UNIT-1

AMPLITUDE MODULATION

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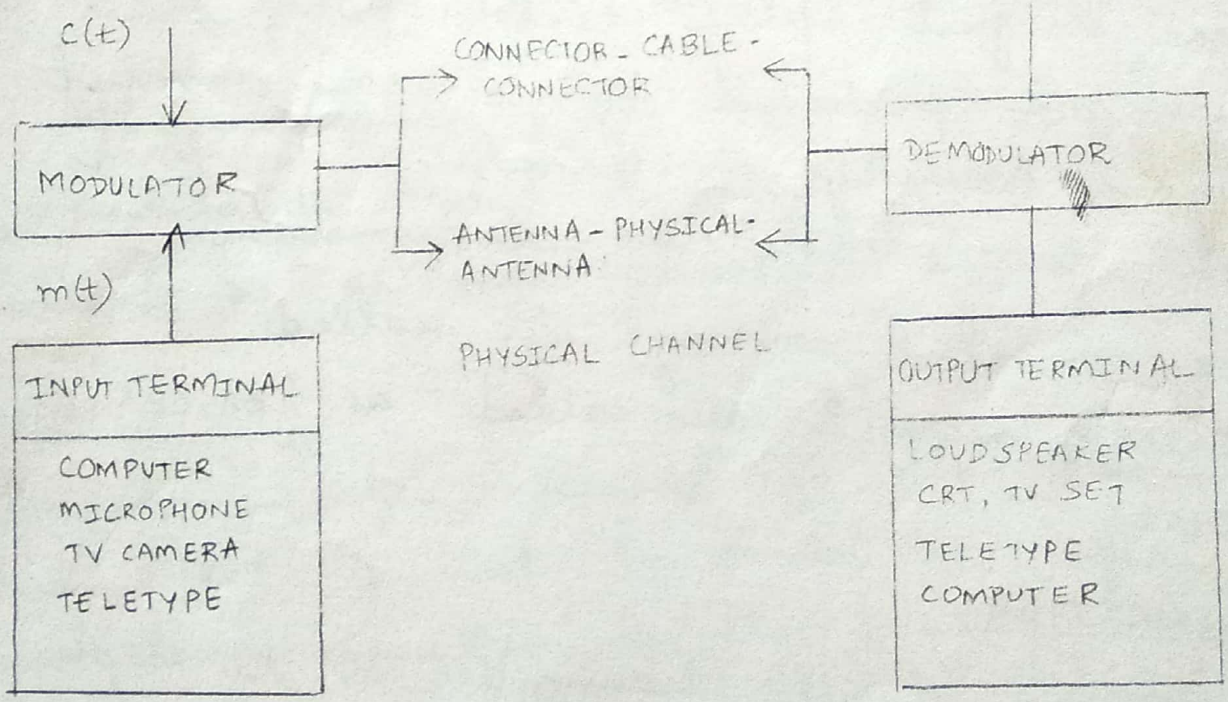
★ INTRODUCTION-

→ The Telecommunication network is considered as a important infrastructure for any development

→ Electronic communication systems are designed to send message or information from a source that generates the messages to one or more destinations

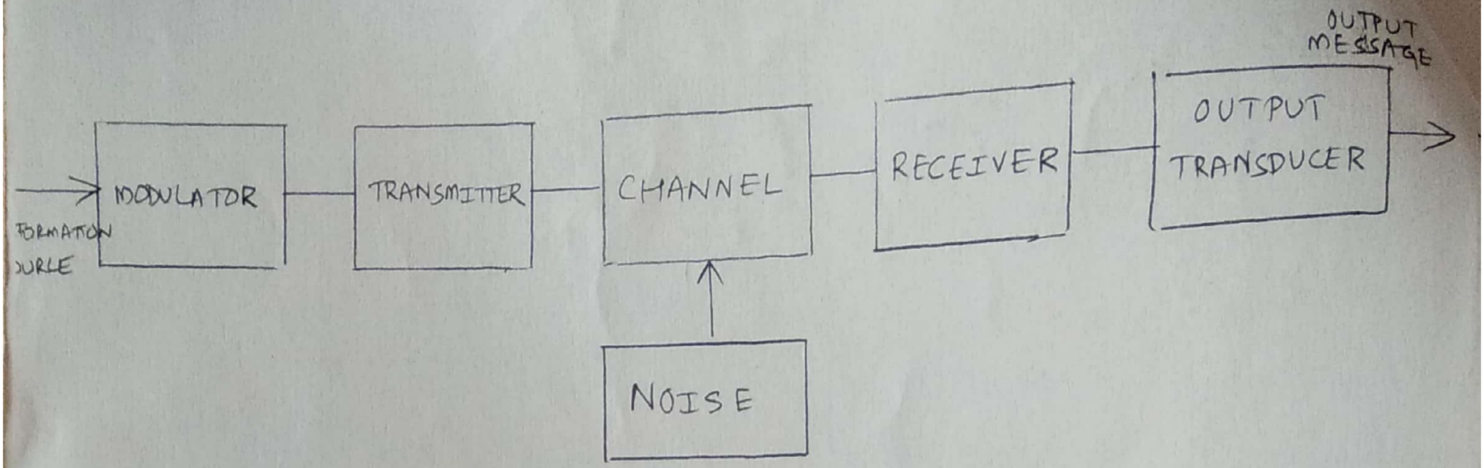
→ Thus, the communication systems become very crucial for the prosperity and development of any nation.



fig(i) ELEMENTS OF COMMUNICATION SYSTEM

→ fig(i) shows the general form of a communication system

★ BLOCK DIAGRAM OF COMMUNICATION SYSTEM -



(i) INPUT TRANSDUCER -

→ The wide variety of possible sources of information results in many different forms of messages.

→ This may be in the form of voice, picture or just plain text.

→ The message produced by a source must be converted by a transducer to form which is suitable for transmission

→ These converted message is called as the 'MESSAGE SIGNAL' also called as 'BASEBAND SIGNAL'

(ii) TRANSMITTER -

→ The purpose of the transmitter is to couple the message to the channel.

→ To achieve this, the transmitter process the message signal into a form suitable for transmission over the channel.

→ The important signal processing operations performed by the transmitter include amplification, filtering and modulation.

→ Modulation is the systematic variation of same attribute of a high frequency carrier in accordance with the message signal, so as to match the properties of transmitted signal to that of the channel

→ The main reasons for modulation are :-

(a) For easy radiation of electromagnetic waves
(b) For multiplexing and frequency assignment
(c) TO overcome equipment limitations
(d) TO reduce noise and interference.

NOTE - After modulation, the transmitter couples the modulated signal to the channel through an antenna or any appropriate device.

(iii) CHANNELS

→ The communication channel is the physical medium that is used to send the signal from the transmitter to the receiver.

→ In wireless transmission, the channel is usually free space which information bearing signals are radiated or telephone channels which employ a variety of physical media such as twisted pair, optical fiber cables and microwave radio.

→ Due to physical limitations all communication channels have only finite bandwidth and information bearing signals have problems of amplitude and phase distortion as it travels over the channel on same radio channels involving long distances.

→ Another form of signal distortion is the multipath effect.
These type of signal distortion is characterised by time variations in signal amplitude called Fading.

→ Apart from the distortions, the signal is attenuated and is corrupted by noise.

(iv) <u>NOISE</u> -

→ In addition to the distortion, signal is attenuated, as it travels over the channel.

→ The signal is corrupted by unwanted and unpredictable electrical disturbance known as noise.

→ Noise in a communication system can be internal noise and external noise.

→ Noise generated by components within a communication system such as resistors, diodes and transistors are internal noise.

→ The noise from sources outside communication system like atmospheric and man made are External noise.

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RECEIVER

→ The function of the receiver is to recover the message signal contained in the received signal.

→ The signal is then converted to a form suitable for the output transducer.

→ The received signal is extremely weak, it is first amplified and then demodulated

→ "DEMODULATION" is the process by which the message signal is recovered from modulated signal.

NOTE - Signal demodulation is performed in the presence of noise and other signal degradations which is distorted to some extent when compared to the original message signal.

★ MODULATION -

→ Modulation is the process of changing some characteristics [amplitude, frequency ~~and~~ or phase] of a carrier wave in accordance with the instantaneous value of the modulating signal.

→ There are 3 types of modulations -

(i) Amplitude modulation
(ii) Frequency modulation
(iii) phase modulation

(i) AMPLITUDE MODULATION-

→ This is defined as the modulation in which the amplitude of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal, keeping its (carrier) frequency and phase constant.

(ii) FREQUENCY MODULATION -

→ This is defined as the modulation in which the frequency of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal, keeping its (carrier) amplitude and phase constant.

(iii) PHASE MODULATION-

→ This is defined as the modulation in which the phase of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal, keeping its (carrier) amplitude and frequency constant.

★ NEED FOR MODULATION-

→ The main purpose of modulation in communication system is to generate a modulate signal suited to the characterstics of the communication channel.

→ The advantages of modulation are :

(1) Reduces the height of antenna-

→ Height of antenna is a function of wavelength 'λ'

The minimum height of antenna is given by $\lambda/4$.

ie, Height of antenna $= \frac{\lambda}{4} = \frac{c}{4f}$ $\quad (\because \lambda = \frac{c}{f})$

where, $\lambda = \frac{c}{f}$

c = velocity of light $= 3 \times 10^8$

f = transmitting frequency.

Ex: If $f = 1MHZ$,

Height of antenna $= \frac{\lambda}{4} = \frac{c}{4f}$

$$= \frac{3 \times 10^8}{4 \times 1 \times 10^6} = 7 \text{ meters}$$

Ex: If $f = 15KHZ$,

Height of antenna $= \frac{\lambda}{4} = \frac{c}{4f}$

$$= \frac{3 \times 10^8}{4 \times 15 \times 10^3} = 5000 \text{ meter}$$

NOTE- As Transmitting Frequency is increased, height of antenna is decreased. $f\uparrow H\downarrow$

(ii) Avoids mixing of signals -

→ All audio (message) signals ranges from 20Hz - 20k

→ The Transmission of message signals from various sources causes the mixing of signals and then it is difficult to separate these signals at the receiver end.

(iii) Increases the range of communication -

→ Low frequency signals have poor radiation and they get highly attenuated. ∴ Baseband signals cannot be transmitted directly over long distances.

→ Modulation increases the frequency of the signal and thus can be transmitted over long distances.

(iv) Allows multiplexing of signals -

→ Modulation allows the multiplexing to be used.

→ Multiplexing means transmission of two or more signals simultaneously over the same communication channel.

(v) Allows Adjustments in the bandwidth -

→ This means bandwidth of a modulated signal may be made smaller or larger

(vi) Improves quality of reception -

→ Modulation techniques like frequency modulation, pulse code modulation reduces the effect of noise which improves the quality of reception.

★ AMPLITUDE MODULATION-

→ Amplitude modulation is defined as the modulation in which the amplitude of the carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal keeping its (carrier) frequency and phase constant.

→ The process of converting the message signal which has a low pass audio or video spectrum to a high frequency band-pass spectrum is achieved by different modulation methods.

→ Also, we can reproduce the message after the transmission.

→ The reverse process, by which the signal is extracted from the higher frequency base band spectrum is known as Demodulation or Detection.

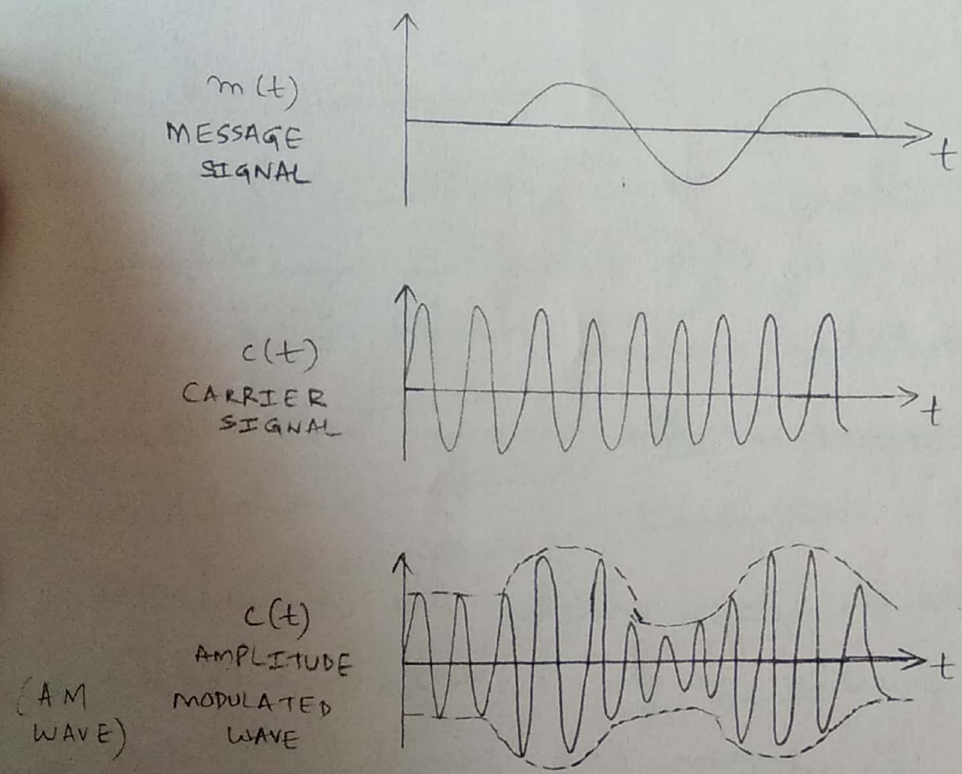
→ Amplitude modulation is a continuous wave modulation technique in which the amplitude of a high frequency carrier wave is varied as a function of the modulating signal or message signal.

