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MODULE 1: AMPLITUDE MODULATION

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AMPLITUDE MODULATION: Introduction, Amplitude Modulation: Time & Frequency – Domain description, Switching modulator, Envelop detector.
DOUBLE SIDE BAND-SUPPRESSED CARRIER MODULATION: Time and Frequency – Domain description, Ring modulator, Coherent detection, Costas Receiver, Quadrature Carrier Multiplexing.
SINGLE SIDE–BAND & VESTIGIAL SIDEBAND METHODS OF MODULATION: SSB Modulation, VSB Modulation, Frequency Translation, Frequency- Division Multiplexing, Theme Example: VSB Transmission of Analog and Digital Television.

MODULE 1: AMPLITUDE MODULATION

1.1Time domain representation of AM

Amplitude Modulation may be defined as a process in which the amplitude of the carrier wave is varied to the instantaneous value (amplitude) of the modulating or base band signal.

Let us consider a sinusoidal carrier wave C(t)given as :

$$C(t) = A_C \cos \omega_c t \quad = A_C \cos 2\pi f_c t \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Let **M(t)** denote the modulating or base band signal.

Then according to amplitude modulation, the maximum amplitude A_C of the carrier will have to be made proportional to the instantaneous amplitude of the modulating signal M(t).

The standard equation for amplitude modulated (AM) wave may be expressed as

$$S(t) = A_C \cos \omega_c t + K_a M(t) A_C \cos \omega_c t \quad \ldots\ldots\ldots(2)$$

Or, $$S(t) = A_C[1 + K_a M(t)] \cos \omega_c t \quad \ldots\ldots\ldots\ldots\ldots(3)$$

Figure 1 shows the modulating signal or base band signal, carrier signal and modulated signal.

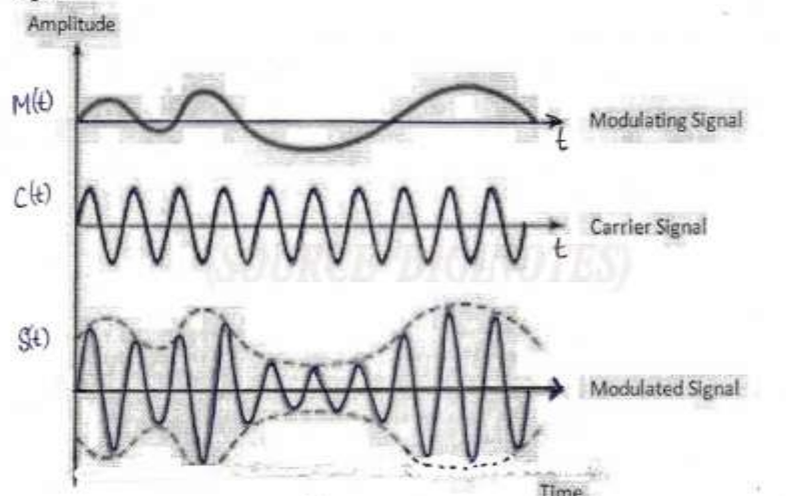


fig 1

Points about Amplitude Modulation

1. It may be observed that equation (1) or (2) describe the time-domain behaviour of amplitude modulated signal.

2. It may be noted that carrier signal [i.e C(t) = Ac cos *Wct is a fixed frequency* signal having frequency *Wc*

3. The modulating or baseband signal M(t) contains the information to be transmitted.

4. In the process of amplitude modulation, this information is super imposed upon the carrier signal in the form of amplitude variations of the carrier signal. In other words, in amplitude modulation, the information is transmitted in the form of amplitude variations of the carrier signal.

5. The resulting signal from the process of amplitude-modulation is called amplitude modulation signal of simply AM wave.

6. In the process of amplitude modulation, the frequency and phase of the carrier remain constant whereas the maximum amplitude varies according to the instantaneous value of the information signal.

