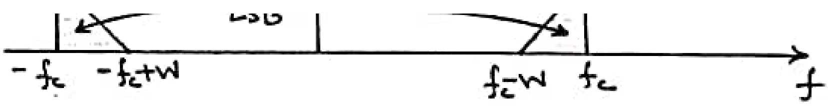
Note:- Basically, a Hilbert Transformer is a system whose transfer function is defined by.

$\boxed{H(f) = -j\,\mathrm{sgn}(f)}$ where $\mathrm{sgn}(f)$ = signum function

Properties of HILBERT TRANSFORM

1) A signal $f(t)$ and its Hilbert Transform $f_h(t)$ have the same energy density spectrum.

$S_{LSSB} = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) + \hat{m}(t)\sin(2\pi f_c t)\right]$



d) Spectrum of LSSB

<u>Note</u>:- Basically, a Hilbert Transformer is a system whose transfer function is defined by.

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<u>Properties of HILBERT TRANSFORM</u>

1) A signal $f(t)$ and its Hilbert Transform $f_h(t)$ have the same energy density spectrum.

2) A signal $f(t)$ and its Hilbert transform $f_h(t)$ have the same autocorrelation function.

3) A signal $f(t)$ and its Hilbert transform $f_h(t)$ are mutually orthogonal, i.e.

$$\boxed{\int_{-\infty}^{\infty} f(t)\, f_h(t)\, dt = 0}$$

4) If $f_h(t)$ is a Hilbert transform of $f(t)$, then the Hilbert transform of $f_h(t)$ is $-f(t)$, i.e.

If $\boxed{H.T[f(t)] = f_h(t)}$ than $\boxed{H.T[f_h(t)] = -f(t)}$

GENERATION OF SSB / SSB MODULATOR

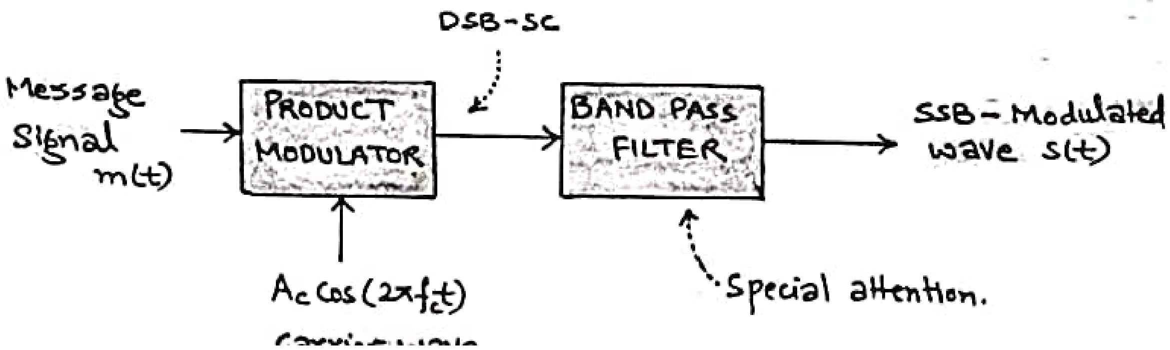
Frequency Discrimination method
(Filter method)

Uses sharp cut-off filters to eliminate the undesired sideband.

Phase Discrimination method
(Phase shift method)

Use phase-shifting network to achieve the same goal.

FREQUENCY DISCRIMINATION METHOD



- Basically consist of a product modulator (Balanced modulator) followed by band-pass filter.

- Output of product modulator ≈ DSB-SC modulated wave (contains two sidebands only.)

- <u>Band Pass filter</u> is designed to pass the desired sideband of DSB-SC & reject the other sideband, depending on whether the USSB or LSSB is the desired modulation.

<u>Design of Band-Pass filter</u> :- There must be a certain separation between the two sidebands that is wide enough to accommodate the transition band of the band-pass filter.

<u>Note</u>:- This separation ≈ $2f_a$ where f_a ≈ lowest frequency component of the message signal.

Fig (a) Spectrum of m(t) with energy gap centered around zero frequency.

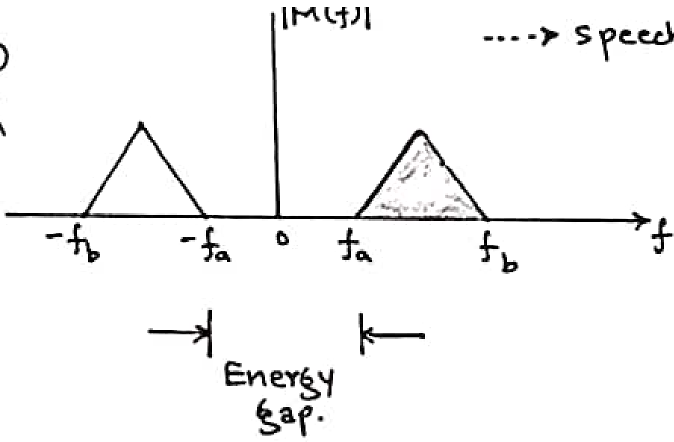


Fig (b) USSB with only +ve frequencies.

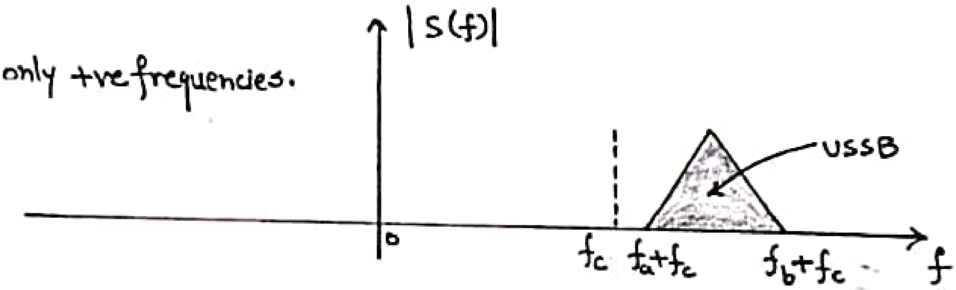
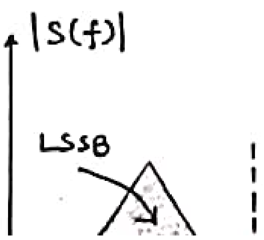
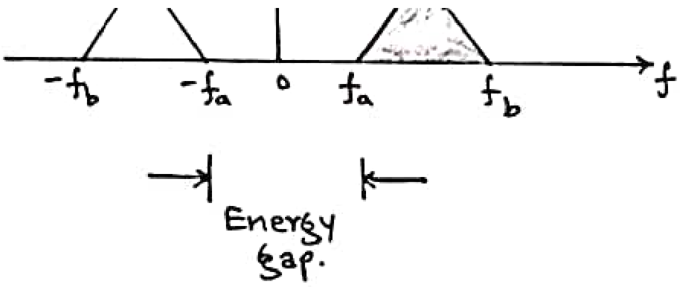


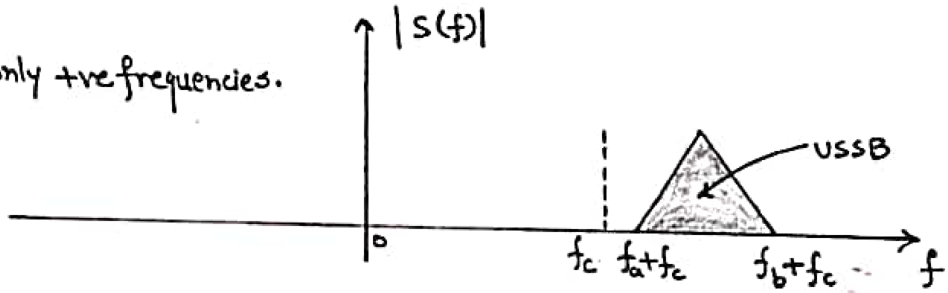
Fig (c) LSSB with only +ve frequencies.