★ TIME DOMAIN DESCRIPTION-

→ consider a sinusoidal carrier wave $c(t)$ defined by, $c(t) = A_c \cos 2\pi f_c t$ where,

A_c is the carrier amplitude

f_c is the carrier frequency.



→ In amplitude modulation, the amplitude of carrier wave $c(t)$ is varied about mean value, linearly with the message signal $m(t)$

→ Thus, the instantaneous value of modulating signal is given by,

$$\boxed{m(t) = A_m \cos(2\pi f_m t)} \quad \text{---- (1)}$$

where, A_m is maximum amplitude of modulating signal

f_m is frequency of modulating signal.

→ The instantaneous value of carrier signal is given by,

$$\boxed{c(t) = A_c \cos(2\pi f_c t)} \quad ---- (2)$$

where,

A_c is maximum amplitude of carrier signal

f_c is frequency of carrier signal

→ The standard equation for AM wave is given by,

$$\boxed{s(t) = A \cos 2\pi f_c t}$$

where the amplitude of the carrier is given by $\boxed{A = A_c + k_a m(t)}$

∴ Substitute value of A in s(t),

$$s(t) = [A_c + k_a m(t)] \cos 2\pi f_c t$$

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

$$\boxed{s(t) = A_c \left[1 + k_a m(t)\right] \cos 2\pi f_c t} \quad --- (3)$$

where,

k_a is a constant called as the amplitude sensitivity of the modulator

→ Substituting eqn (1) in eqn (3) we get,

$$s(t) = A_c \left[1 + \underbrace{k_a A_m}_{\mu} \overbrace{\cos(2\pi f_m t)}^{m(t)}\right] \cos(2\pi f_c t) \quad --- (3)(a)$$

$$s(t) = A_c \left[1 + \mu \cos(2\pi f_m t)\right] \cos(2\pi f_c t)$$

where,

$$\boxed{\mu = K_a A_m}$$

μ is the modulation Index / modulation factor

→ eqn (3)(a) can be written as,

$$\boxed{s(t) = A_c \cos(2\pi f_c t) + \mu A_c \cos(2\pi f_c t) \cdot \cos(2\pi f_m t)} \quad \text{---- (4)}$$

eqn (4) can be expanded by trignometrical relation as,

$$\cos a . \cos b = \frac{1}{2}\cos(a-b) + \frac{1}{2}\cos(a+b)$$

$$\therefore s(t) = A_c \cos(2\pi f_c t) + \frac{\mu A_c}{2}\cos[2\pi f_c - 2\pi f_m]t + \frac{\mu A_c}{2}\cos[2\pi f_c + 2\pi f_m]t \quad \text{---- (5)}$$

→ eqn (5) is the amplitude modulated signal, consists of three frequency components -

(i) The first term is carrier itself. It has a frequency 'f_c' and amplitude 'A_c'

(ii) The second component is $\frac{\mu A_c}{2}\cos 2\pi[f_c - f_m]t$

It has frequency $[f_c - f_m]$ called as F_{LSB} Lower Side band and having amplitude $\frac{\mu A_c}{2}$

(iii) The third component is $\frac{\mu A_c}{2}\cos 2\pi[f_c + f_m]t$.

It has frequency $[f_c + f_m]$ called as F_{USB} called upper Side band and having amplitude $\frac{\mu A_c}{2}$

→ Let E_{max} and E_{min} denote maximum and minimum values of the modulated wave

From equation $s(t) = A_c[1 + k_a A_m \cos 2\pi f_m t] \cos 2\pi f_c t$ ∵ (eqn 3 (a))

we get,

$$E_{max} = A_c[1 + \mu]$$

$$E_{min} = A_c[1 - \mu]$$

$$\therefore \frac{E_{max}}{E_{min}} = \frac{1+\mu}{1-\mu}$$

solving for μ we get,

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

★ FREQUENCY DOMAIN DESCRIPTION -

→ To obtain the spectrum of the Amplitude modulation wave, consider the general term of A.M wave given by the equation below,

$$s(t) = A_c[1 + k_a m(t)] \cos 2\pi f_c t \quad \because (\text{eqn } 3)$$

$$\boxed{s(t) = A_c \cos 2\pi f_c t + A_c k_a m(t) \cos 2\pi f_c t} \quad \text{----}(1)$$

→ Taking fourier transform of $s(t)$ on both the sides of eqn (1) we get,

$$s(f) = \frac{A_c}{2}[\delta(f - f_c) + \delta(f + f_c)] + \frac{k_a A_c}{2}[M(f - f_c) + M(f + f_c)]$$

--- (1) (a)

→ The spectrum of A.M wave is as shown in fig (i.e.)

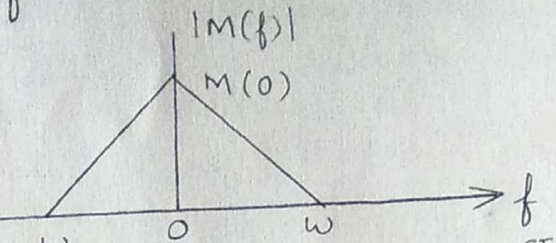


fig (a) SPECTRUM OF BASEBAND SIGNAL

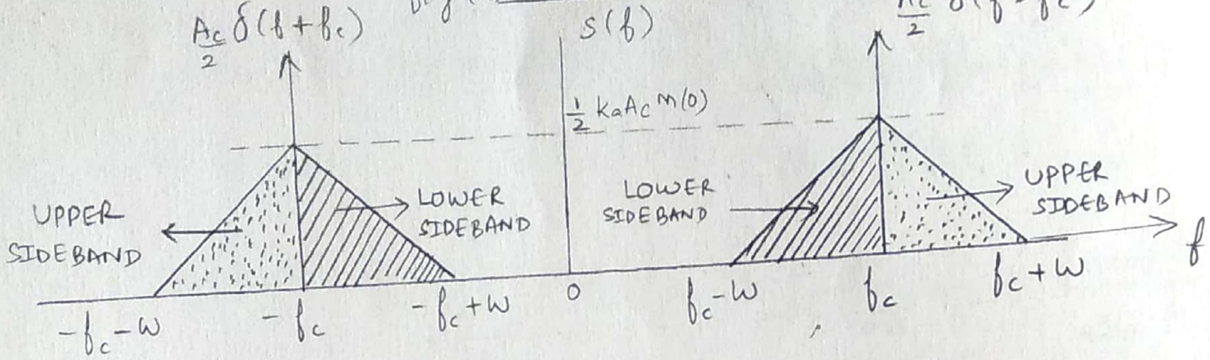


fig (b) SPECTRUM OF MODULATED SIGNAL

→ The amplitude spectrum of the AM wave has 2 sidebands on either sides of $\pm f_c$ (lower sideband, upper sideband)

→ For +ve frequencies,

★ The highest frequency component of the AM wave equals $f_c + W$ and is called UPPER SIDEBAND f_{USB}

★ The lowest frequency component of the AM wave equals $f_c - W$ and is called LOWER SIDEBAND f_{LSB}

TRANSMISSON BANDWIDTH (B_T)

→ The difference between upper sideband and lower sideband frequencies defines the transmission bandwidth 'B_T'

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

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

$$B_T = \cancel{f_c} + f_m - \cancel{f_c} + f_m$$

$$B_T =$$

$\therefore$ Bandwidth required for transmission of an AM wave is twice the modulating signal frequency ie $2f_m$

$\longrightarrow$ For the spectrum $S(f)$ as given in eqn (1)(a) is plotted as shown,

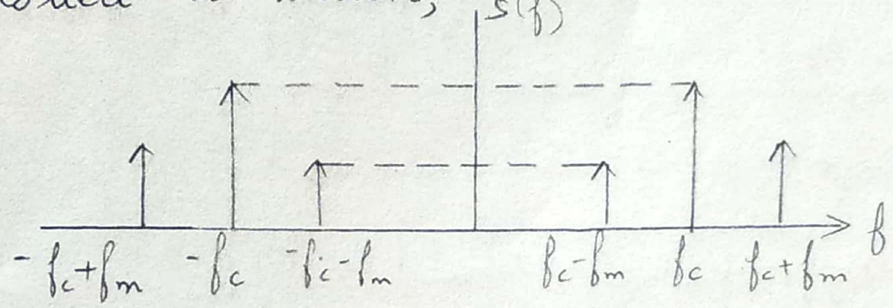


fig (i) SPECTRUM OF SINGLE TONE A.M WAVE

From the fig, Bandwidth required for transmission is,

$$B_T = \cancel{f_c} + f_m - (\cancel{f_c} - f_m)$$

$\therefore$ $\boxed{B_T = 2f_m}$ which means TWICE the message bandwidth

★ (1) SINGLE TONE MODULATION-

REPEATED

$\longrightarrow$ A single tone modulating signal $m(t)$ has a single frequency component 'f_m' and is defined as follows,

$$\boxed{m(t) = A_m \cos(2\pi f_m t)} \quad ---- (1)$$

where,

A_m is the amplitude of modulating wave

f_m is the frequency of modulating wave

→ Let $\boxed{c(t) = A_c \cos(2\pi f_c t)}$ --- (2)

where,

A_c is the amplitude of the carrier wave

f_c is the frequency of the carrier wave

→ The Time domain expression for the standard AM wave is,

$$\boxed{s(t) = A_c[1 + k_a m(t)] \cos 2\pi f_c t} \quad \text{--- (3)}$$

Substituting eqn (1) in eqn (3), we get

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

→ Since, w.k.T modulation Index $\boxed{\mu = k_a A_m}$

we get,

$$\boxed{s(t) = A_c[1 + \mu \cos 2\pi f_m t] \cos 2\pi f_c t} \quad \text{--- (4)}$$

eqn (4) is further expanded by means of trignometric relation as,

$$\cos a . \cos b = \frac{1}{2} \cos[a-b] + \frac{1}{2} \cos[a+b]$$

$$s(t) = A_c \cos(2\pi f_c t) + \mu A_c \underbrace{\cos(2\pi f_c t)}_{\cos a} . \underbrace{\cos(2\pi f_m t)}_{\cos b} \quad \star$$

$$\boxed{s(t) = A_c \cos(2\pi f_c t) + \frac{\mu A_c}{2} \cos[2\pi f_c - 2\pi f_m]t + \frac{\mu A_c}{2} \cos[2\pi f_c + 2\pi f_m]t} \quad \text{---- (5)}$$

→ Taking fourier transform on both sides of eqn (5) we get,

$$\boxed{s(f) = \frac{A_c}{2}\left[\delta(f - f_c) + \delta(f + f_c)\right] + \frac{\mu A_c}{4}\left\{\left[\delta(f - (f_c - f_m)\right] + \delta\left[f + (f_c - f_m)\right]\right\} + \frac{\mu A_c}{4}\left\{\delta[f - (f_c + f_m)] + \delta[f + (f_c + f_m)]\right\}}$$

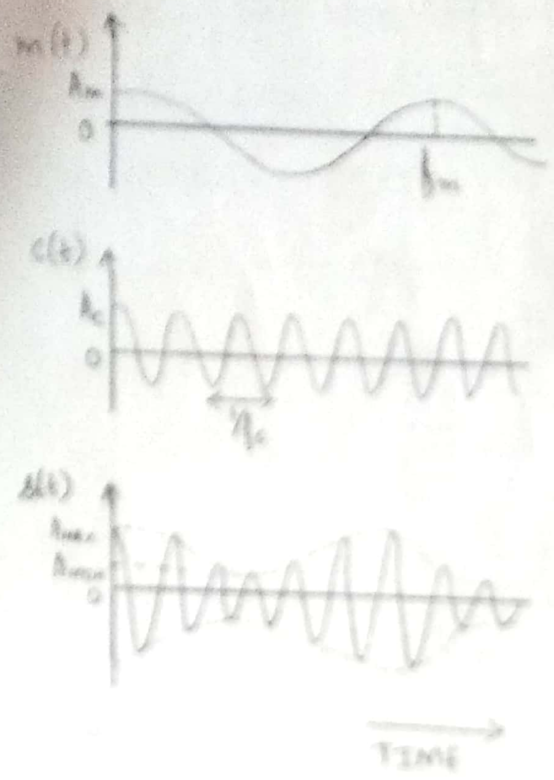


fig (a) TIME DOMAIN

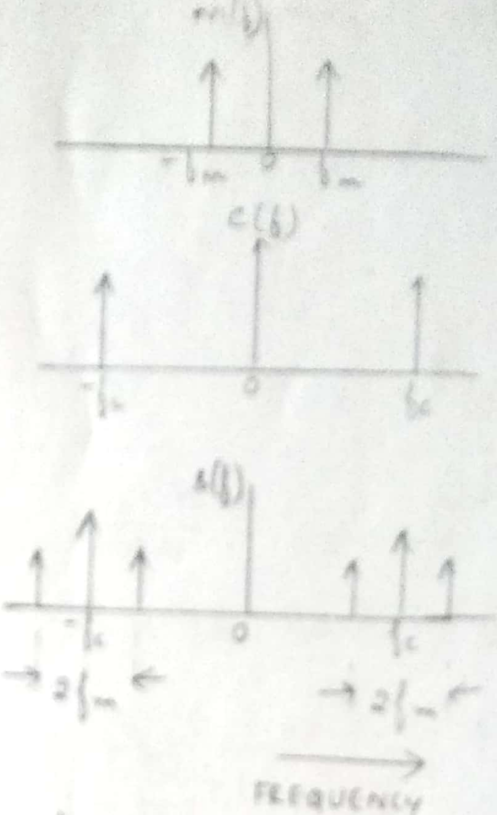


fig (b) FREQUENCY DOMAIN

→ Standard amplitude modulation produced by a single tone (a) modulating wave (b) carrier wave (c) AM wave

→ Practically, the AM wave $s(t)$ is a voltage or current wave.