7. Equation (3) represents an amplitude modulated wave. This wave has a constant frequency cos *wct and amplitude Ac [1+K, M(t)] . This implies that the amplitude* of the wave is changing around Ac in accordance with the value of the modulating signal M(t). The frequency of the AM signal remains unchanged and is equal to *Wc*

8. The AM wave has time-varying amplitude called as the envelope of the AM wave

1.2 Frequency - Domain Representation or Spectrum of AM Waves Frequency

Mathematical Expression and Waveforms

Let m(t) is the modulating signal and the carrier signal is given by the expression:

$$C(t) = A_c \cos 2\pi f_c t \quad \text{.....................(1)}$$

Then the equation for the AM will be

$$s(t) = A_c \cos 2\pi f_c t + A_c \cos 2\pi f_c t \ K_a m(t) \ \text{..........(2)}$$

This equation describes the AM wave in time-domain. However, if we want to know the frequency description or frequencies present in AM wave, we will have to find its spectrum or frequency-domain representation.

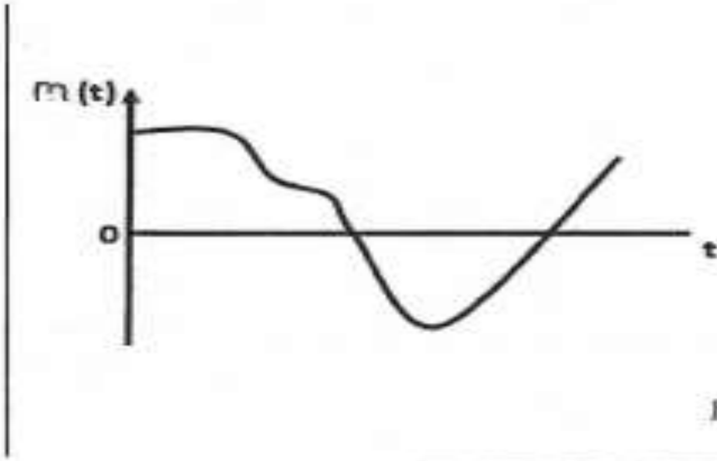
For this purpose, first we have to take the Fourier transform of AM wave.

Let S(f) or S(ω) denote the Fourier transform of s(t),

C(f) or C(ω) denotes the Fourier transform of c(t)

M(f) or M(ω) denoted the Fourier transform of m(t).

Let the modulating signal m(t) and its Fourier transform M(f) be shown in figure 1 (a) .



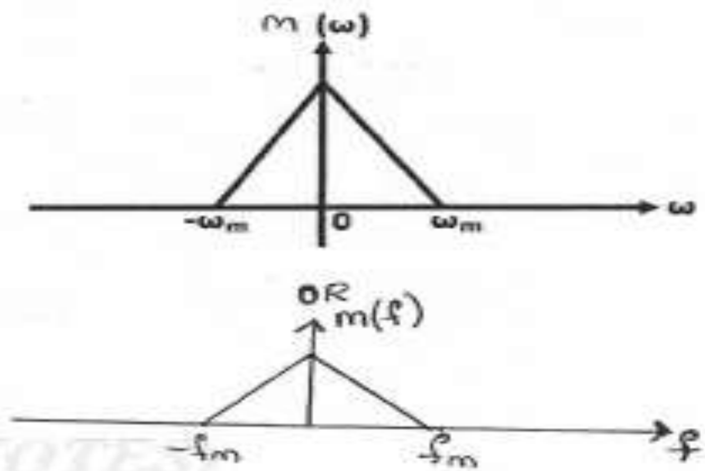


Fig 1 (a)

Hence we can say that the modulating signal contains frequencies from 0 to ω_m or simply the bandwidth of modulating signal is ω_m . We know that the Fourier transform of a cosine signal $\cos \omega_c t$ consists of two impulse at ω_c and $-\omega_c$ as :

$$\cos \omega_c t \leftrightarrow \pi[\delta(\omega + \omega_c) + \delta(\omega - \omega_c)] \quad ....(3)$$

Since the carrier signal is $C(t) = A_c \cos \omega_c t$, therefore

$$A \cos \omega_c t \leftrightarrow \pi A[\delta(\omega + \omega_c) + \delta(\omega - \omega_c)] \quad ....(4)$$

OR .

$$\cos 2\pi f_c t \longleftrightarrow \frac{1}{2}\{\delta[f+f_c] + \delta[f-f_c]\}$$

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

$$A_c \cos 2\pi f_c t \longleftrightarrow \frac{A_c}{2}\{\delta(f+f_c) + \delta(f-f_c)\}$$

Figure 1 (b) shows the carrier signal $A_c \cos 2\pi f_c t$ and its Fourier transform.