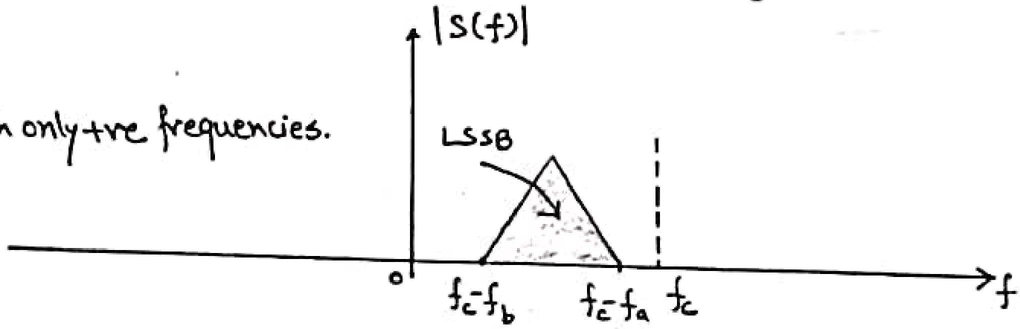
around zero frequency.

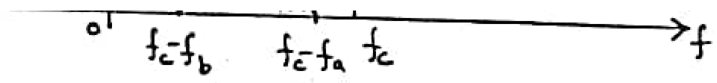


Fig(b) USSB with only +ve frequencies.

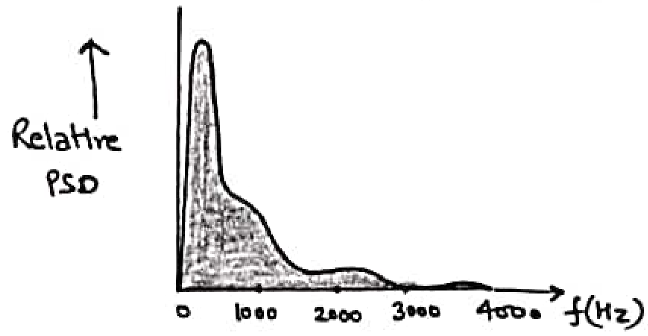


Fig(c) LSSB with only +ve frequencies.

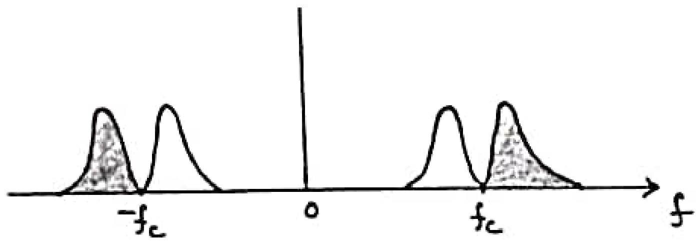




Disadvantage:- The design requirement of Band Pass filter, limits the applicability of SSB modulation to speech signals for which $f_a \approx 100\,Hz$, but for video signals & computer data whose spectral content extends down to almost zero frequency.

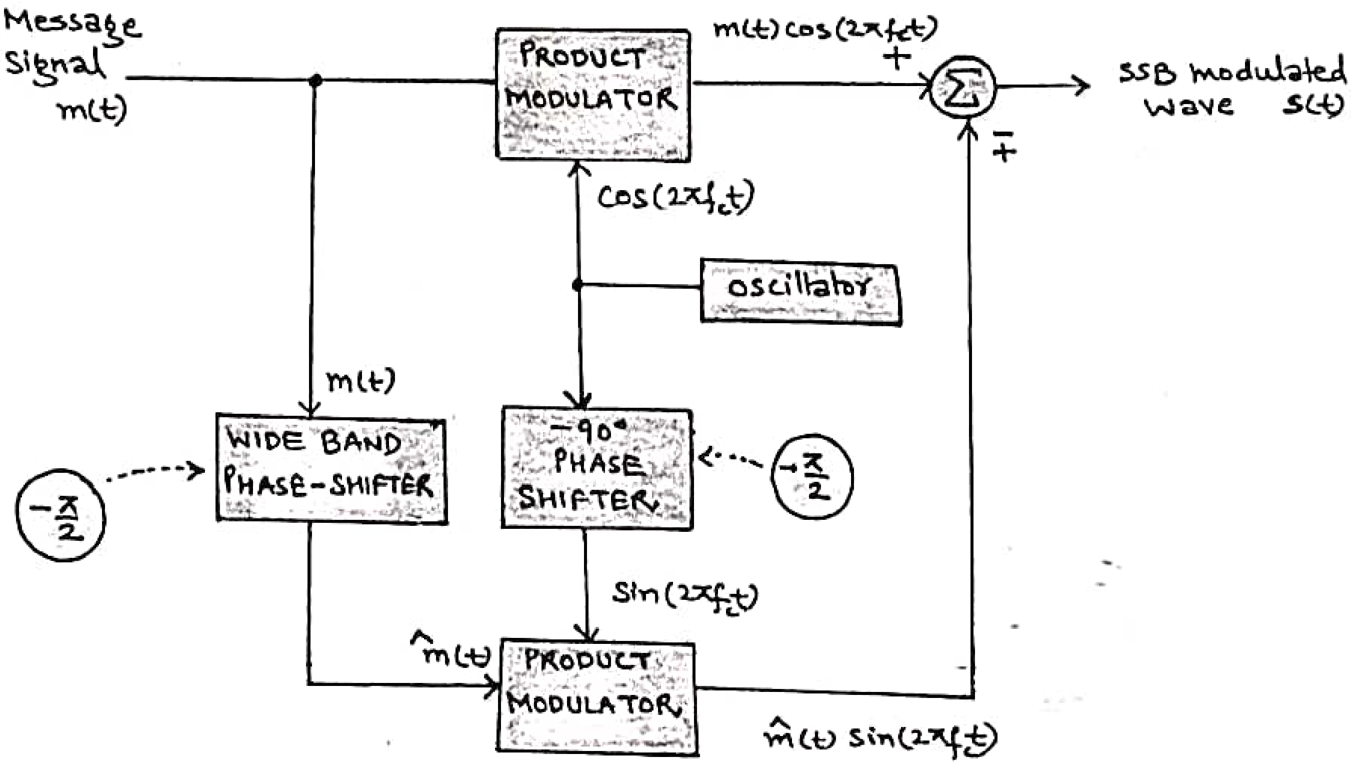


(Speech Signal)



Corresponding USSB spectrum

PHASE DISCRIMINATION METHOD



⊛ Represents Time domain description of SSB wave.

* Having two parallel paths $\begin{cases} \rightarrow \text{In-phase} \\ \rightarrow \text{Quadrature} \end{cases}$ } Each Involve Product modulator

* Sinusoidal carrier applied to the two product modulator are in phase-Quadrature (using -90° phase shifter).

* Special block ≈ WIDE BAND PHASE SHIFTER
  specially designed → To produce the Hilbert transform $\hat{m}(t)$ In response to incoming $m(t)$.

Note:- The role of the Quadrature path including wide-band phase shifter is basically to interfere with the in-phase path so as to eliminate power in one of the two sidebands (USSB or LSSB) depending on requirements.

Also, the two modulators are different in their structures.

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The time domain description of SSB signal is given by

$$s(t) = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) \overset{\text{USSB}}{\underset{\text{LSSB}}{\mp}} \hat{m}(t)\sin(2\pi f_c t)\right]$$

Advantage of Phase Discrimination method.

1) It can generate the SSB at any frequency.
2) It can use the low audio frequencies as modulating signals.
3) It is easy to switch from one sideband to the other.

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2) It can use the low audio frequencies as modulating signals.
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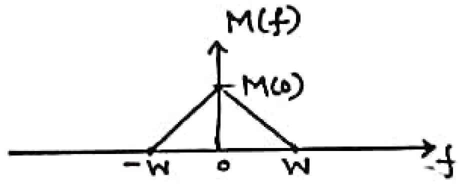
NOTE:

GENERATION OF SSB

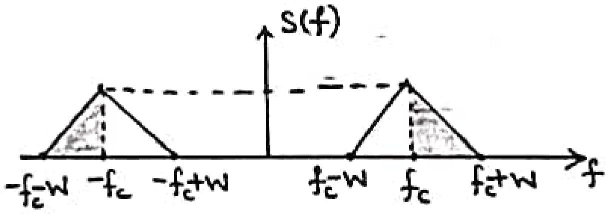
- **Frequency Discrimination method.** (Used for Multi-tone SSB generation.)
- **Phase Discrimination method.** (Used only for single-tone SSB generation.)