→ The average power delivered by an AM wave to a $1\,\Omega$ is calculated as follows,

(i) Average carrier power $P_c = \dfrac{A_c^2}{2}$

(ii) P_{USB} upper side frequency power $= \dfrac{\mu^2 A_c^2}{8}$

P_{LSB} lower side frequency power $= \dfrac{\mu^2 A_c^2}{8}$

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

$= A_c \cos 2\pi f_c t + \dfrac{\mu A_c}{2} \cos[2\pi(f_c + f_m)t] + \dfrac{\mu A_c}{2} \cos[2\pi(f_c - f_m)t]$

Total power in the modulated wave is

$P_t = \dfrac{(A_c/\sqrt{2})^2}{R} + \dfrac{(\mu A_c/2\sqrt{2})^2}{R} + \dfrac{(\mu A_c/2\sqrt{2})^2}{R}$

$$\therefore P_{USB} = P_{LSB} = \frac{\mu^2 A_c^2}{8R}$$

P_{SB}

→ The Total power P_t is given by,

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

$$P_t = \frac{A_c^2}{2R} + 2\left[\frac{\mu^2 A_c^2}{8R}\right]$$

$$P_t = \frac{A_c^2}{2R} + \frac{\mu^2 A_c^2}{4R}$$

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

P_c

$$\therefore P_t = P_c\left[1 + \frac{\mu^2}{2}\right] \quad \text{--- (I)}$$

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

For 100% modulation, $\mu = 1$ $\therefore$ we have $\frac{P_t}{P_c} = 1 + \frac{1^2}{2} \Rightarrow \frac{2+1}{2}$

$\Rightarrow P_t = P_c\left[\frac{3}{2}\right]$

$P_t = 1.5 P_c$

$$\therefore \frac{P_t}{P_c} = 1.5 \quad \text{or} \quad \boxed{P_t = 1.5 P_c}$$

Also $P_c = \frac{1}{1.5} P_T$ ie $\boxed{P_c = 0.66 P_T}$

NOTE - As modulation index m increases, the power in the side band $= \frac{P_c m^2}{2}$ increases

The Power in the carrier remains unchanged even after modulation.

→ To relate voltage and current before and after modulation,

Let E_t be the effective or rms voltage of the modulated wave.

→ Let E_c be the effective value of the unmodulated carrier.

→ The total power in the amplitude modulated signal is given by,

$$P_t = \frac{E_t^2}{R}$$

But W.K.T $P_t = P_c\left(1+\frac{m^2}{2}\right)$ which is derived from equation of total power in the modulated wave $\left[\because P_t = \frac{(A_c/\sqrt{2})^2}{R} + \frac{(mA_c/2\sqrt{2})^2}{R} + \frac{(mA_c/2\sqrt{2})^2}{R}\right]$

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

$$P_t = \frac{E_c^2}{R}\left(1+\frac{m^2}{2}\right)$$

$$\therefore E_t^2 = E_c^2\left(1+\frac{m^2}{2}\right)$$ Here $m = \mu$

$$\therefore E_t = E_c\sqrt{1+\frac{m^2}{2}}$$

Similarly, let it be the effective or rms current after modulation.
Let I_c be the effective or value of current before modulation.

If R is the resistance in which these currents flow then,

$$\frac{P_t}{P_c} = \frac{I_t^2 R}{I_c^2 R}$$

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

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

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

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

★ (2) MULTI TONE MODULATION

→ We know from fourier analysis any periodic signal can be expressed in terms of several sinusoids at harmonic frequencies.

$\therefore$ Modulation by a non-sinusoidal periodic signal can be considered as modulation by several sinusoids

→ when several sine waves simultaneously modulate the carrier, the carrier power will be uneffected, but the total sideband power will now be the sum of the individual sideband power.

This can be shown by considering the message signal $m(t)$ as the sum of two sinusoids.

→ We have the expression for A.M wave given by,

$$s(t) = A_c\left[1 + K_a m(t)\right] \cos 2\pi f_c t$$

consider two modulating signal,

$$m_1(t) = A_{m_1} \cos 2\pi f_{m_1} t$$

$$m_2(t) = A_{m_2} \cos 2\pi f_{m_2} t$$

ie, $m(t) = m_1(t) + m_2(t)$

$$m(t) = A_{m_1} \cos 2\pi f_{m_1} t + A_{m_2} \cos 2\pi f_{m_2} t$$

$\therefore s(t) = A_c \left[1 + k_a (m_1(t) + m_2(t))\right] \cos 2\pi f_c t$

$$s(t) = A_c \left[1 + k_a \left[A_{m_1} \cos 2\pi f_{m_1} t + A_{m_2} \cos 2\pi f_{m_2} t\right]\right] \cos 2\pi f_c t$$

$$s(t) = A_c \left[1 + \underbrace{k_a A_{m_1}}_{\mu_1} \cos 2\pi f_{m_1} t + \underbrace{k_a A_{m_2}}_{\mu_2} \cos 2\pi f_{m_2} t\right] \cos 2\pi f_c t$$

$$s(t) = A_c \left[1 + \mu_1 \cos 2\pi f_{m_1} t + \mu_2 \cos 2\pi f_{m_2} t\right] \cos 2\pi f_c t$$

$\Rightarrow$

$\therefore$ $$s(t) = A_c \cos 2\pi f_c t + \mu_1 A_c \cos 2\pi f_c t \cos 2\pi f_{m_1} t + \mu_2 A_c \cos 2\pi f_c t \cos 2\pi f_{m_2} t \quad \text{----(I)}$$

W.K.T,

$$\boxed{\cos A . \cos B = \frac{1}{2} \cos (A-B) + \frac{1}{2} \cos (A+B)}$$

$\therefore$ Substituting the formula $\cos A . \cos B$ in eqn (I)

we get,

$$\boxed{s(t) = A_c \cos 2\pi f_c t + \frac{\mu_1 A_c}{2} \cos 2\pi [f_c - f_{m_1}] t + \frac{\mu_1 A_c}{2} \cos 2\pi [f_c + f_{m_1}] t + \frac{\mu_2 A_c}{2} \cos 2\pi [f_c - f_{m_2}] t + \frac{\mu_2 A_c}{2} \cos 2\pi [f_c + f_{m_2}] t}$$

---- (1)

$\longrightarrow$ From the above eqn (1) it is clear that, when we have two modulating frequencies, we get four additional frequencies. They are -

2 upper Sidebands (USB) :- $f_c + f_{m_1}$, $f_c + f_{m_2}$

2 lower Sidebands (LSB) :- $f_c - f_{m_1}$, $f_c - f_{m_2}$

→ The Total Transmitted power in amplitude modulated wave is,

$$P_T = P_c + P_{USB1} + P_{USB2} + P_{LSB1} + P_{LSB2}$$

$$\frac{A_c^2}{(\sqrt{2})^2 R} = \frac{A_c^2}{2R}$$

$$P_T = \frac{(A_c/\sqrt{2})^2}{R} + \frac{\mu_1 A_c^2}{8R} + \frac{\mu_1^2 A_c^2}{8R} + \frac{\mu_2^2 A_c^2}{8R} + \frac{\mu_2^2 A_c^2}{8R}$$

$$P_T = \frac{A_c^2}{2R} + \cancel{2} \cdot \frac{\mu_1 A_c^2}{4\,\cancel{8}R} + \cancel{2} \cdot \frac{\mu_2^2 A_c^2}{4\,\cancel{8}R}$$

$$P_T = \frac{A_c^2}{2R} + \frac{\mu_1^2 A_c^2}{4R} + \frac{\mu_2^2 A_c^2}{4R}$$

$$P_T = \frac{A_c^2}{2R}\left[1 + \frac{\mu_1^2}{2} + \frac{\mu_2^2}{2}\right]$$

$$P_T = P_c\left[1 + \frac{\mu_t^2}{2}\right] \qquad \because \text{WKT, } P_c = \frac{A_c^2}{2R}$$

where,

$$\frac{\mu_t^2}{\cancel{2}} = \frac{\mu_1^2}{\cancel{2}} + \frac{\mu_2^2}{\cancel{2}}$$

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

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

μ_t is defined as an effective modulator index

In General,

Total modulation index is given by,

$$\boxed{\mu_t = \sqrt{\mu_1^2 + \mu_2^2 + \mu_3^2 + \cdots \mu_n^2}}$$

★ GENERATION OF AM WAVE-

→ The generation of amplitude modulated wave requires the use of non-linear device.

→ There are two important methods of A.M generation for low power applications. They are-

(i) Square-law modulator
(ii) Switching modulator

(1) ★ SQUARE-LAW MODULATOR-

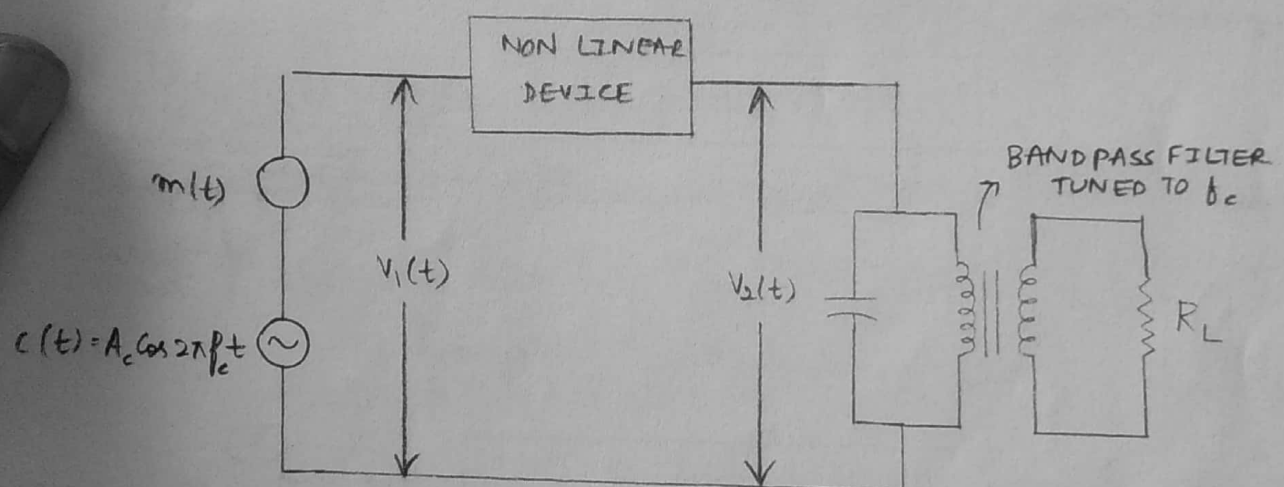


fig (i) SQUARE-LAW MODULATOR

→ The Square law modulator consists of 3 elements-

(i) SUMMER- This adds the carrier and modulating signal.

(ii) NON-LINEAR DEVICE- This is a device with non linear input-output relation

(iii) BAND PASS FILTER- This extracts desired signal (term) from the modulator product of the carrier.

→ In the arrangement of square law modulator semiconductor diodes or transistors can be used as non linear element

→ Single or double tuned circuit can be used as the filter

→ when a non linear element (diode - load resistor combination) such as diode is suitably biased and the signal applied is relatively weak, it is possible to approximate the transfer characteristics as :-

o/p signal [illegible]

$$\boxed{v_2(t) = a_1 v_1(t) + a_2 v_1^2(t)} \quad \text{------ (1)}$$

① Determine spectral content of output signal
② To extract the desired AM wave from $V_2(t)$ we need a bandpass filter
③ To avoid spectral distortion by presence of undesired modulation products in $V_2(t)$

where a_1 and a_2 are constants

→ The input voltage $v_1(t)$ is the sum of carrier signal and modulating signal

ie,
$$\boxed{v_1(t) = \underbrace{A_c \cos 2\pi f_c t}_{c(t)} + m(t)} \quad \text{--- (2)}$$

substituting eqn (2) in eqn (1),

$$\therefore v_2(t) = a_1 \left[A_c \cos 2\pi f_c t + m(t)\right] + a_2 \underbrace{\left[A_c \cos 2\pi f_c t + m(t)\right]^2}_{(a+b)^2}$$

W.K.T $(a+b)^2 = a^2 + 2ab + b^2$

$$\Rightarrow V_2(t) = a_1 A_c \cos 2\pi f_c t + a_1 m(t) + a_2 \left[A_c^2 \cos^2 2\pi f_c t + m^2(t) + 2 m(t) A_c \cos 2\pi f_c t\right]$$

$$v_2(t) = \underline{a_1 A_c \cos 2\pi f_c t} + a_1 m(t) + a_2 A_c^2 \cos^2 2\pi f_c t + a_2 m^2(t) + 2 \underline{a_2 m(t) A_c \cos 2\pi f_c t}$$

$$V_2(t) = \underbrace{a_1 A_c \cos 2\pi f_c t}_{\text{AM WAVE}} + 2 a_2 m(t) A_c \cos 2\pi f_c t +$$
$$a_1 m(t) + a_2 A_c^2 \cos^2 2\pi f_c t + a_2 m^2(t)$$

$$V_2(t) = \underbrace{a_1 A_c \left[1 + \frac{2a_2}{a_1} m(t)\right] \cos 2\pi f_c t}_{\text{AM WAVE}} + \underbrace{a_1 m(t) + a_2 A_c^2 \cos^2 2\pi f_c t + a_2 m^2(t)}_{\text{UNWANTED TERMS}} \quad \text{------ (3)}$$

→ The first term of eqn (3) is the desired AM wave with $K_a = \frac{2a_2}{a_1}$, amplitude sensitivity of the AM wave.