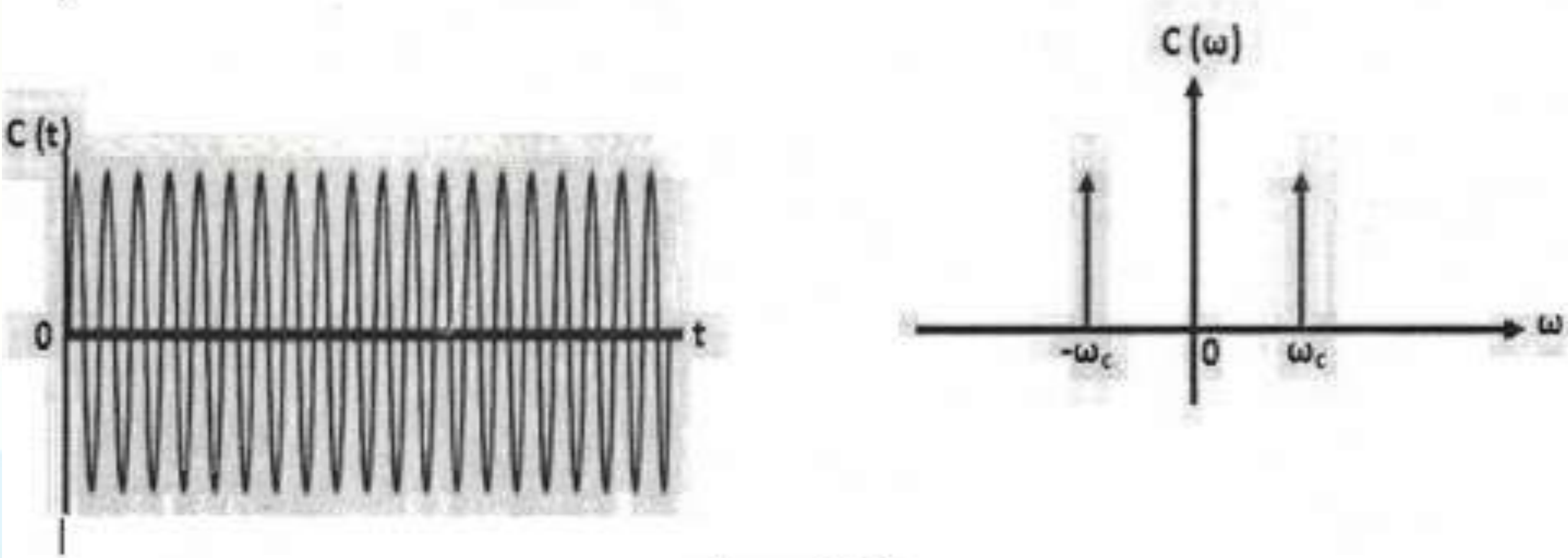


Figure 1 (b)

Now, the Am wave is given as :

$$s(t) = Ac \cos 2\pi fc\, t + Ac\, Ka\, m(t) \cos 2\pi fc\, t \quad ....(5)$$

1.3 Modulation Index or Modulation Factor

In AM wave, the modulation index (μ) is defined as the ratio of amplitudes of the modulating and carrier waves as under :

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

When $A_m <= A_c$,the modulation index 'μ' has values between 0 and 1 and no distortion is introduced in the AM wave . But if Am> Ac, then 'μ' is greater than 1 . This will distort the shape of the AM signal. The distortion is called as 'over modulation' .

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

However, this modulation index is expressed as percentage and it is called as 'percentage modulation' .

Therefore,

$$Percent\ Modulation = \frac{A_m}{A_c} \times 100$$

In order to calculate modulation index 'μ' which is :

we must express A_m and A_c in terms of A_{max} and A_{min} .

From the fig.1, we can write, $$A_m = \frac{A_{max} - A_{min}}{2} \quad \text{.......(1)}$$

And $$A_C = A_{MAX} - A_{MIN} \quad \text{.......(2)}$$

Substituting the value of A_m from equation (1) into equation (2), we get

$$A_c = A_{max} - \left[\frac{A_{max} - A_{min}}{2}\right]$$

$$A_c = A_{max} - \frac{A_{max}}{2} + \frac{A_{min}}{2}$$

$$A_c = \frac{A_{max} + A_{min}}{2} \quad \text{.......(3)}$$

But ,

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

Now, substituting the values of A_m and A_c from equation (1) and (3), we get

$$\mu = \frac{\frac{(A_{max} - A_{min})}{2}}{\frac{(A_{max} + A_{min})}{2}}$$

hence

$$\mu = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} \quad \text{.......(4)}$$

1.4 Switching Modulator

Generation of AM Waves using the switching modulator could be understood in a better way by observing the switching modulator diagram. The switching modulator using a diode has been shown in fig 3(a) .