DRAW BACK OF FREQUENCY DISCRIMINATION METHOD

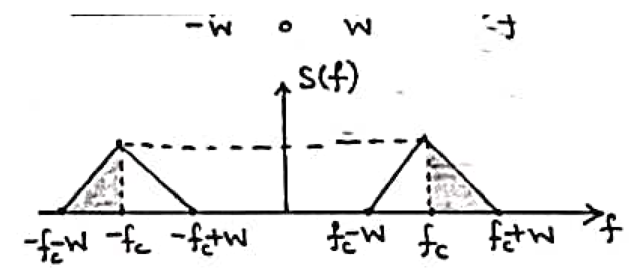
$m(t) \longleftrightarrow$



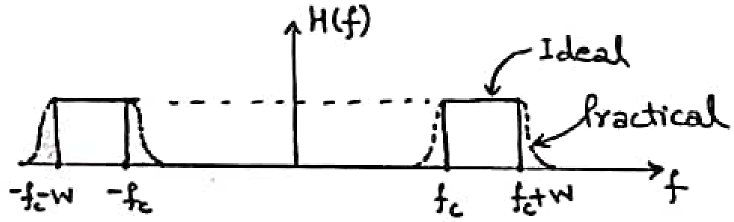
$S_{DSB}(t) \longleftrightarrow$



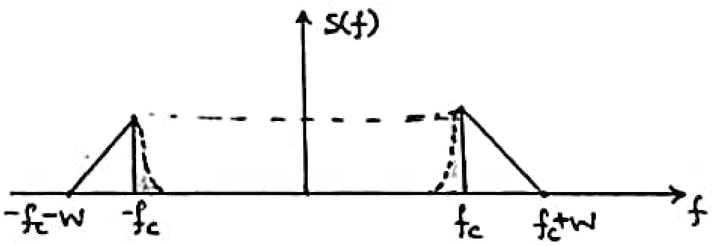
$S_{DSB}(t)$ $\longleftrightarrow$



BPF $\longleftrightarrow$

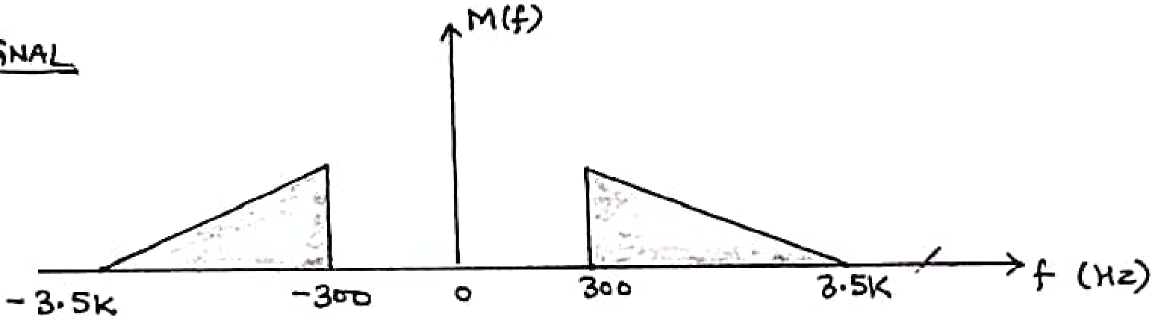


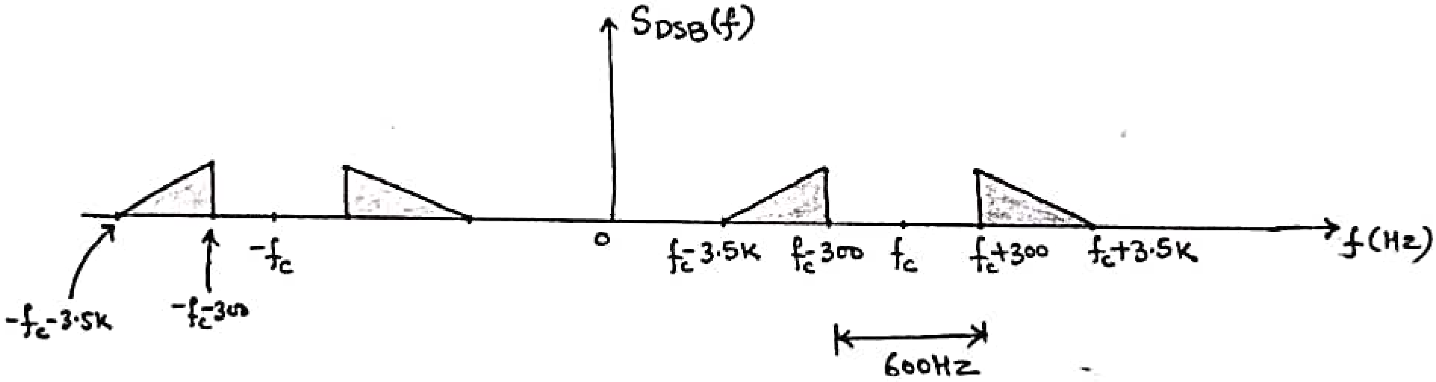
USSB $\longleftrightarrow$

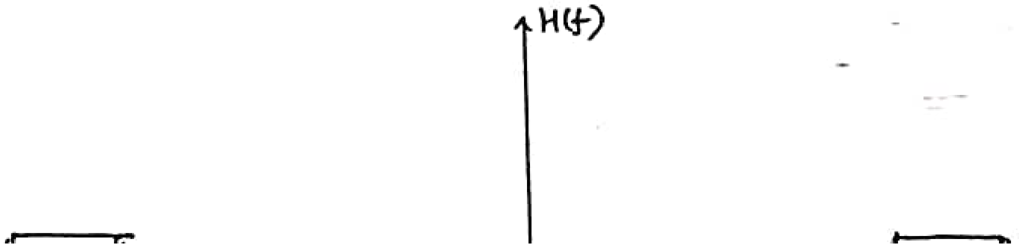


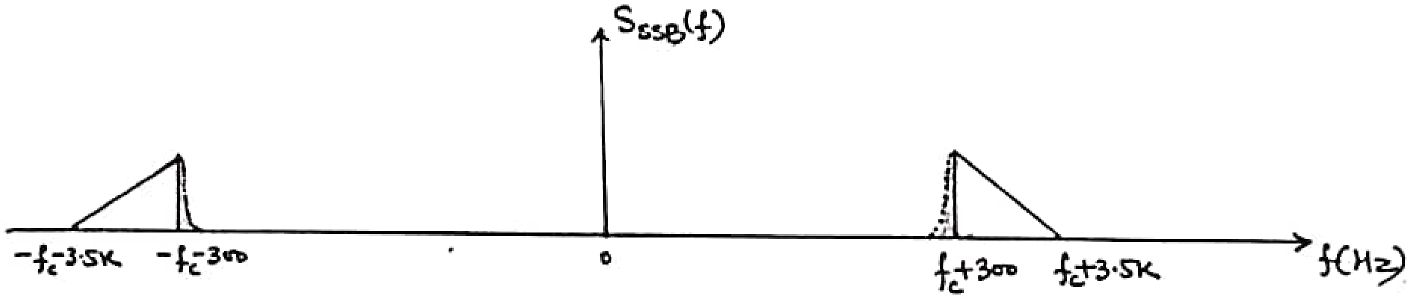
Since, BPF is not ideal, resulting SSB signal contains additional frequency component from other sideband. Because of above drawback SSB is limited only for voice transmission.

VOICE SIGNAL









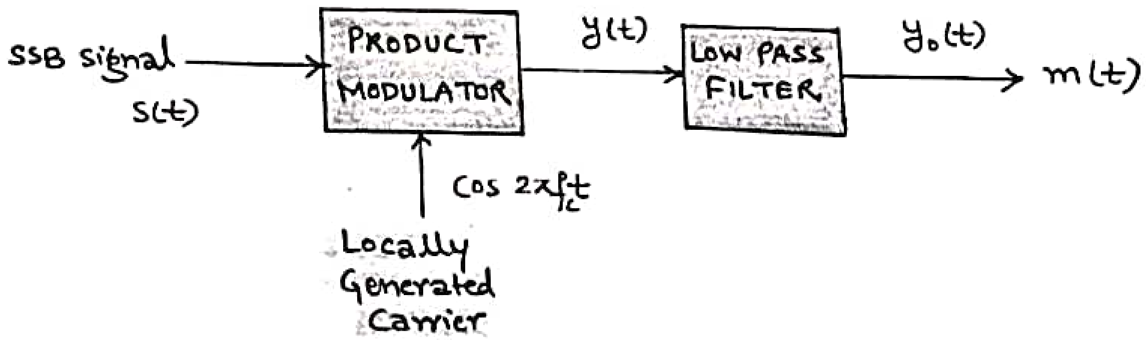
Note:- To transmit a message signal (i.e. voice signal), by SSB, the band gap of 600 Hz is properly adjust between sideband. So that voice signal can be confortably transmitted.