→ The remaining three terms are unwanted and the removed by appropriate filtering,

$$\therefore\ s(t) = a_1 A_c [1 + K_a m(t)] \cos 2\pi f_c t$$

NOTE - Here the unwanted terms are removed by the Bandpass filter (BPF)

The Bandpass filter is required to have the centre frequency = f_c with a bandwidth twice the message bandwidth ie, $2f_m$.

★ (2) SWITCHING MODULATOR -

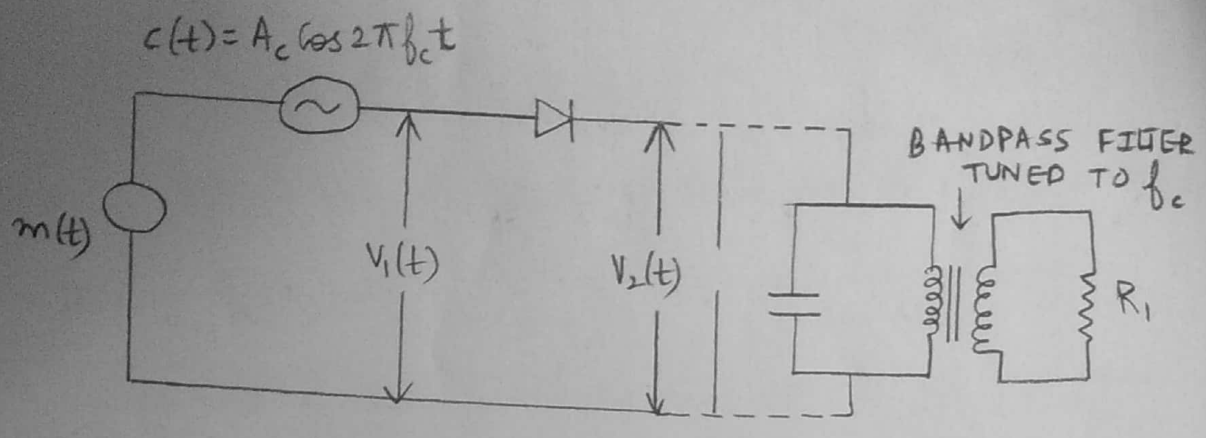


fig (i) SWITCHING MODULATOR

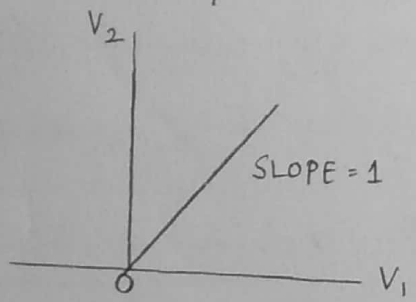


fig (ii) IDEALIZED INPUT - OUTPUT RELATION

→ consider a semiconductor diode used as an ideal switch to which a carrier wave c(t) and an message signal m(t) are simultaneously applied as in fig (i) of switching modulator.

→ It is assumed that the carrier wave c(t) applied to the diode is large in amplitude and also assumed to be ideal.

→ The total input '$v_1(t)$' to the diode is given by,

$$v_1(t) = m(t) + c(t)$$

$$\boxed{v_1(t) = m(t) + A_c \cos 2\pi f_c t} \quad \text{——— (1)}$$

where, $|m(t)| << A_c$

→ The output of the diode is,

$$V_2(t) = \begin{cases} V_1(t), & c(t) > 0 \\ 0, & c(t) < 0 \end{cases}$$

ie, the output of the diode varies between 0 and V_1 at a rate equal to carrier frequency $T_0 = \frac{1}{f_c}$

→ The non-linear behaviour of the diode can be replaced by assuming the weak modulating signal compared with the carrier wave. Thus, the output of the diode is approximately equal to linear time varying operation.

→ Mathematically the output of the diode can be written as,

$$V_2(t) = V_1(t) \cdot g_p(t) \quad \text{------ (2)}$$

$$V_2(t) = [m(t) + A_c \cos 2\pi f_c t]\, g_p(t) \quad \text{------ (3)}$$

where,

$g_p(t)$ is a rectangular pulse train with a period equal to $T_0 = 1/f_c$ as in fig (iii)

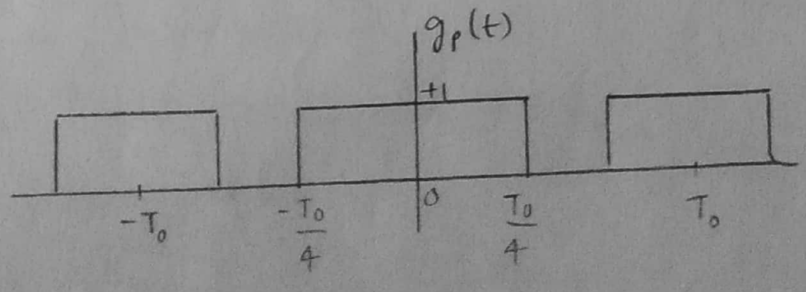


fig (iii) PERIODIC PULSE TRAIN

→ Representing $g_p(t)$ by its fourier series, we have

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

$$g_p(t) = \frac{1}{2} + \underbrace{\frac{2}{\pi} \cos 2\pi f_c t}_{n=1} + \text{odd harmonic components} \quad \text{------ (4)}$$

Substituting eqn (4) in eqn (3),

$$V_2(t) = \left[m(t) + A_c \cos 2\pi f_c t\right]\left[\frac{1}{2} + \frac{2}{\pi} \cos 2\pi f_c t + \text{------}\right]$$

$$V_2(t) = \frac{1}{2} m(t) + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{2A_c}{\pi} \cos^2 2\pi f_c t + \text{------}$$

W.k.T, $\boxed{\cos^2\theta = \frac{1}{2} + \frac{\cos 2\theta}{2}}$

$$\Rightarrow V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{2A_c}{\pi}\left[\frac{1}{2} + \frac{\cos 2(2\pi f_c t)}{2}\right]$$

$$\Rightarrow V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{\cancel{2}A_c}{\cancel{2}\pi} + \frac{\cancel{2}A_c \cos 4\pi f_c t}{\cancel{2}\pi}$$

$$\Rightarrow V_2(t) = \frac{m(t)}{2} + \frac{2m(t)}{\pi} \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t + \frac{A_c}{\pi} + \frac{A_c \cos 4\pi f_c t}{\pi} + \text{------} (5)$$

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→ The required AM wave centred at f_c is obtained by passing '$V_2(t)$' through an ideal 'BPF' having a centre frequency 'f_c' and bandwidth $B_T = 2W\,Hz$

→ The output of the Bandpass filter is,

$$V_2'(t) = \frac{2}{\pi} m(t) \cos 2\pi f_c t + \frac{A_c}{2} \cos 2\pi f_c t$$

$$V_2'(t) = \frac{A_c}{2} \cos 2\pi f_c t \left[1 + \frac{2.2}{\pi \cdot A_c} m(t)\right]$$

$$V_2'(t) = \frac{A_c}{2} \cos 2\pi f_c t \left[1 + \frac{4}{\pi A_c} m(t)\right]$$ where,

$$K_a = \frac{4}{\pi A_c} = \text{amplitude sensitivity}$$

$$\therefore \boxed{V_2'(t) = \frac{A_c}{2} \cos 2\pi f_c t \left[1 + K_a m(t)\right]}$$

★ **DETECTION OF AM WAVES** (OR) (DEMODULATION OF AM WAVES)

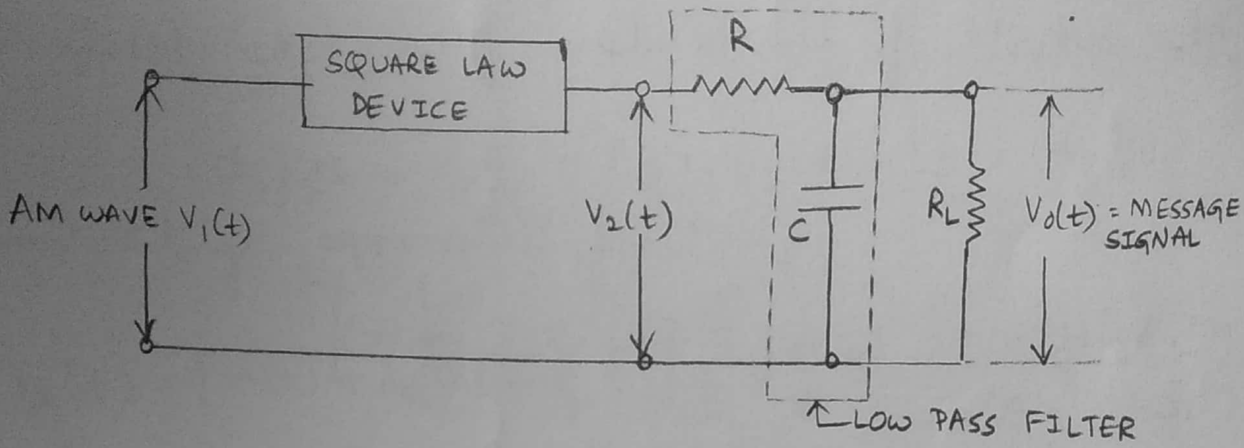
→ Detection/Demodulation is the process of recovering the original message signal from the modulated wave at the receiver

→ Demodulation is the inverse of the modulation process.

→ There are two types of detectors -
(i) Square law demodulator/detector
(ii) Envelope detector

★ (1) SQUARE LAW DETECTOR -

A demodulator whose output voltage is proportional to the square of the amplitude modulated input voltage known as square law demodulator



fig(i) SQUARE LAW DETECTOR

→ A square law detector is obtained by using a square law modulator for the purpose of detection

→ An AM signal can be demodulated by squaring it and then passing the squared signal through a low pass filter (LPF)

→ The transfer characteristics of a non-linear device is given by, ★

$$\boxed{V_2(t) = a_1 V_1(t) + a_2 V_1^2(t)} \quad \text{—— (1)}$$

where,

$v_1(t) \rightarrow$ input voltage
$V_2(t) \rightarrow$ output voltage
$a_1, a_2 \rightarrow$ constants

→ The input voltage of the AM wave is given by,

$$\boxed{V_1(t) = A_c\,[1 + K_a m(t)] \cos 2\pi f_c t} \quad \text{------ (2)}$$

Substitute eqn (2) in eqn (1) we get,

$$\Rightarrow V_2(t) = a_1 \{ A_c [1 + K_a m(t)] \cos 2\pi f_c t \} + a_2 \{ A_c [1 + K_a m(t)] \cos 2\pi f_c t \}^2$$

$$V_2(t) = a_1 A_c [1 + K_a m(t)] \cos 2\pi f_c t + a_2 \{ A_c^2 \underbrace{[1 + K_a m(t)]^2}_{(a+b)^2} \underbrace{\cos^2}_{\cos^2\theta} 2\pi f_c t \}$$

WKT,

$$(a+b)^2 = a^2 + b^2 + 2ab$$

$$\cos^2\theta = \frac{1 + \cos 2\theta}{2}$$

$$\therefore V_2(t) = a_1 A_c [1 + K_a m(t)] \cos 2\pi f_c t + a_2 A_c^2 \underbrace{\cos^2 2\pi f_c t}_{\cos^2\theta} [1^2 + K_a^2 m^2(t) + 2K_a m(t)]$$

$$\Rightarrow V_2(t) = a_1 A_c [1 + K_a m(t)] \cos 2\pi f_c t + a_2 A_c^2 \left[\frac{1 + \cos 2(2\pi f_c t)}{2} \right] [1 + K_a^2 m^2(t) + 2K_a m(t)]$$

$$\boxed{V_2(t) = a_1 A_c [1 + K_a m(t)] \cos 2\pi f_c t + \frac{a_2 A_c^2}{2} [1 + K_a^2 m(t) + 2K_a m(t)] (1 + \cos 4\pi f_c t)} \quad \text{------ (3)}$$

→ In eqn (3) $\frac{a_2 A_c^2}{\cancel{2}} \cancel{2} K_a m(t)$ $= a_2 A_c^2 K_a m(t)$ is the desired term which is due to $a_2 V_1^2$ term from eqn (1). Hence the name of the detector is <u>SQUARE LAW DETECTOR</u>

→ The desired term is extracted by using a LPF. Thus, the output of the LPF is,

$$\boxed{V_0(t) = a_2 A_c^2 k_a m(t)}$$

∴ The message signal m(t) is recovered at the output of the message signal.