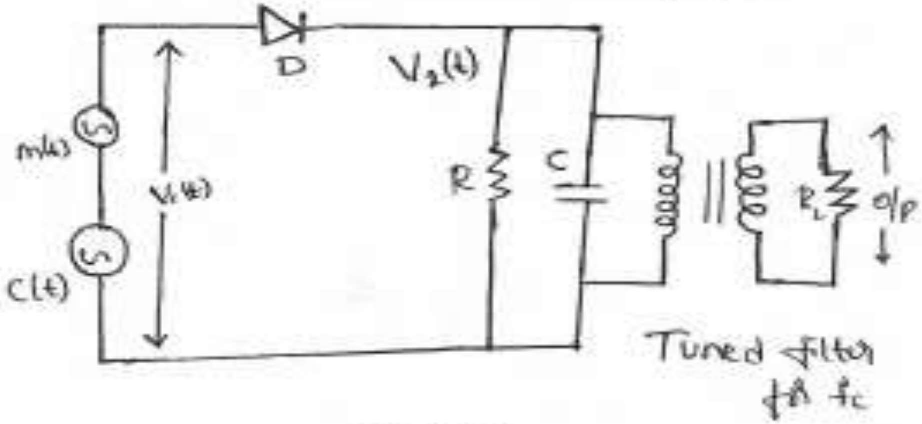


Fig 3 (a)

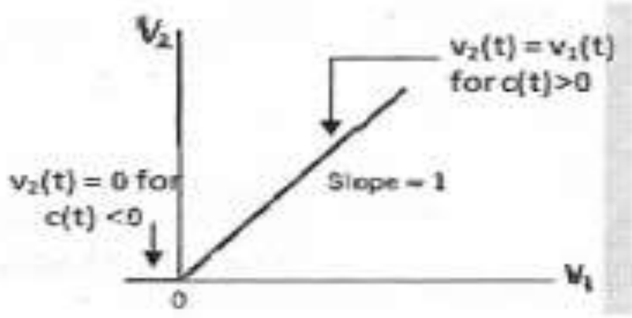


Fig 3(b)

This diode is assumed to be operating as a switch .

The modulating signal m(t) and the sinusoidal carrier signal c(t) are connected in series with each other. Therefore, the input voltage to the diode is given by :

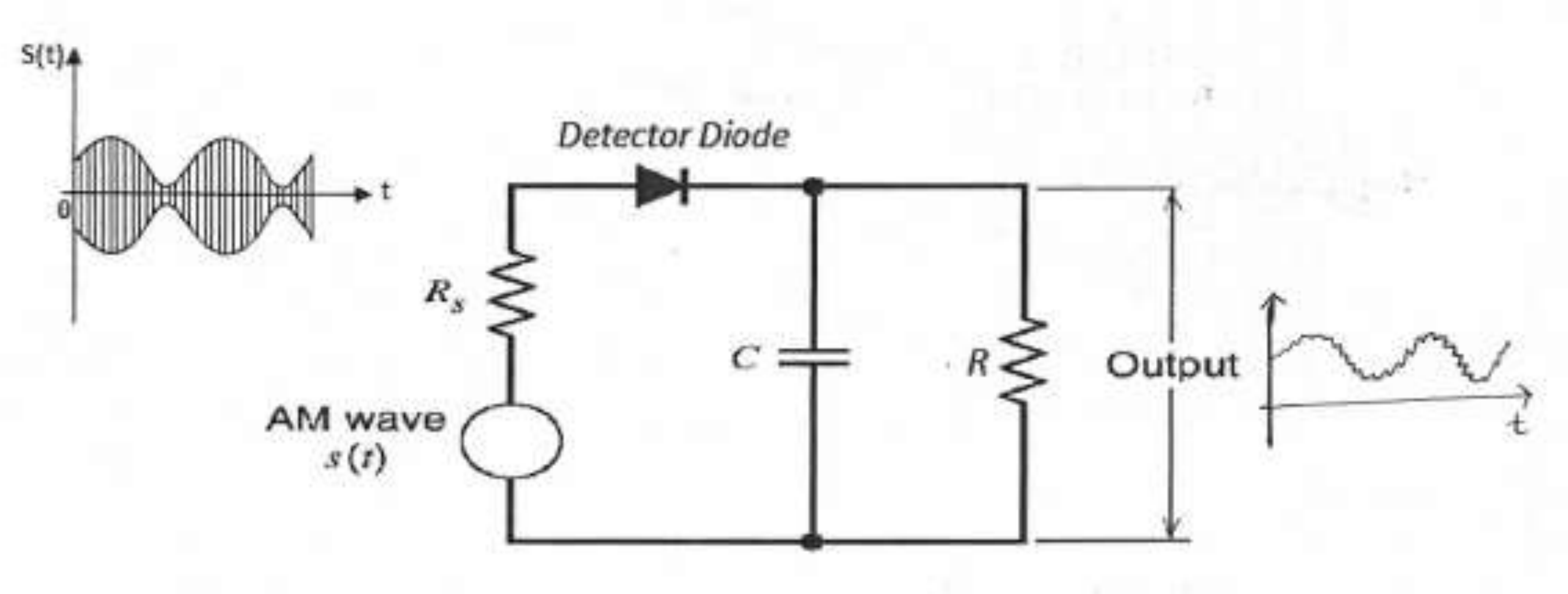
$$v_1(t) = c(t) + m(t) = A_c \cos(2\pi f_c t) + m(t)$$