But not suitable for video signal, & audio signal.

SSB DEMODULATOR

COHERENT DETECTION OF SSB (synchronous detection).

It use similar arrangement as used in detecting DSB-SC signal.



$$s(t) = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) \mp \hat{m}(t)\sin(2\pi f_c t)\right]$$

o/p of product modulator.

$$y(t) = s(t).\cos(2\pi f_c t)$$

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$$= \frac{A_c}{2}\left[m(t)\cos 2\pi f_c t \mp \hat{m}(t)\sin(2\pi f_c t)\right]\cos(2\pi f_c t)$$

$$= \frac{A_c}{2} m(t)\underbrace{\cos^2(2\pi f_c t)}_{\cos^2 A = \frac{1+\cos 2A}{2}} \mp \frac{A_c}{2}\hat{m}(t)\underbrace{\cos(2\pi f_c t)\sin(2\pi f_c t)}_{\cos A \sin B = \frac{1}{2}[\sin(A+B) - \sin(A-B)]}$$

$$y(t) = \frac{A_c}{2} m(t)\left(\frac{1+\cos 4\pi f_c t}{2}\right) \mp \frac{A_c}{4}\hat{m}(t)\left[\sin(4\pi f_c t - \sin 0)\right]$$

$$y(t) = \underbrace{\frac{A_c}{4} m(t)}_{\text{scaled}} + \underbrace{\frac{A_c}{4} m(t)\cos(4\pi f_c t) \mp \frac{A_c}{4}\hat{m}(t)\sin(4\pi f_c t)}_{\text{Unwanted}}$$

Pass through

$$= \frac{A_c}{2} m(t) \underbrace{\cos^2(2\pi f_c t)}_{\cos^2 A = \frac{1+\cos 2A}{2}} \mp \frac{A_c}{2} \hat{m}(t) \underbrace{\cos(2\pi f_c t)\sin(2\pi f_c t)}_{\cos A \,\cancel{\cos}\, \sin B = \frac{1}{2}[\sin(A+B) - \sin(A-B)]}$$

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$$y(t) = \underbrace{\frac{A_c}{4} m(t)}_{\text{scaled message signal}} + \underbrace{\frac{A_c}{4} m(t)\cos(4\pi f_c t) \mp \frac{A_c}{4} \hat{m}(t)\sin(4\pi f_c t)}_{\text{Unwanted component.}}$$

Pass through L.P.F

Allow only first term.

$$\boxed{y_o(t) = \frac{A_c}{4} m(t)}$$

VESTIGIAL SIDEBAND MODULATION (VSB)

SSB modulation works easily for a speech signal with an energy gap centered around zero frequency. But, the spectra of wideband signals (like TV video signals & computer data) contains significant low frequencies, so it is impractical to use SSB modulation.

Also, the spectra of the wideband data can easily use DSB-SC modulation. However, DSB-SC requires a transmission bandwidth equal to twice the message bandwidth, which violates the bandwidth conservation requirement.

To overcome this practical limitations, we need a compromise method of modulation that lies between SSB & DSB-SC in its spectral characteristics.

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To overcome this practical limitations, we need a <u>compromise</u> method of modulation that lies between SSB & DSB-SC in its spectral characteristics.

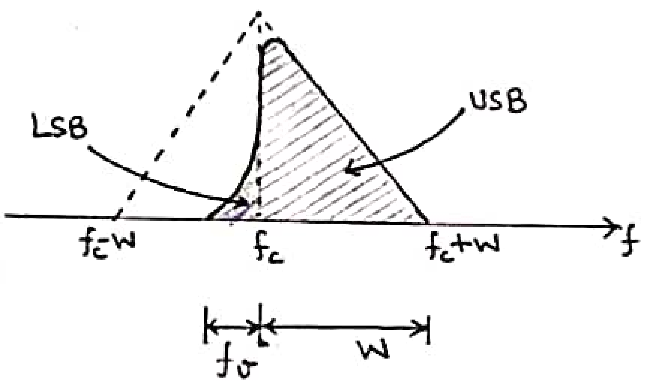
$\boxed{\text{Vestigial sideband (VSB)} \approx \text{compromise scheme.}}$

In VSB modulation, Instead of completely removing a sideband, a trace or vestige of that sideband is transmitted; hence name

In VSB modulation, Instead of completely removing a sideband, a trace or vestige of that sideband is transmitted; hence name "vestigial sideband".

Also, Instead of transmitting the other sideband in full, almost the whole of this second band is also transmitted.

VSB bandwidth lies between the SSB bandwidth W, & DSB-SC bandwidth $2W$.



$$\boxed{B_T = f_v + W}$$

f_v = vestige Bandwidth

W = message Bandwidth

Typically;

$$\boxed{f_v = 25\% \text{ of } W}$$

SIDEBAND SHAPING FILTER (GENERATION OF VSB)

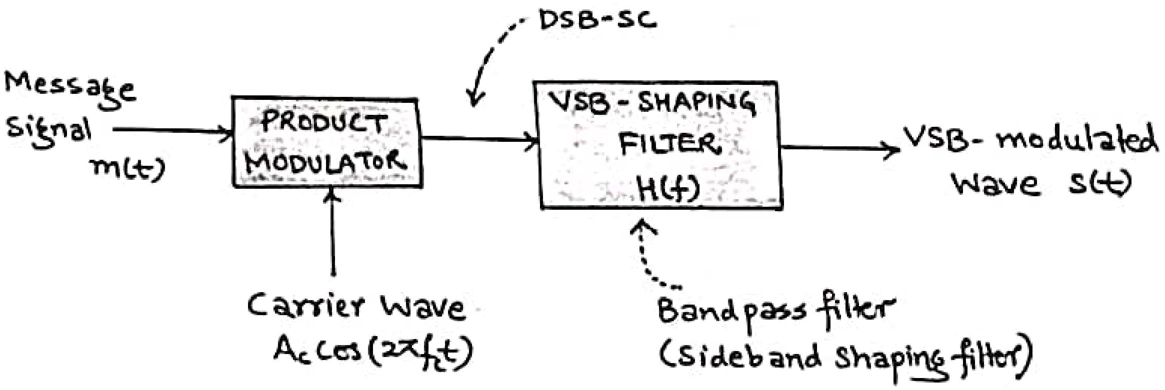
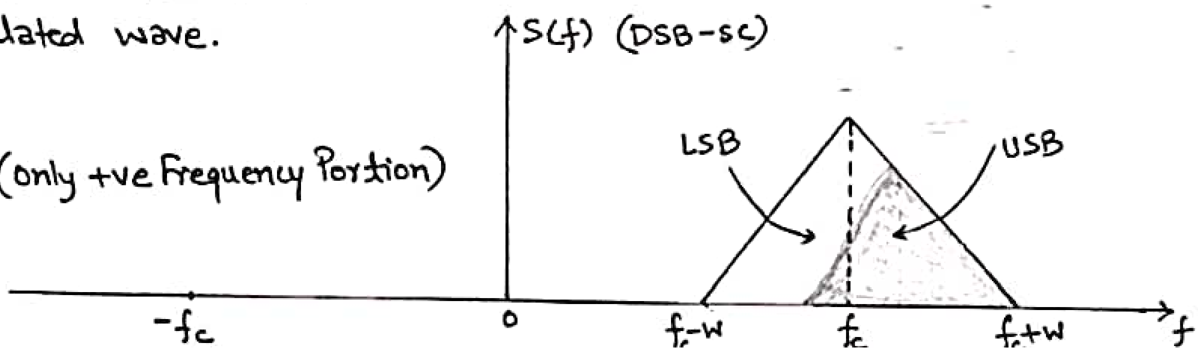


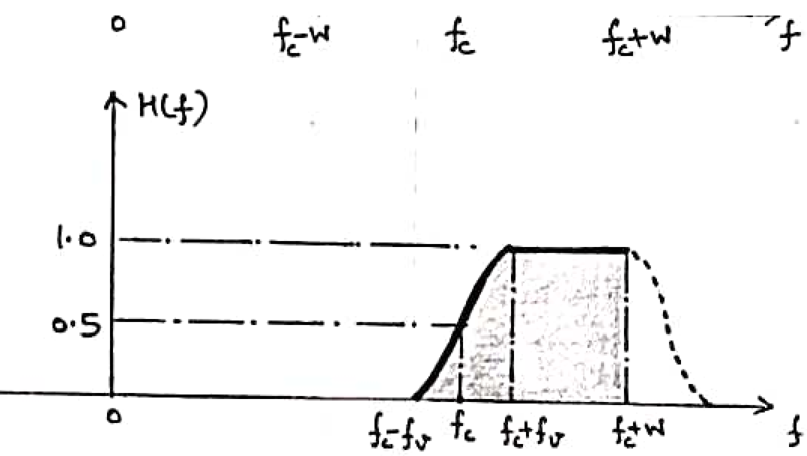
Fig: VSB modulator using frequency discrimination.