<u>Distortion in the detector output -</u>

→ The Term which passes through the LPF to the load resistance R_L is as follows : $\frac{1}{2} a_2 A_c^2 k_a^2 m^2(t)$

→ This is an unwanted signal and gives rise to a signal distortion 'D'

The ratio of the desired signal to the undesired signal is given by,

$$D = \frac{\overbrace{\cancel{a_2 A_c^2 k_a} m(t)}^{(V_0)} \rightarrow \text{desired}}{\frac{1}{2} \cancel{a_2} A_c^{\cancel{2}} k_a^{\cancel{2}} m^{\cancel{2}}(t) \rightarrow \text{undesired}}$$

$$D = \frac{1}{\frac{1}{2} k_a m(t)}$$

$$D = \frac{2}{k_a m(t)}$$

<u>NOTE</u> - we should minimize this ratio to minimise the distortion

To make this ratio large the quantity $|k_a m(t)|$ is kept small, also requires modulation index to be kept small.

★ (2) ENVELOPE DETECTOR -

Electronic ckt that takes high frequency signal as input and provides an output which is the envelope of original signal

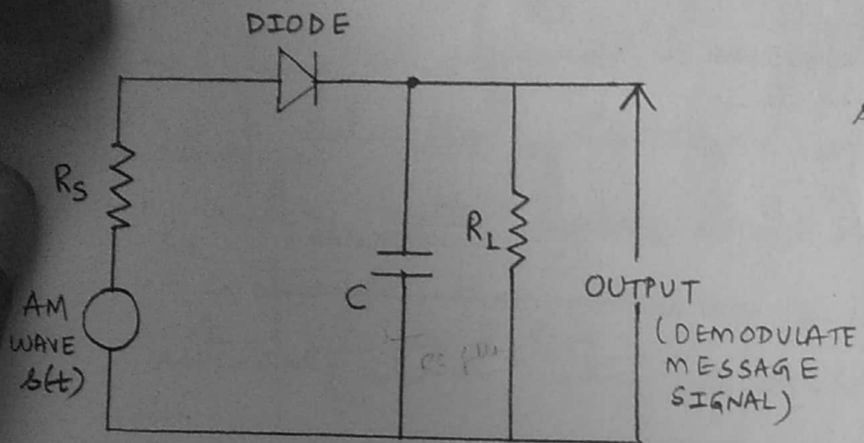


fig (i) ENVELOPE DETECTOR

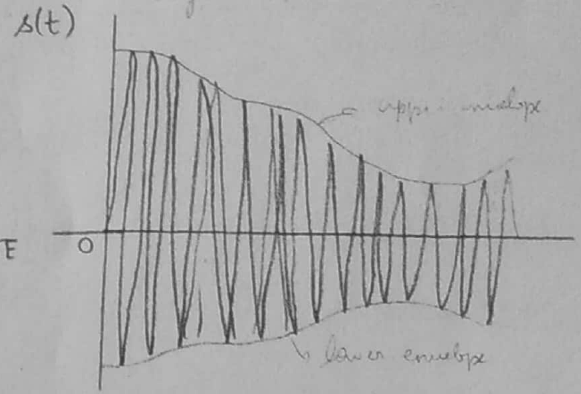


fig (ii) AM WAVE INPUT

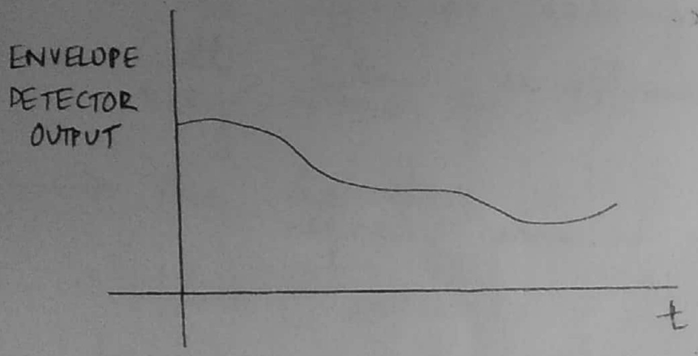


fig (iii) ENVELOPE DETECTOR

→ C charges on the rising edge & releases slowly through the resistor when the signal falls

→ Diode in series rectifies the incoming signal allowing current flow only when positive input terminal is at higher potential than the negative input terminal

→ Envelope detector is a simple and highly effective device used to demodulate AM wave

→ It consists of a diode and a resistor capacitor [RC] filter

→ In an envelope detector, the output of the detector follows the envelope of the modulated wave, such detectors are widely used in all A.M receiver system.

OPERATION -

→ During positive half cycle of the input signal, diode is forward biased

Capacitor 'C' charges upto peak value of i/p signal

when the input voltage falls below this value the diode becomes reverse biased and capacitor 'C' discharges slowly through the load resistor R_L.

∴ only positive half cycle of AM wave appears across R_L.

→ The discharging process continues until the next positive half cycle.

when the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.

SELECTION OF RC TIME CONSTANT -

→ The Capacitor charges through 'D' and R_s when the diode is 'ON'

→ The capacitor discharges through 'R_L' when the diode is 'OFF'

→ The charging time constant R_sC should be short as compared to the carrier period $1/f_c$

∴ $\boxed{R_s C << \frac{1}{f_c}}$ ⇒ Capacitor 'C' charges rapidly

→ The discharging time constant $R_L C$ should be long enough to ensure that the capacitor discharges slowly through the load resistance 'R_L' between positive peak of the carrier wave

ie $$\boxed{\frac{1}{f_c} << R_L C << \frac{1}{W}}$$

where, W is maximum modulating frequency

→ The capacitor voltage or detector output is very same as the envelope of A.M wave.

→ The detector output usually has a small ripple at the carrier frequency. This ripple is easily removed by Low Pass Filter.

★ ADVANTAGES OF AMPLITUDE MODULATION (AM)

(1) AM Receivers are simple and detection is easy.

(2) AM Receivers are cost efficient

(3) AM Transmitters are less complex

(4) AM waves can travel a longer bandwidth

(5) AM have low Bandwidth

★ DISADVANTAGES OF AMPLITUDE MODULATION (AM)

(1) AM needs larger Bandwidth

(2) AM waves gets affected due to noise

(3) Power is wasted in the transmitted signal.

(1) **AM NEEDS LARGER BANDWIDTH** -

→ The Transmitted signal requires twice the Bandwidth of the message signal ie, $B_T = 2f_m$.

→ This is due to the transmission of both sidebands out of which only one sideband is sufficient to convey all the information.

∴ Bandwidth is double than actually required

(2) **AM WAVES GETS AFFECTED DUE TO NOISE** -

→ when the AM wave travels from transmitter to receiver over a communication channel, noise gets added to it.

→ The noise ~~ch~~ changes the amplitude of the envelope of AM in a random manner

As the information is contained in the amplitude variations of the AM wave, the noise will contaminate the information contents in the AM

∴ The performance of AM is very poor in presence of noise.

POWER IS WASTED IN THE TRASMITTED SIGNAL-

→ Most of the transmitted power is in the carrier, which does not carry information

→ Power wastage due to AM transmission :- (DSB-FC)

W.K.T, the total power transmitted by an AM wave is given by,

$$P_T = P_C + P_{USB} + P_{LSB} \quad ----(1)$$

$$P_T = P_C + \frac{\mu^2}{4} P_c + \frac{\mu^2}{4} P_c \quad ---(2)$$

In Eqn (2), carrier component does not contain any information and one sideband is redundant.

So, out of the total power $P_T = P_C \left[1 + \frac{\mu^2}{2}\right]$,

The wasted power is given by,

$$\text{Power wastage} = P_c + \frac{\mu^2}{4} P_c$$

★ APPLICATIONS OF AMPLITUDE MODULATION- (AM)

(1) Radio Broadcasting

(2) Picture Transmission in a TV system

★ TYPES OF AMPLITUDE MODULATION (AM)

- DSB-FC (Double Sideband Full Carrier System)
- DSB-SC (Double Sideband Suppressed Carrier System)
- SSB-SC (Single Sideband Suppressed Carrier System)
- ISB (Independent ~~Carrier~~ Sideband System)
- VSB (Vestigial Sideband System)

DOUBLE SIDEBAND SUPPRESSED CARRIER MODULATION-

→ To overcome the drawback of power wastage in AM wave (DSB-FC), an DSB-SC method is used.

→ DSB-SC is a method of transmission where only the Two sidebands are transmitted without the carrier (suppressing carrier)

(OR)

The conventional AM wave in which the carrier is suppressed is called DSB-SC modulation.

→ To save power and bandwidth both the carrier and one of the sidebands can be suppressed. This method of transmission with only one sideband is known as SINGLE SIDEBAND (SSB) transmission.

→ There are two representations or descriptions of DSB-SC wave :-

(i) Time-Domain Representation of DSB-SC wave

(ii) Frequency-Domain Representation of DSB-SC wave

Product modulation

DSBSC modulation is reduced to zero

→ whenever message signal m(t) is switched off

modulation signal s(t) undergoes a phase reversal

whenever message signal m(t) crosses zero

(1) TIME DOMAIN DESCRIPTION-

→ Let m(t) be the message signal having a bandwidth equal to 'W' Hz and carrier is

$\boxed{c(t) = A_c \cos 2\pi f_c t}$ represents the carrier

Then the time domain expression for DSB-SC wave is,

$$\boxed{s(t) = m(t)\, c(t)}$$

∴ It becomes after substituting for c(t) as,

$$\boxed{s(t) = A_c \cos(2\pi f_c t)\, m(t)} \quad ---- (1)$$

→ From eqn (1), we see that DSBSC signal can be created by a multiplier.

→ The actual devices available for multiplication yield an output carrier and also lower and upper sidebands giving an amplitude modulated signal

→ If we require only the product signal, we must suppress the carrier so that only the sidebands will remain

→ Thus, the suppression may be achieved by adding to the amplitude modulated signal, a carrier opposite in phase but equal in magnitude, so that only product part of the A.M remains.

→ The product signal represents the double sideband - suppressed carrier or DSB - SC signal

NOTE - The product signal $s(t)$ undergoes a <u>phase reversal</u> whenever the baseband signal crosses zero

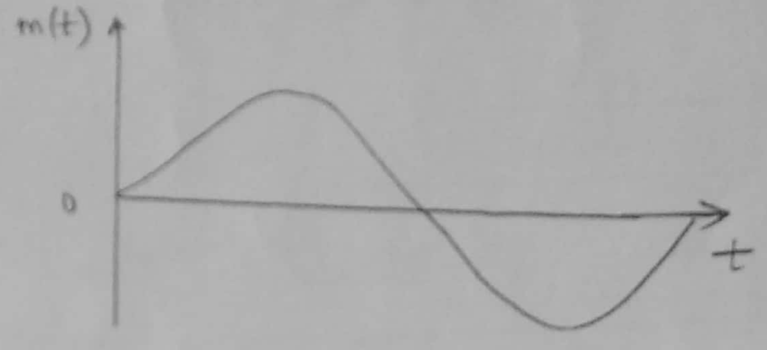


fig (i) MODULATING SIGNAL m(t) (MESSAGE)

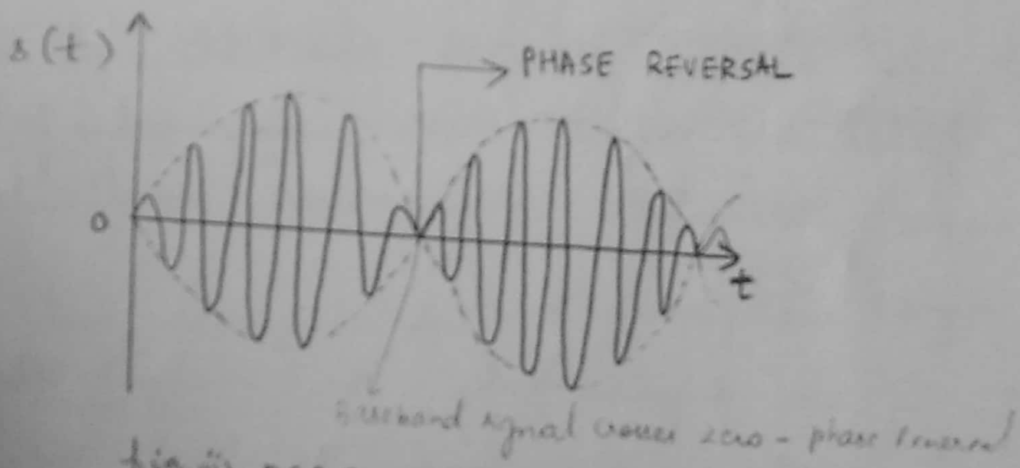


fig (ii) DSBSC MODULATED WAVE s(t)

2) FREQUENCY DOMAIN DESCRIPTION-

→ As seen from fig (ii) DSBSC modulated wave $s(t)$, the envelope of the DSBSC modulated wave is different from fig (i) message signal.