$$v_2(t) = \underbrace{\frac{1}{2}m(t)}_{\text{Modulating Signal}} + \underbrace{\frac{1}{2}A_c\cos(2\pi f_c t) + \frac{2}{\pi}m(t)\cos(2\pi f_c t)}_{\text{AM Wave}} + \underbrace{\frac{2A_c}{\pi}\cos^2(2\pi f_c t)}_{\text{Second harmonic of carrier}}$$

1.5Envelope detector / Demodulation

The envelope demodulator is a simple and very efficient device which is suitable for the detection of a narrowband AM signal.

A narrowband AM wave is the one in which the carrier frequency fcis much higher as compared to the bandwidth of the modulating signal.An envelope demodulator produces an output signal that follows the envelope of the input AM signal exactly. It is used in all the commercial AM radio receivers. The circuit diagram of the envelope demodulator is shown in fig below .



Advantages of Standard Amplitude Modulation

1. Am transmitters are less complex.
2. AM receivers are simple, detection is easy.
3. AM receivers are cost efficient.
4. AM waves can travel a longer distance.
5. Low bandwidth

Applications of AM

1. Radio broadcasting
2. Picture transmission in a TV system

Disadvantages of Standard Amplitude Modulation

The disadvantages

1. Power wastage takes place in DSB-FC transmission
2. DSB-FC system is bandwidth inefficient system
3. AM wave gets affected due to noise

1.6 Power wastage in DSB-FC transmission

The carrier signal in the DSB-FC system does not convey any information . The information is contained in the two sidebands only.

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

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

Out of these three terms in the above equation , the carrier component does not contain any information and one sideband is redundant . Hence, out of the total power, the

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

Bandwidth Requirement of DSB-FC

The bandwidth (BW) of DSB-FC system is 2fm. This is due to the simultaneous transmission of both the sidebands, out of which only one is sufficient to convey all the information.

1.7 Ring Modulator for The Double Sideband Suppressed Carrier Generation

It consists of *four diodes, an audio frequency transformer Tl and RF transformer T2* The carrier signal is assumed to be a *square wave with frequency fc and it is connected* between the centre taps of the two transformers. The DSB-SC output is obtained at the secondary of the RF transformer T2 .