Assume, the vestige of the VSB lies in the Lower sideband of the DSB-SC modulated wave.

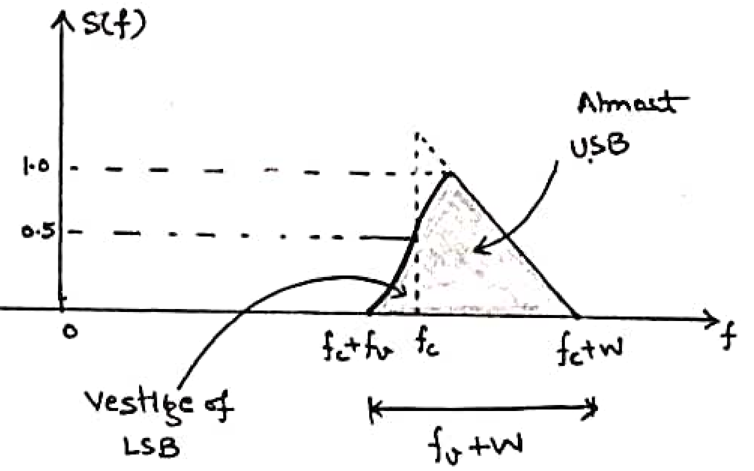
DSB-SC (only +ve Frequency Portion)



Amplitude response of side-band shaping filter (only +ve Frequency Portion).



VSB (only +ve Frequency Portion)



The only requirement that the sideband shaping performed by $H(f)$ must satisfy is that the transmitted vestiges compensates for the spectral portion missing from the other sideband.

$H(f)$ must satisfy the following condition.

$$\boxed{\underbrace{H(f+f_c)}_{\substack{\text{+ve freq. Part of } H(f) \\ \text{Shifted to Left by } f_c}} + \underbrace{H(f-f_c)}_{\substack{\text{-ve freq. part of } H(f) \\ \text{shifted to right by } f_c}} = 1} \quad \text{for } -W \leq f \leq W$$

Properties of the sideband shaping filter follow above condition:

---

1) The transfer function of the sideband shaping filter exhibits odd symmetry about the carrier frequency f_c.

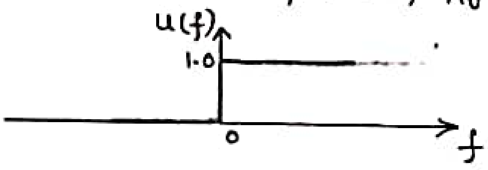
Properties of the sideband shaping filter follow above condition:

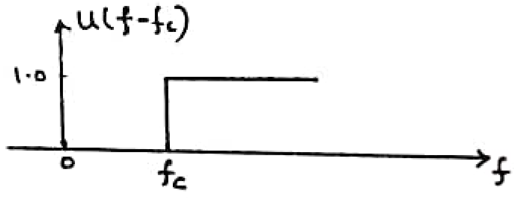
1) The transfer function of the sideband shaping filter exhibits odd symmetry about the carrier frequency f_c.

Let $\boxed{H(f) = u(f-f_c) - H_v(f-f_c)}$ for $f_c - f_v < |f| < f_c + W$

When $u(f-f_c) = \begin{cases} 1 & \text{for } f > f_c \\ 0 & \text{for } f < f_c \end{cases}$ where $u(f)$ = Unit step frequency function

& $H_v(f-f_c)$ = Frequency shifted function of new Low pass transfer function, $H_v(f)$ } completely determine by the vestige of modulated wave $s(t)$





$-H_v(f-f_c)$

$-H_v(f)$

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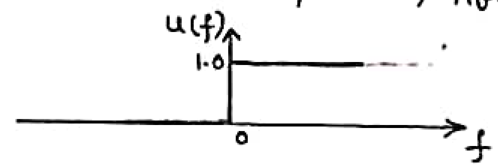
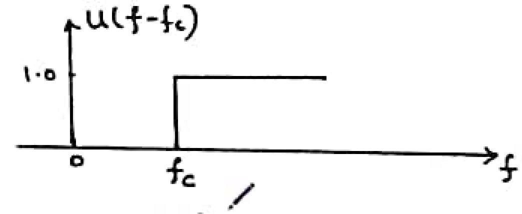
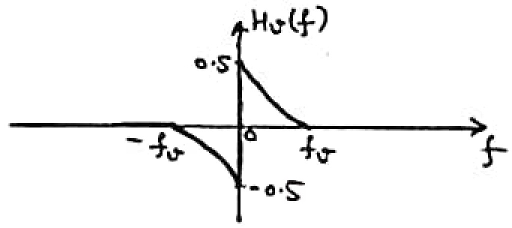
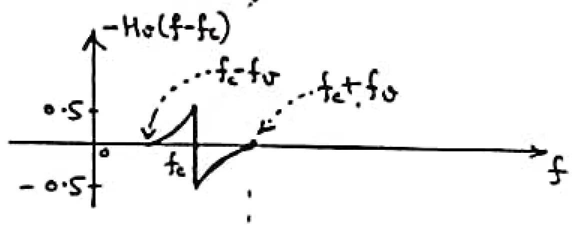
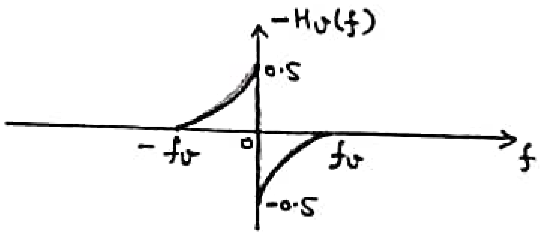
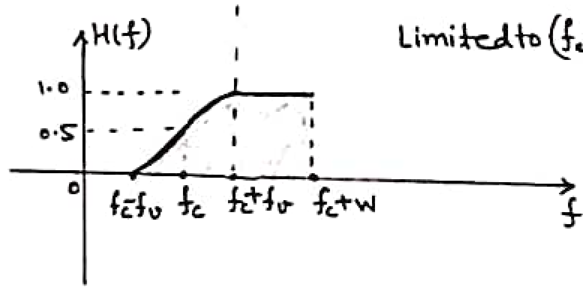








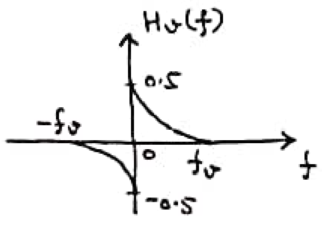


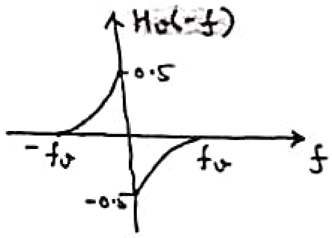


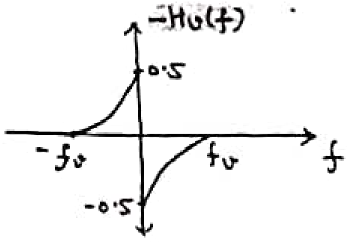
Limited to $(f_c + W)$

Note :- $H_v(f)$, satisfy the property of odd symmetry about zero frequency.