→ This is due to the suppression of the carrier from the AM wave

→ Now Taking the fourier transform of eqn (1),

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

$$\Rightarrow \boxed{S(f) = \frac{1}{2} A_c \left[M(f-f_c) + M(f+f_c)\right]} \quad \text{------ (2)}$$

where,

$S(f) \rightarrow$ fourier transform of the modulated wave $s(t)$

$M(f) \rightarrow$ fourier transform of the message signal $m(t)$

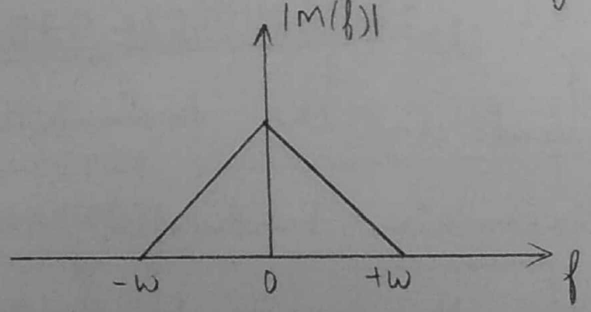


fig (i) SPECTRUM OF MESSAGE SIGNAL $m(t)$

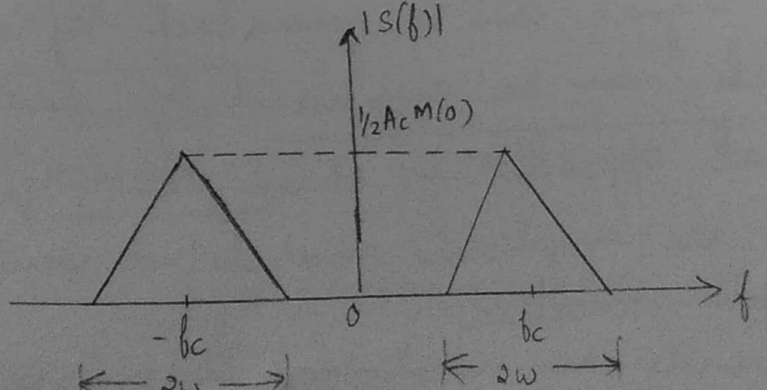


fig (ii) SPECTRUM OF DSBSC SIGNAL $s(t)$

→ when the spectrum of the modulating signal $m(t)$ is band limited in the interval $-W$ and $+W$ as in fig (i), then the corresponding spectrum of the DSBSC modulated signal $S(f)$ is as in fig (ii)

NOTE - The modulation process just shifts the spectrum of the modulating signal by $\pm f_c$ and the transmission bandwidth for DSBSC modulated wave remains same as that required for AM wave equal to $2W$.

→ The amplitude spectrum drawn exhibits the following factors -

(i) on either sides of $\pm f_c$, we have two sidebands designated as lower and upper side bands.

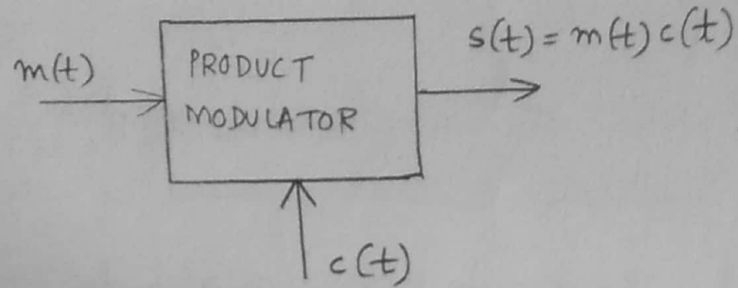
(ii) The impulse are absent at $\pm f_c$ in the amplitude spectrum signifying the fact that the carrier term is suppressed in the transmitted wave.

(iii) The minimum transmission bandwidth required is $2W$ ie, TWICE the message bandwidth

NOTE - A DSB-SC signal can be generated by a multiplier
A carrier signal can be suppressed by adding a carrier signal opposite in phase but equal in magnitude to the amplitude modulated wave, so the carrier gets cancelled
∴ Double sidebands are available in DSB-SC wave.

GENERATION OF DSBSC WAVES

→ A DSB-SC wave simply consists of the product of the modulating signal and the carrier signal.



→ The devices used to generate DSB-SC waves are known as the product modulators

→ There are two types of modulators :-

(i) Balanced modulator

(ii) Ring modulator

★ (1) BALANCED MODULATOR-

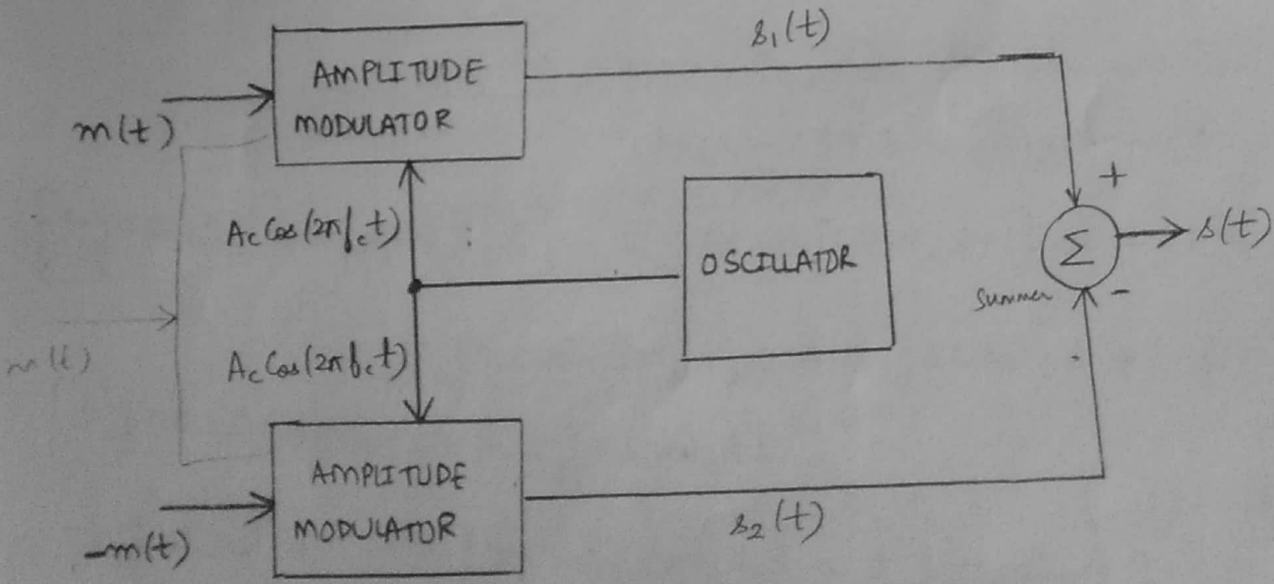


fig (i) BALANCED MODULATOR

→ fig (i) shows the block diagram of a balanced modulator used for generating a DSB-SC signal

→ It consists of two amplitude modulators that are interconnected so as to suppress the carrier.

→ one input to the amplitude modulator is from an oscillator that generates a carrier wave.

→ The second input to the amplitude modulator in the top path is the modulating signal $+m(t)$ while in the bottom path is $-m(t)$

→ The output of the two AM modulators are as follows –

$$s_1(t) = A_c[1 + K_a m(t)] \cos 2\pi f_c t$$

$$s_2(t) = A_c[1 - K_a m(t)] \cos 2\pi f_c t$$

→ The output of the summer is,

$$s(t) = s_1(t) - s_2(t)$$

$$s(t) = A_c[1 + k_a m(t)] \cos 2\pi f_c t - [A_c(1 - k_a m(t)) \cos 2\pi f_c t]$$

$$= A_c \cos 2\pi f_c t + A_c k_a m(t) \cos 2\pi f_c t - [A_c \cos 2\pi f_c t - A_c K_a m(t) \cos 2\pi f_c t]$$

$$= \cancel{A_c \cos 2\pi f_c t} + A_c k_a m(t) \cos 2\pi f_c t - \cancel{A_c \cos 2\pi f_c t} + A_c K_a m(t) \cos 2\pi f_c t$$

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$$s(t) = A_c k_a m(t) \cos 2\pi f_c t + A_c k_a m(t) \cos 2\pi f_c t$$

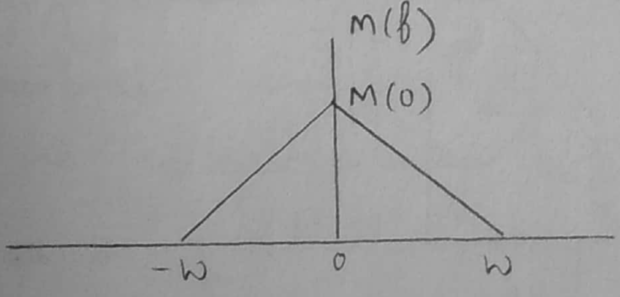
$$\therefore \boxed{s(t) = 2 A_c k_a m(t) \cos 2\pi f_c t} \quad \text{------ (1)}$$

→ The Balanced modulator output is equal to the produnt of the modulating signal m(t) and carrier signal c(t) except the scaling factor

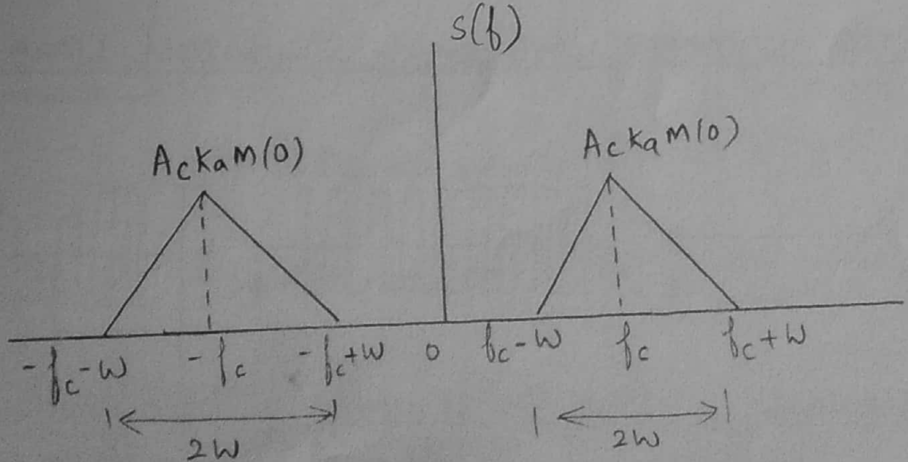
Taking fourier transform on Both sides of eqn (1) we get,