Diode Ring Modulator

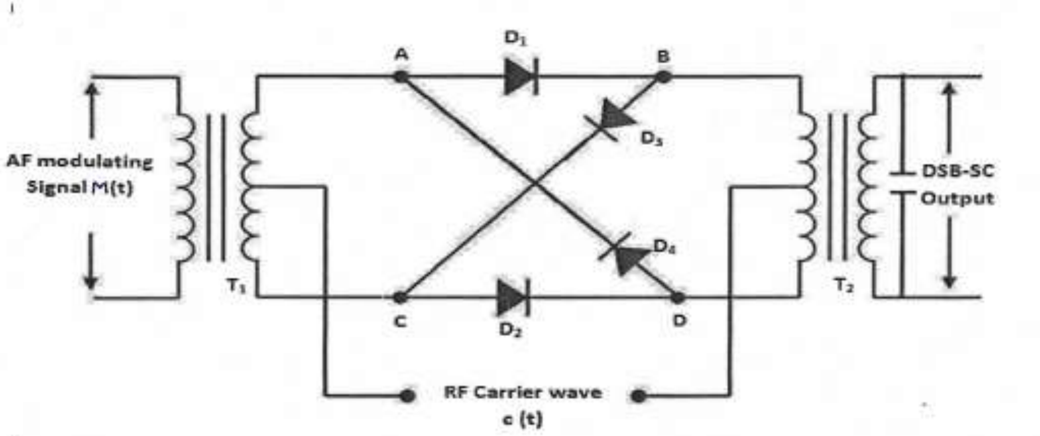
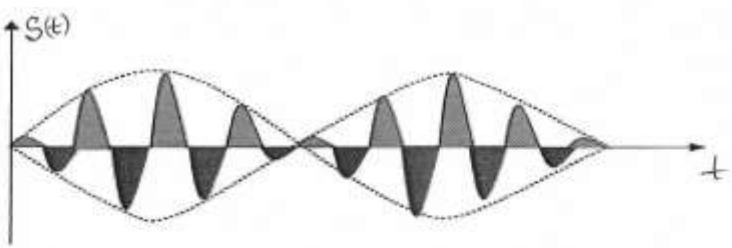
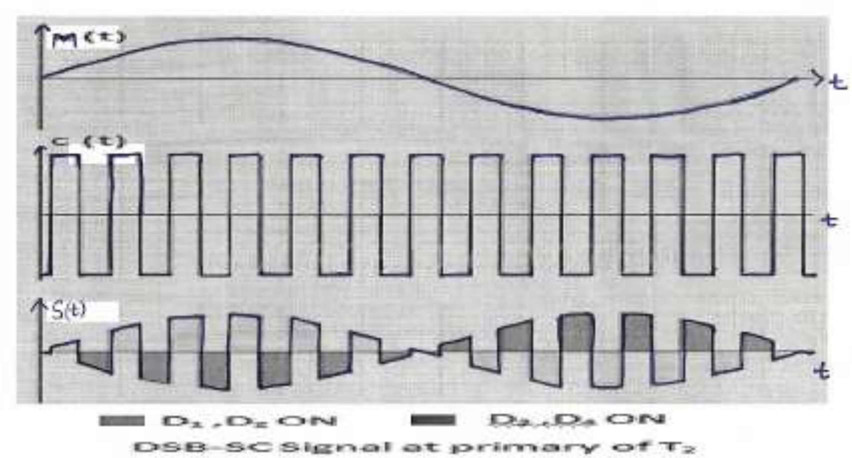


Fig. 1 : Ring Modulator



DSB-SC output (Output of transformer T2)



1.8 Coherent Detection of DSB-SC Waves

Analysis of Coherent Detection

Let the output of the local oscillator be given by : $c(t) = A_c' \cos(2\pi f_c t + \varphi)$

The frequency is fc and the phase difference is arbitrary equal to φ . This phase difference has been measured with respect to the original carrier c(t) at the DSB-SC generator .Therefore, the output of the product modulator is given by :

$$V(t) = s(t).c(t)$$

But $s(t) = A_c \cos(2\pi f_c t).M(t)$

$$V(t) = A_c \cos(2\pi f_c t).M(t).A_c' \cos(2\pi f_c t + \varphi)$$

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

$$V(t) = \frac{1}{2} A_c A_c' \cos(2\pi f_c t + 2\pi f_c t + \varphi)\, m(t) + \frac{1}{2} A_c A_c' \cos(2\pi f_c t - 2\pi f_c t + \varphi)\, m(t)$$

$$V(t) = \frac{1}{2} A_c A_c' \cos(4\pi f_c t + \varphi)\, m(t) + \frac{1}{2} A_c A_c' \cos(\varphi)\, m(t)$$

The coherent detection of the DSB-SC signal is shown in fig.1 .