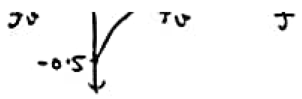
$$\boxed{H_v(-f) = -H_v(f)}$$







2) The transfer function $H_v(f)$ is required to satisfy the above condition only for frequency interval $-W \le f \le +W$, where W is the message bandwidth. So, $H(f)$ having arbitrary specification for



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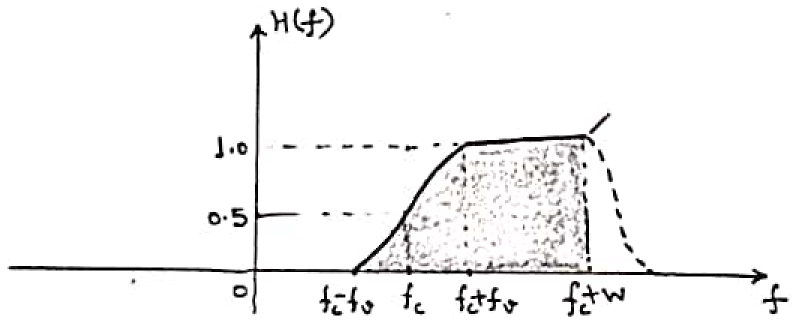
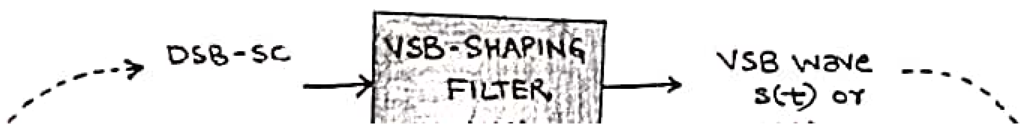
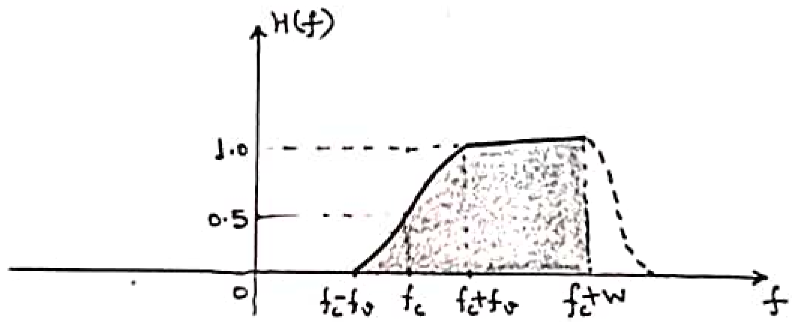
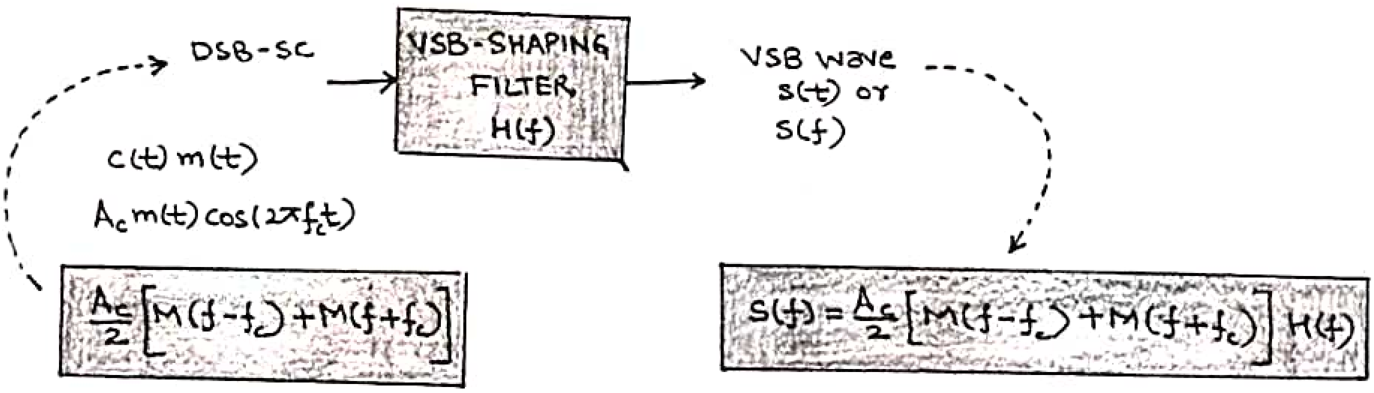
$|f| > f_c + W$ (Shown by dashed line)



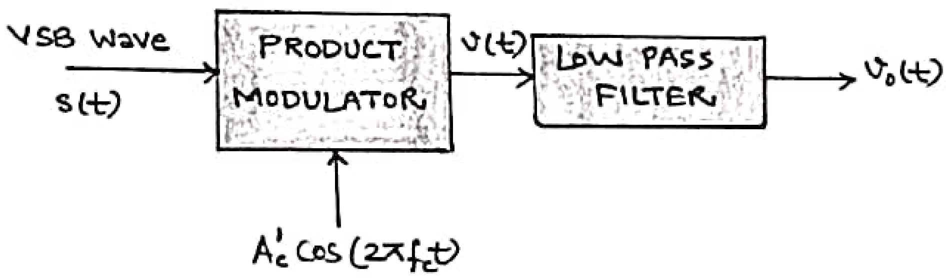


$|f| > f_c + W$ (shown by dashed line)





COHERENT OR SYNCHRONOUS DETECTION OF VSB.



Note: It is assumed that the local sinusoid is in perfect synchronism with the carrier in the modulator responsible for generating the VSB-modulated wave.

Setting the phase $\phi = 0$ in the local sinusoid.

output of product modulator

Fourier
$$v(t) = A_c' s(t) \cos(2\pi f_c t) \quad \text{------ Time domain.}$$

Fourier Transform

$$v(t) = A_c' s(t) \cos(2\pi f_c t) \quad \text{------ Time domain.}$$

$$V(f) = \frac{A_c'}{2}\left[S(f-f_c) + S(f+f_c)\right] \quad \text{---- Frequency domain.} \qquad (1)$$

Also, VSB, (Frequency domain)

$$S(f) = \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right] H(f) \qquad (2)$$

Substitute eq^n (2) in (1)

$$S(f-f_c) = \frac{A_c}{2}\left[M(f-2f_c) + M(f)\right] H(f-f_c) \quad \text{---- } S(f) \text{ shifted right by } f_c.$$

$$S(f+f_c) = \frac{A_c}{2}\left[M(f) + M(f+2f_c)\right] H(f+f_c) \quad \text{--- } S(f) \text{ Shifted Left by } f_c.$$

So,

$$V(f) = \frac{A_c A_c'}{4}\left\{\left[M(f-2f_c) + M(f)\right] H(f-f_c) + \left[M(f) + M(f+2f_c)\right] H(f+f_c)\right\}$$

$$= \underline{A_c A_c'}\, M(f)\left[H(f-f_c) + H(f+f_c)\right] + \frac{A_c A_c'}{4}\left[M(f-2f_c)H(f-f_c) + M(f+2f_c)H(f+f_c)\right]$$

$$V(f) = \frac{A_c A_c'}{4}\left\{\left[M(f-2f_c)+M(f)\right]H(f-f_c)+\left[M(f)+M(f+2f_c)\right]H(f+f_c)\right\}$$

$$= \frac{A_c A_c'}{4} M(f) \underbrace{\left[H(f-f_c)+H(f+f_c)\right]}_{\substack{\equiv 1 \\ \text{within } -W \le f \le W}} + \frac{A_c A_c'}{4}\left[M(f-2f_c)H(f-f_c)+M(f+2f_c)H(f+f_c)\right]$$

$$V(f) = \underbrace{\frac{A_c A_c'}{4} M(f)}_{\substack{\text{Scaled} \\ \text{version of} \\ m(t)}} + \underbrace{\frac{A_c A_c'}{4}\left[M(f-2f_c)H(f-f_c)+M(f+2f_c)H(f+f_c)\right]}_{\substack{\text{High frequency Component} \\ \text{(Carrier of freq } 2f_c) \\ \text{(Removed by LPF)}}}$$

So,

$$\boxed{v_o(t) = \frac{A_c A_c'}{4} m(t)}$$

Examples, Which build on the continuous-wave modulation theory :-

1) Superheterodyne Receiver : (All radio & TV receiver)

2) Television Signals :

3) Frequency Division Multiplexing :

SUPERHETERODYNE RECEIVER

or

"Superhet"