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

$$\therefore \boxed{S(f) = A_c k_a \left[M(f - f_c) + M(f + f_c) \right]}$$



fig(i) MESSAGE SPECTRUM



fig(ii) DSB-SC SPECTRUM

★ (2) RING MODULATOR

(Also called as Lattice)
double balanced modulator

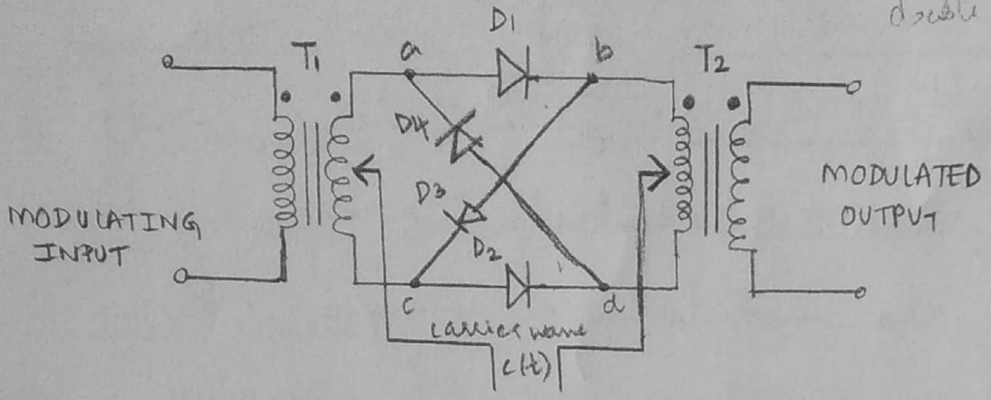


fig (i) BALANCED RING MODULATOR

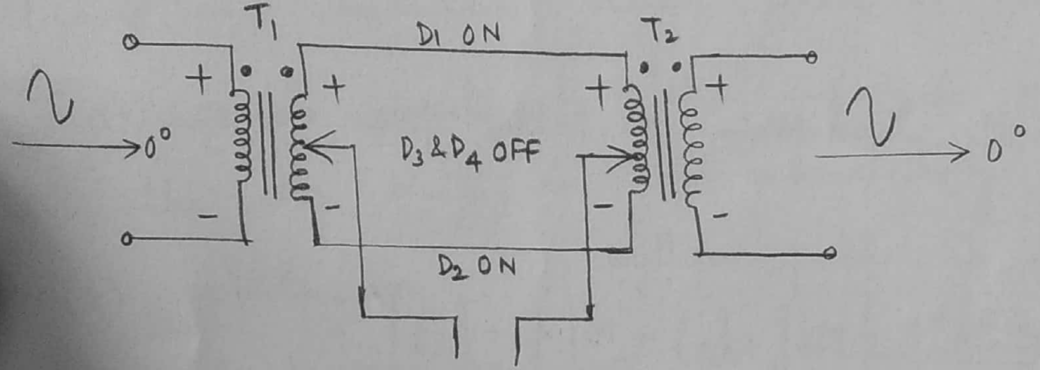


fig (ii) EQUIVALENT CIRCUIT WHEN SQUARE WAVE CARRIER POSITIVE

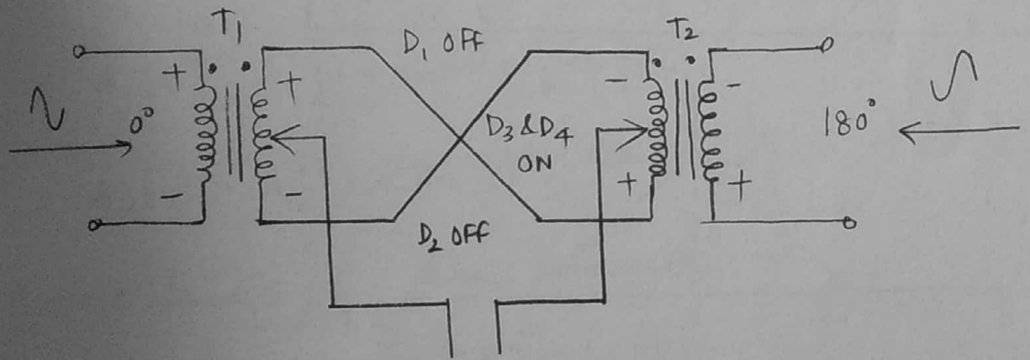


fig (iii) EQUIVALENT CIRWIT WHEN SQUARE WAVE CARRIER NEGATIVE

RING MODULATOR WAVEFORMS - SINUSOIDAL WAVE

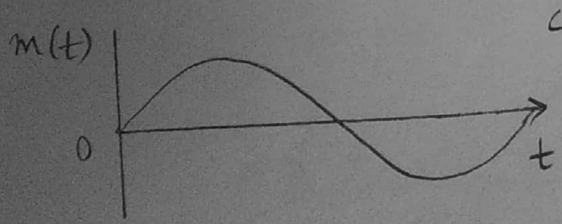


fig (a) MESSAGE SIGNAL

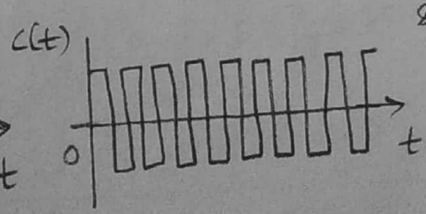


fig (b) SQUARE WAVE CARRIER

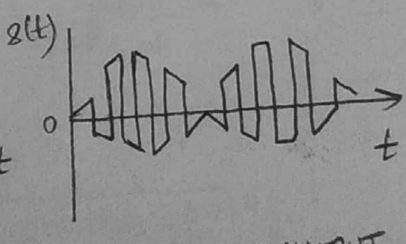


fig (c) MODULATED OUTPUT BEFORE FILTERING

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Ring modulators are one of the most widely used circuit for generating DSBSC wave

→ Ring modulators are product modulators used for generating DSB-SC modulated wave.

→ Ring modulators consists of :-

(i) Input transformer 'T_1'

(ii) output transformer 'T_2'

(iii) Four diodes connected in a Bridge circuit (Ring)

→ The carrier amplitude 'A_c' is greater than the modulating signal amplitude 'A_m' ie,

$\boxed{A_c > A_m}$

→ The carrier frequency 'f_c' is greater than the modulating signal 'f_m' = W ie $\boxed{f_c > W}$

→ These conditions ensures that the diode operation is controlled by c(t) only

→ The diodes are controlled by a square wave carrier c(t) of frequency 'f_c' which is applied by means of two center tapped transformers.

→ The modulating signal m(t) is applied to the input transformer 'T_1'

→ The output appears across the secondary of the transformer 'T_2'

→ we assume that the diodes are ideal and the transformers are perfectly balanced.

OPERATION-

(outer diodes)

(i) When the carrier is positive → The diodes D_1 & D_2 are forward biased and diodes D_3 & D_4 are Reverse biased. Hence, the modulator multiplies the message signal $m(t)$ by $+1$,

ie, $\boxed{V_0(t) = m(t)}$

(Inner diodes)

(ii) When the carrier is Negative → The diodes D_3 & D_4 are forward biased and diodes D_1 & D_2 are Reverse biased. Hence, the modulator multiplies the message signal $m(t)$ by -1,

ie, $\boxed{V_0(t) = -m(t)}$

→ The square wave carrier $c(t)$ can be represented by a fourier series as :

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

$$\boxed{c(t) = \frac{4}{\pi}\left[\underbrace{\cos 2\pi f_c t}_{n=1} - \underbrace{\frac{1}{3}\cos 6\pi f_c t}_{n=2} + \cdots\right]} \quad \text{---} (1)$$

→ The ring modulator output is,

$$s(t) = c(t) \cdot m(t) \quad \text{------} (2)$$

Substituting eqn (1) in eqn (2), we get

$$s(t) = \left[\underbrace{\frac{4}{\pi} \cos 2\pi f_c t}_{\text{desired DSBSC signal}} - \frac{4}{3\pi} \cos 6\pi f_c t + \cdots\right] m(t)$$

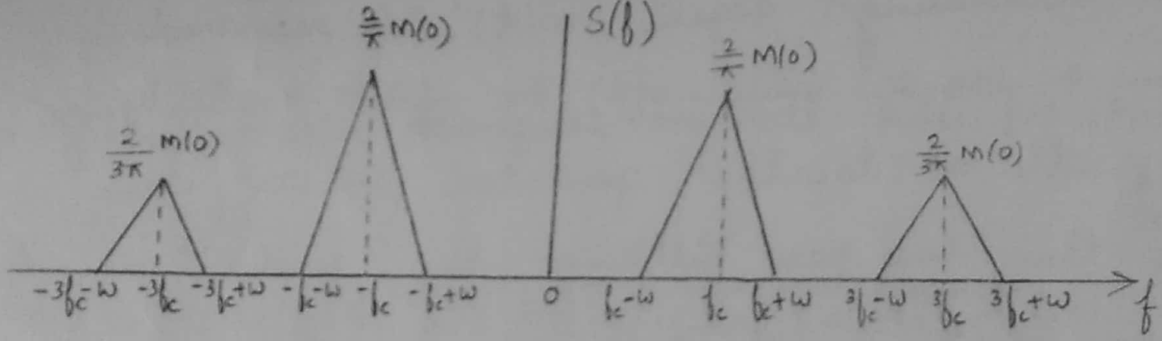
c(t)

$$\therefore \; s(t) = \frac{4}{\pi} m(t) \cos 2\pi f_c t - \frac{4}{3\pi} m(t) \cos 6\pi f_c t + \cdots] \quad \text{------ (3)}$$

→ Taking fourier transform on Both sides of eqn (3) we get,

$$S(f) = \frac{\cancel{4}^{2}}{\cancel{2}\pi}\left[M(f-f_c) + M(f+f_c)\right] - \frac{\cancel{4}^{2}}{\cancel{2} \times 3\pi}\left[M(f-3f_c) + M(f+3f_c)\right]$$

$$\therefore \; \boxed{S(f) = \frac{2}{\pi}\left[M(f-f_c) + M(f+f_c) - \frac{2}{3\pi}\left[M(f-3f_c) + M(f+3f_c)\right]\right]}$$



AMPLITUDE SPECTRUM OF S(f)

→ The DSB-SC wave is extracted from $s(t)$ by passing equation (3) $s(t)$ through an ideal BPF having centre frequency 'f_c' and bandwidth equal to 2W Hz.

∴ The output of the BPF is,

$$\boxed{s(t) = \frac{4}{\pi} m(t) \cos 2\pi f_c t} \quad \because \text{From eqn (3)}$$

★ COHERENT DETECTION OF DSBSC WAVES -

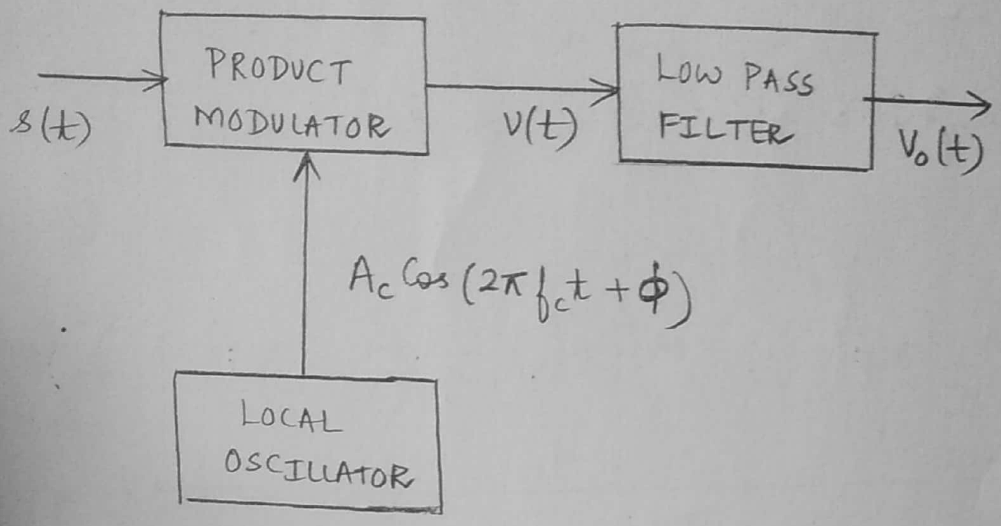


fig (i) COHERENT DETECTIVE FOR DSBSC

→ The modulating signal $m(t)$ is recovered from a DSB-SC wave $s(t)$ by first multiplying $s(t)$ with a locally generated carrier wave and then low pass filtering the product as in fig (i)

→ For a proper recovery of modulating signal $m(t)$, the local oscillator output should be exactly coherent or synchronized in both frequency and phase with the carrier wave $c(t)$ used in the product modulator to generate $V_0(t)$ with the local oscillator output equal to $\cos(2\pi f_c t + \phi)$

→ The product modulator output can be given as,

$$V(t) = s(t) . \cos(2\pi f_c t + \phi) \quad \text{—— (1)}$$

$$V(t) = s(t) \cdot \cos(2\pi f_c t + \phi) \quad \text{---} (1)$$

W.K.T, $s(t) = A_c \cos 2\pi f_c t \cdot m(t)$ —— (2)

Substituting eqn (2) in eqn (1), we get,

$$\Rightarrow V(t) = A_c \cos(2\pi f_c t + \phi) \cos(2\pi f_c t) \cdot m(t)$$

W.K.T,

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

$$V(t) = \frac{A_c m(t)}{2}\left[\cos(\cancel{2\pi f_c t} + \phi - \cancel{2\pi f_c t})\right] + \frac{A_c m(t)}{2}\left[\cos(2\pi f_c t + \phi + 2\pi f_c t)\right]$$

$$\Rightarrow V(t) = \frac{A_c m(t)}{2}\cos\phi + \frac{A_c m(t)}{2}\cos(4\pi f_c t + \phi) \quad \text{——} (\text{I})$$

→ Taking Fourier Transform on Both sides for eqn(I) we get,

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

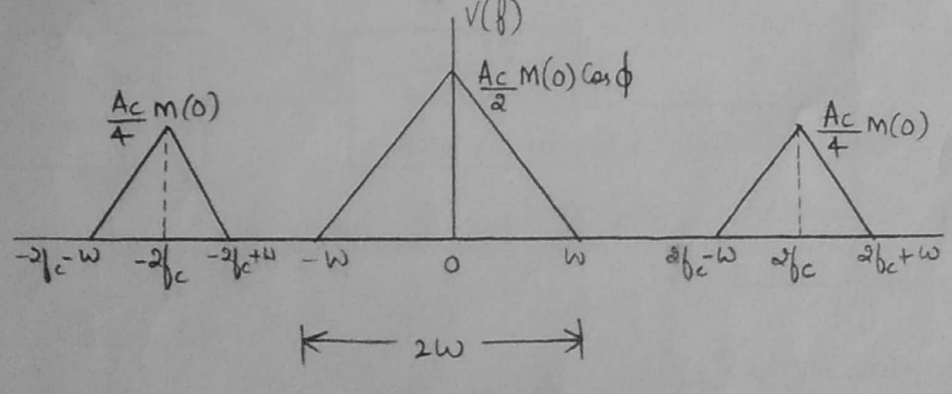


fig (ii) AMPLITUDE SPECTRUM OF V(f)

→ The desired message signal is obtained by passing V(t) through a low pass filter having the bandwidth greater than 'W' Hz but less than '$2f_c - W$' Hz

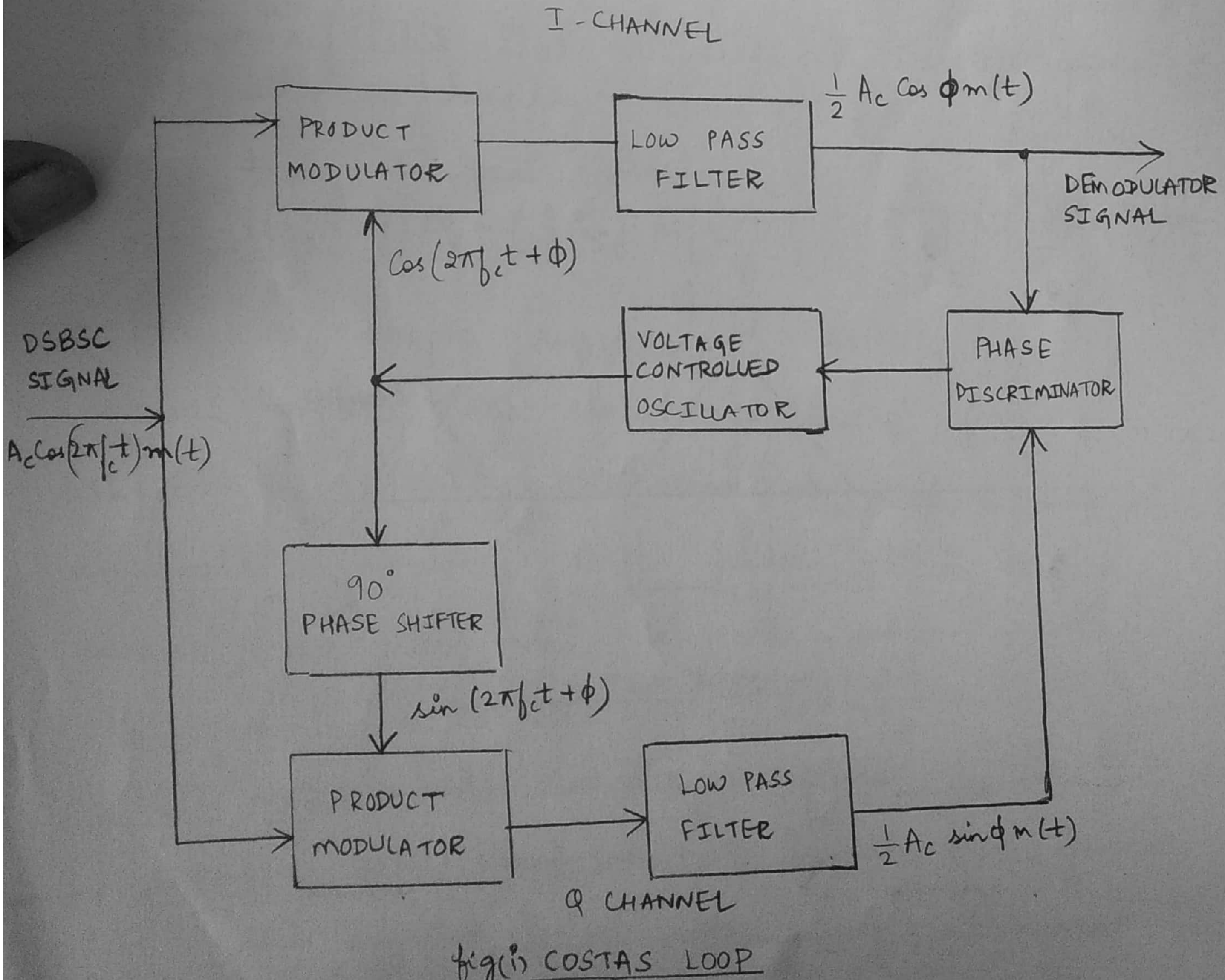
→ The output of the LPF is,

$$\boxed{V_0(t) = \frac{A_c}{2} \cos\phi \, m(t)}$$

→ The demodulated signal $V_0(t)$ is proportional to $m(t)$ where $\phi \rightarrow$ phase error.

→ when ϕ = Constant, $V_0(t)$ is proportional to $m(t)$
when $\phi = 0$, Amplitude of $V_0(t)$ is maximum
when $\phi = \pm\frac{\pi}{2}$, Amplitude of $V_0(t)$ is minimum

★ COSTAS LOOP



fig(i) COSTAS LOOP

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→ The Costas loop is a method of obtaining practical synchronous receiver system, suitable for demodulating DSB-SC waves.

→ The Costas receiver consists of two coherent detector supplied with the same input signal (DSB-SC wave) $A_c \cos(2\pi f_c t) m(t)$, but with the individual local oscillator signals that are in phase quadrature with respect to each other (ie, the local oscillator signal supplied to the product modulators are 90° out of phase)

→ The frequency of the local oscillator is adjusted to be the same as the carrier frequency 'f_c'

→ The detector in the upper path is referred to as the In-phase coherent detector (or) I-channel detector

→ The detector in the lower path is referred to as the Quadrature phase coherent detector (OR) Q-channel detector

→ These two detectors are coupled together to form a negative feedback system designed in such a way so as to maintain the local oscillator synchronous with the carrier wave.

OPERATION -

(i) when local oscillator signal is of the same phase as the carrier wave $A_c \cos(2\pi f_c t)$ used to generate the incoming DSB-SC wave under these conditions, the I-channel output contains the desired demodulated signal $m(t)$, whereas the Q-channel output is zero

$$V_{oI} = \frac{1}{2} A_c m(t) \cos\phi$$

i.e, whenever the carrier is synchronised

$\phi = 0$ and $\cos\phi = \cos(0) = 1$

$\therefore$ $\boxed{V_{oI} = \frac{1}{2} A_c m(t) \cdot 1}$ and

$\sin\phi = \sin(0) = 0$

$\therefore$ $\boxed{V_{oQ} = 0}$

(ii) when local oscillator phase changes by a small angle 'ϕ' radians, the I-channel output will remain unchanged, but Q-channel produces some output which is proportional to $\sin\phi$

NOTE - The output of I and Q-channels are combined in phase discriminator (which consists of a multiplier followed by a LPF), a dc control signal is obtained that automatically corrects for local phase errors in the voltage controlled oscillator [VCO]

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QUADRATURE CARRIER MULTIPLEXING (OR) QUADRATURE AMPLITUDE MODULATION - (QAM)

→ Quadrature amplitude modulation (QAM) is a technique in which we can transmit more number of signals (DSB-SC wave) within the same channel bandwidth

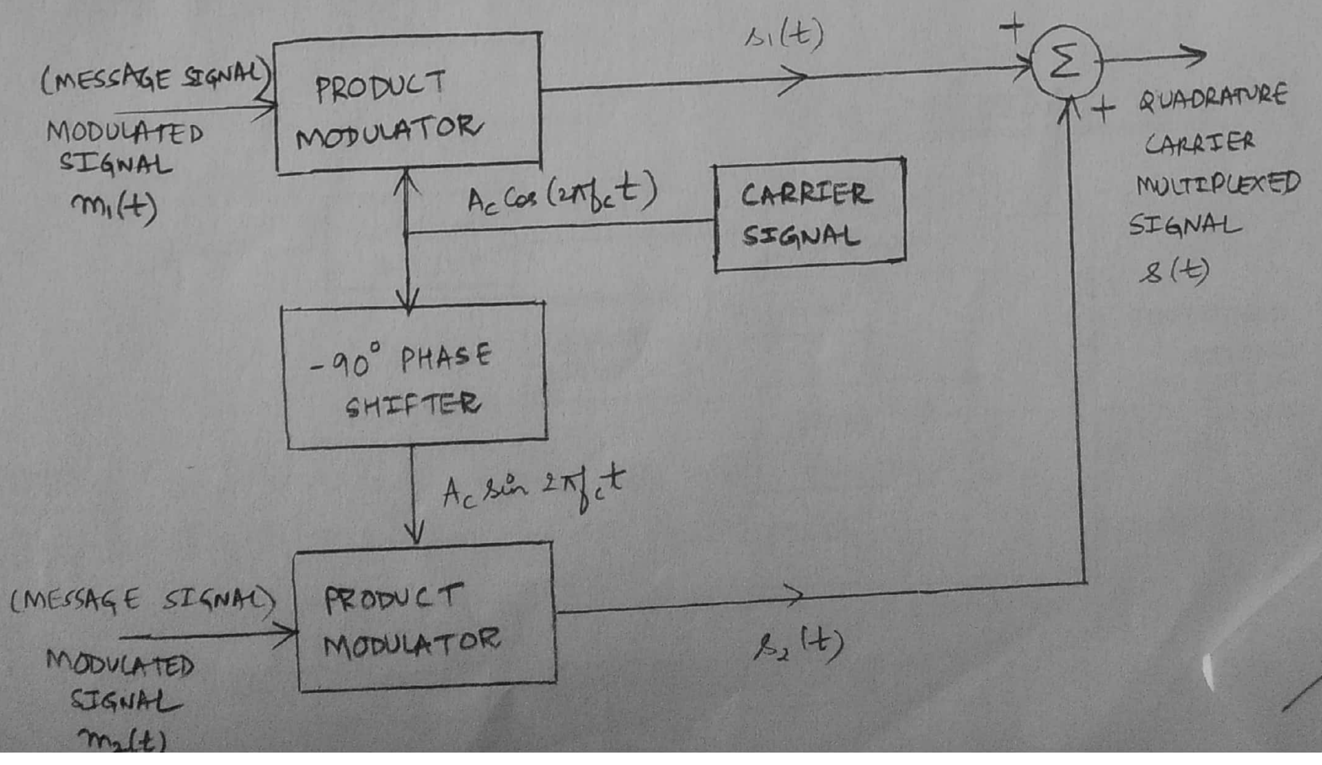
∴ QAM is a bandwidth conservation scheme.

PRINCIPLE OF QAM-

→ The QAM enables two DSB-SC modulated waves to occupy the same transmission channel bandwidth and allows the separation of the two message signals at the receiver output.

∴ QAM is called as Bandwidth Conservation scheme

(i) QAM TRANSMITTER :-



→ QAM transmitter consists of two product modulators that are supplied with two carrier waves of the same frequency but differing in phase by -90°

→ The output of the two product modulators are summed to produce multiplexed signal $s(t)$

ie,

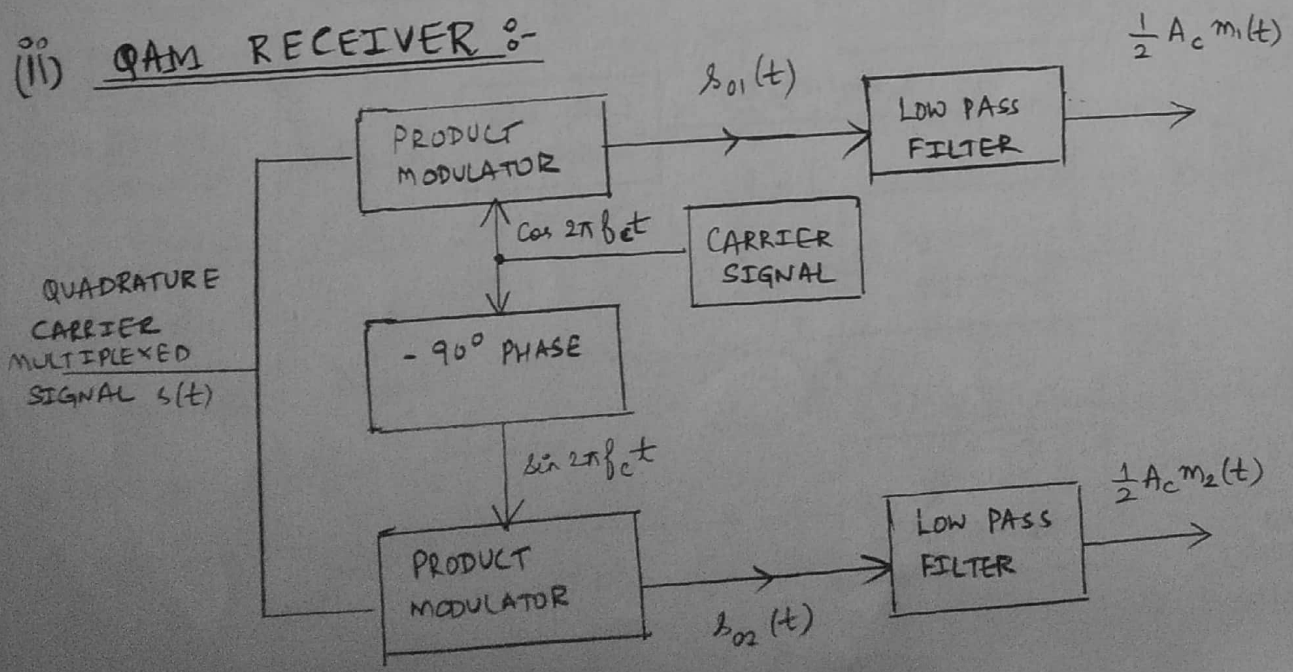
$$\boxed{s(t) = A_c m_1(t) \cos 2\pi f_c t + A_c m_2(t) \sin 2\pi f_c t}$$

where,
$m_1(t)$ and $m_2(t)$ denotes the two different message signals applied to the product modulator.

→ Thus, $s(t)$ occupies a channel bandwidth of '$2W$' centered at the carrier frequency 'f_c'

where, 'W' is the message bandwidth of $m_1(t)$ or $m_2(t)$

(ii) QAM RECEIVER :-



→ QAM receiver consists of two coherent detectors which are fed by locally generated carrier signals having same frequency but out of phase by 90°

→ The received multiplexed signal $s(t)$ is applied to the two product modulator.

→ The output of the top product modulator is given by,

$$\boxed{s_1(t) = s(t) \cos 2\pi f_c t}$$

→ The top LPF removes the high frequency term and allows only $\frac{A_c m_1(t)}{2}$, The output of LPF is,

$$\therefore \boxed{s_1(t) = \frac{A_c}{2} m_1(t)}$$

→ The output of the bottom product modulator is given by,

$$\boxed{s_2(t) = s(t) . \sin 2\pi f_c t}$$

→ The bottom LPF removes the high frequency term and allows only $\frac{A_c}{2} m_2(t)$. The output of LPF is

$$\therefore \boxed{s_2(t) = \frac{A_c}{2} m_2(t)}$$

NOTE - For correct operation of Quadrature carrier multiplexing system, it is necessary to maintain the correct phase and frequency relationship between the local oscillators used in transmitter and receiver of the system.

SALIENT FEATURES OF QAM-

(1) we can transmit more number of DSB-SC wave within the same channel bandwidth

(2) QAM is a bandwidth conservation scheme

(3) QAM has application in colour Television [CTV]