Perform additional function

- **Carrier Frequency Tuning**

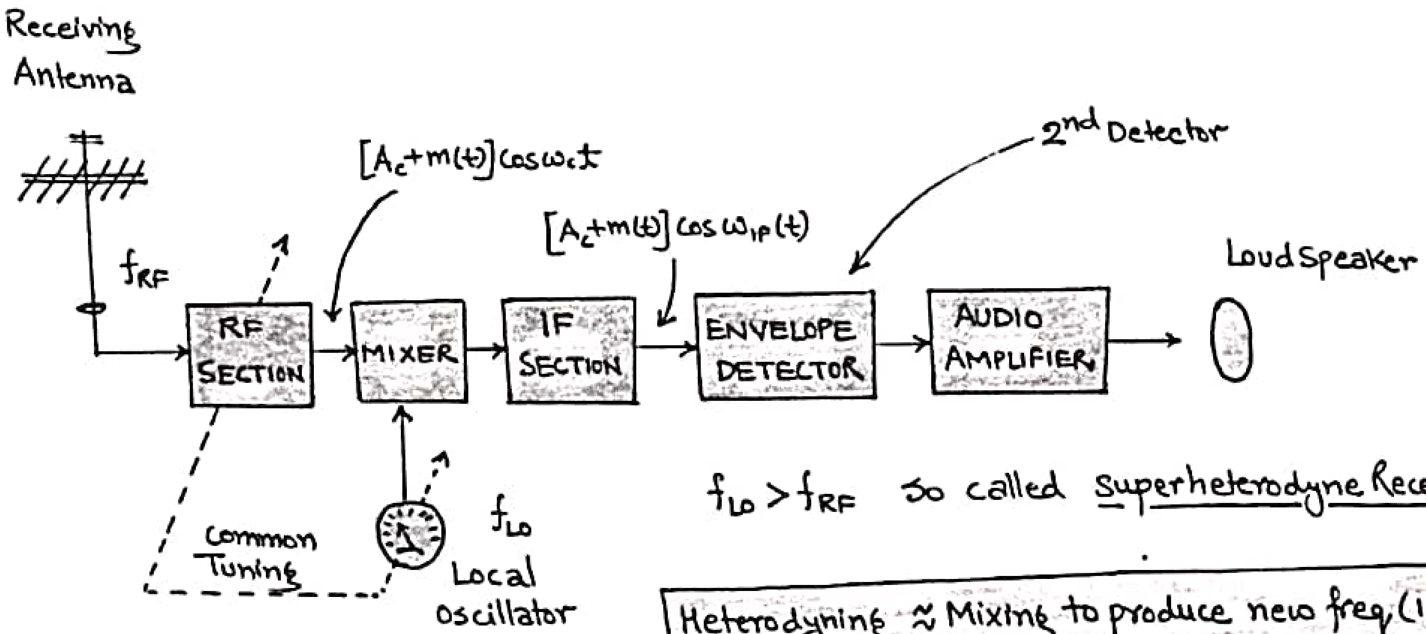
  Selection of desired signal (i.e. desired radio or TV Station)

- **Filtering**

  Separate the desired signal from other modulated signal (may picked up along the way)

- **Amplification**

  To compensate for the loss of signal power occured during the transmission.



$f_{LO} > f_{RF}$ so called <u>superheterodyne Receiver</u>

$\boxed{\text{Heterodyning} \approx \text{Mixing to produce new freq. (IF)}}$

Fig: <u>Basic elements of an AM radio receiver of the superheterodyne type.</u>

- AM signal is picked up by the receiving antenna $\longrightarrow$ Amplified in RF section (Tuned to carrier frequency of $s(t)$).

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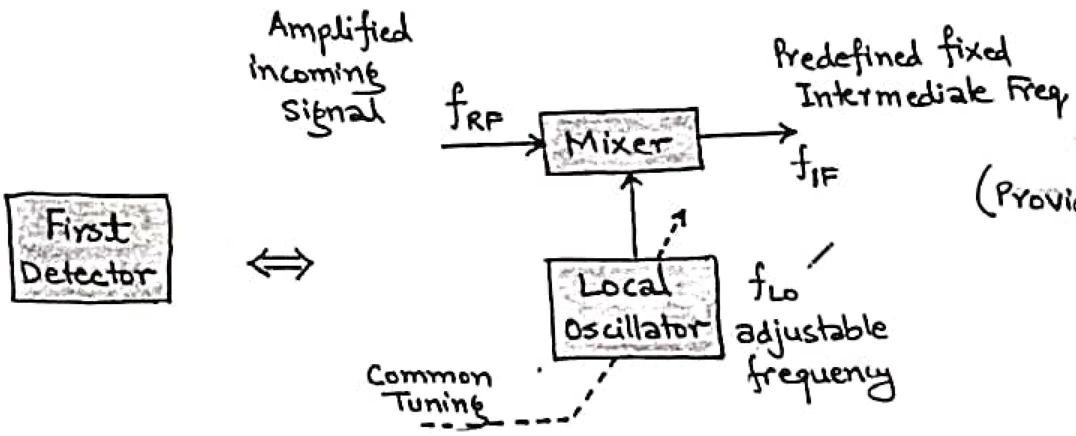

(Provide a heterodyning function)

* The mixture generates sum & difference frequencies at the output. The difference is selected i.e $(f_{LO} - f_{RF})$ by a proper tuned circuit.

$$\boxed{f_{IF} = f_{LO} - f_{RF}} \approx 455\text{ KHz in commercial radio receivers.}$$

$$\boxed{f_{IF} = f_{LO} - f_{RF}} \approx 455\,KHz$$ in Commercial radio receivers.

<u>Note:-</u> IF section consist of one or more stages of tuned amplification & also provide the selectivity in the receiver.

- The output of IF section is applied to a demodulator (coherent detection), and the final operation is the power amplification of the recovered message signal.

ADVANTAGE OF SUPERHETERODYNE RECEIVER

All incoming RF Carrier Range (0.535 - 1.605 MHz AM radio) → Convert to Fixed IF 455 KHz → All the succeeding stages operate on fixed IF (Circuit design become Simple)

↓

Improves the performance.

Constituent Stages of Superheterodyne Receiver

RF Amplifier : This is class C tuned voltage amplifier.

Main function is Rejection of Image Signal or Image frequency (f_{is})

Since, $\boxed{f_{IF} = f_{LO} - f_{RF}}$ $\quad f_{LO} > f_{RF}$

" The desired signal frequency f_{RF} is below the local oscillator frequency f_{LO} by an amount f_{IF} i.e. intermediate frequency."

Image signal f_{is} is a signal whose frequency is above the f_{LO} by the same amount of f_{IF}

$$f_{is} = f_{LO} + f_{IF}$$

For AM radio.

So, $$f_{is} = (f_{RF} + f_{IF}) + f_{IF}$$ $\because f_{RF} + f_{IF} = f_{LO}$

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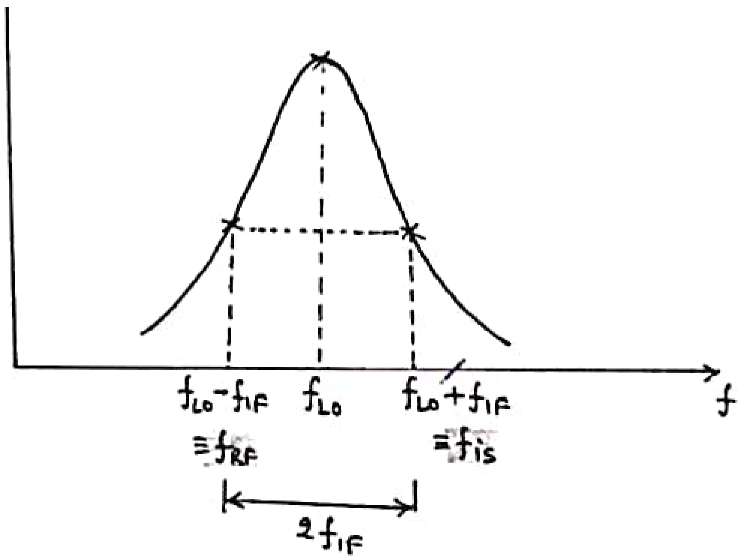
$$f_{is} = f_{LO} + f_{IF}$$

For AM radio.

so, $$f_{is} = f_{RF} + f_{IF} + f_{IF}$$ $\because f_{RF} + f_{IF} = f_{LO}$

$$\boxed{f_{IS} = f_{RF} + 2f_{IF}}$$

so, Image signal is $2f_{IF}$ more than f_{RF} $\longrightarrow$ Intercept by an antenna & reaches the mixer.



So,

$$\boxed{f_{is} = f_{RF} + 2f_{IF}}$$ --- Undesirable

∴ Cannot be distinguished by the IF amplifier and will be treated in the same manner as the desired signal.

(Desired Station)

$IF_1 = 21 - 20 = 1\,MHz$
$IF_2 = 22 - 21 = 1\,MHz$ } Same

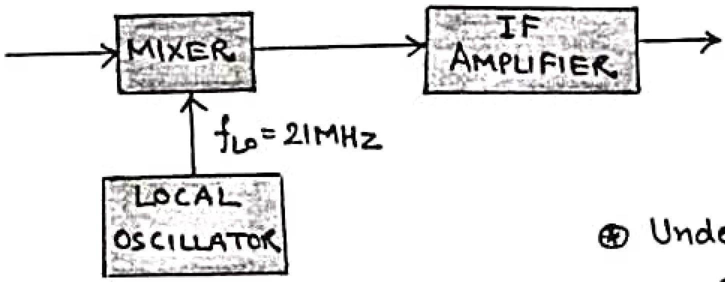
(Desired Station)

$f_{RF_1} = 20MHz$

$f_{RF_2} = 22MHz$

(Undesired Station)

$IF_1 = 21 - 20 = 1MHz$
$IF_2 = 22 - 21 = 1MHz$ } Same



Receive disired (20MHz) and Undesired (22MHz) Signal.

⊕ Undesired signal

$f_{is} = 22MHz$

$= f_{RF_1} + 2 f_{IF}$

$f_{RF_2} = (20 + 2 \times 1) = f_{is}$

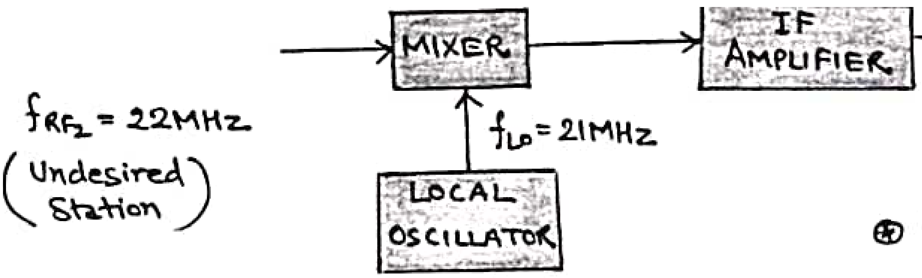
Note: The rejection of an image frequency ≈ Using single tuned circuit before the IF stage.

Image signal rejection (α) $\boxed{= \sqrt{1 + Q^2 \rho^2}}$

where Q ≈ Quality factor

$$Q = \frac{\omega_0}{\Delta\omega} = \frac{f_0}{BW} = \frac{f_0}{\Delta f}$$

$\rho = \frac{f_{is}}{\ } - \frac{f_{RF}}{\ }$



and Undesired (22MHz) Signal.

⊕ Undesired signal

$$f_{is} = 22MHz$$
$$= f_{RF_1} + 2 f_{IF}$$
$$f_{RF_2} = (20 + 2\times1) = f_{is}$$

Note: The rejection of an image frequency ≈ Using single tuned circuit before the IF stage.

<u>Image signal rejection</u> (α) $\boxed{= \sqrt{1 + Q^2 \rho^2}}$

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$$Q = \frac{\omega_0}{\Delta\omega} = \frac{f_0}{BW} = \frac{f_0}{\Delta f}$$

$$\boxed{\rho = \frac{f_{is}}{f_{RF}} - \frac{f_{RF}}{f_{is}}}$$

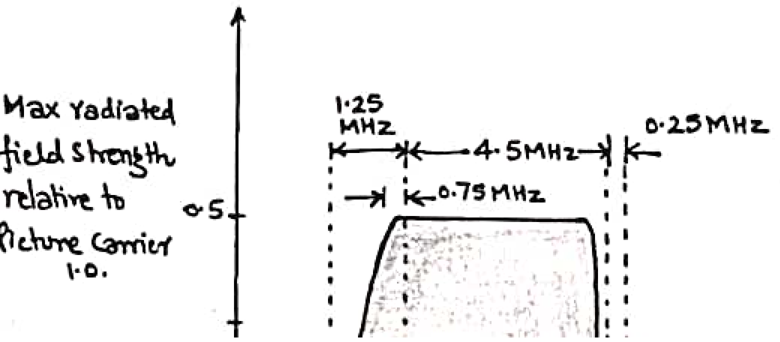
TELEVISION SIGNALS

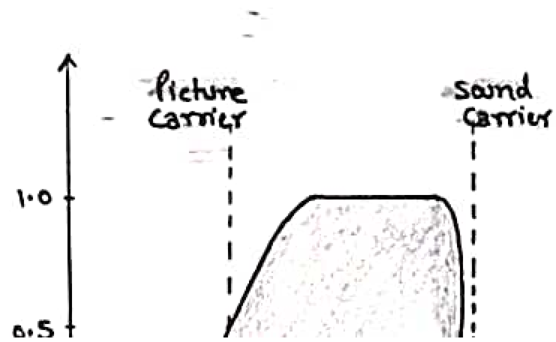
VSB plays an important role in commercial TV,

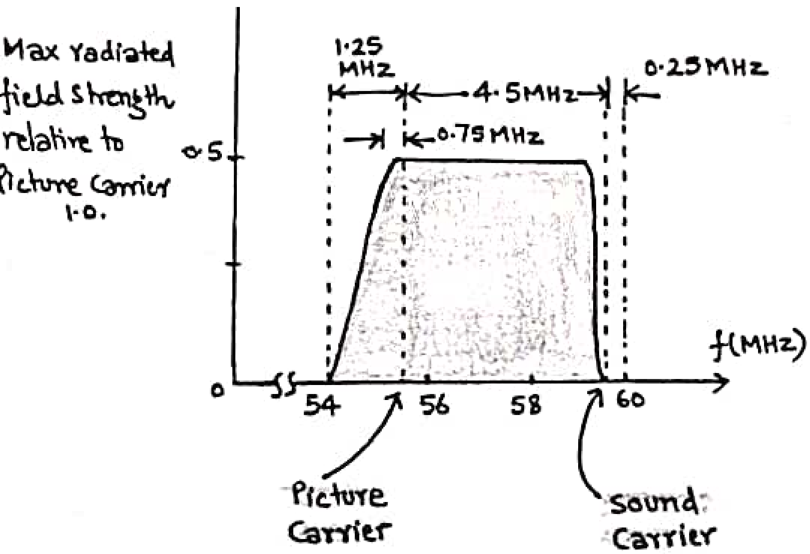
Video signals → Large Bandwidth; → Significant Low-Freq. content } suggest the use of VSB.

Note:- At the receiver side, the circuitry used for demodulation should be simple & inexpensive.

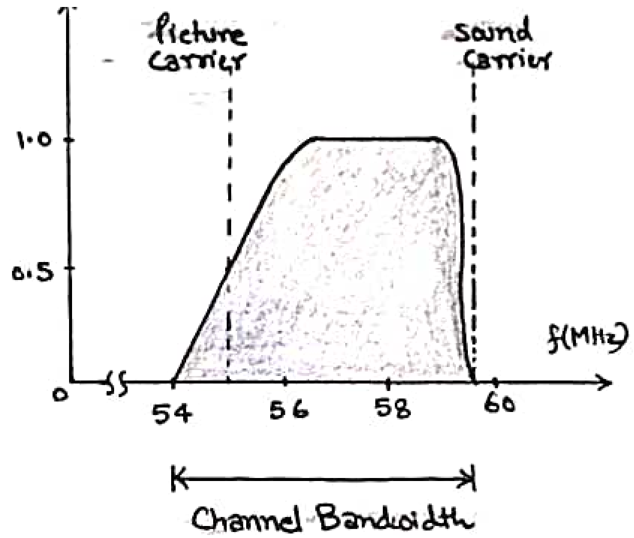
So, Envelope detection is used which requires the addition of a carrier to the VSB modulated wave.







a) Idealized amplitude spectrum of a transmitted TV signal.



b) Amplitude response of VSB shaping filter in the receiver.

Note:- { Picture Carrier frequency ≈ 55.25 MHz
Sound Carrier frequency ≈ 59.75 MHz }

(*) The Information content of the TV signal lies in a <u>baseband spectrum</u>

- The Information content of the TV signal
extending from 1.25 MHz below the picture carrier to 4.5 MHz above it.

Note:

- Use of Envelope detection (VSB + Carrier) produces waveform distortion in the video signal recovered at the detector output.
- The waveform distortion is produced by the quadrature Component of the VSB modulated wave.
- The percentage modulation & width of the VSB must be minimizing in order to reduce the extent of waveform distortion.