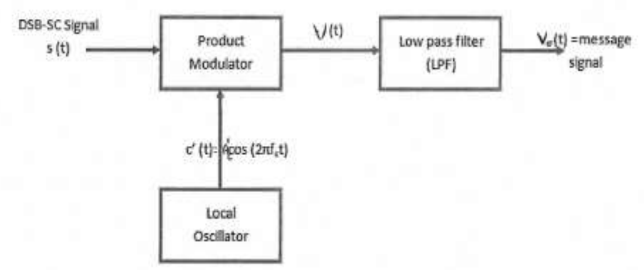


Fig 1: Coherent Detection of DSB-SC modulated wave

Signal v(t) is then passed through a low pass filter, which allows only the second term to pass through and will reject the first term .Therefore, the filter output is given by :

$$V_o(t) = \frac{1}{2} A_c A_c' \cos(\varphi)\, m(t)$$

Thus, output voltage of the coherent demodulator is proportional to the message signal m(t) if the phase error $\cos\varphi$ is constant .

Effect of Phase Error on the Demodulated Output

Let us consider the expression for the output of coherent detector is given by :

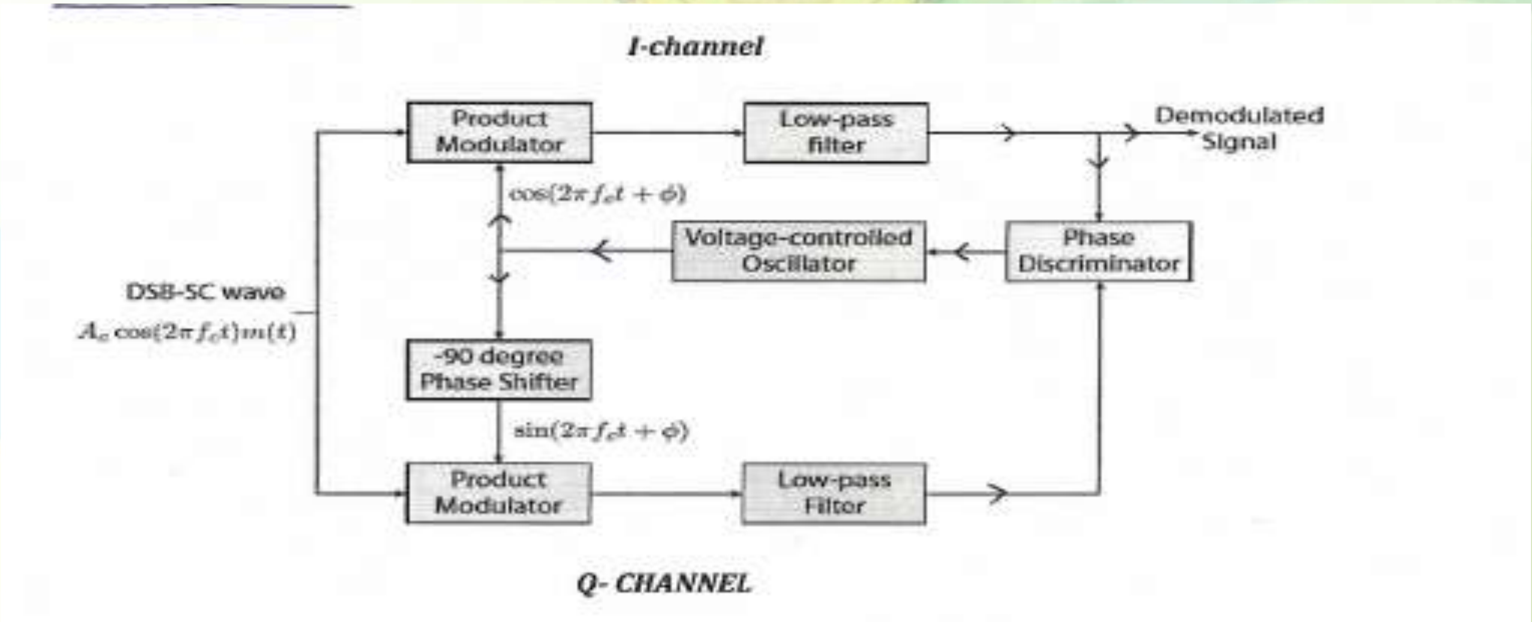
$$V_o(t) = \frac{1}{2} A_c A_c' \cos(\varphi)\, m(t)$$

1.9 Costas receiver

The detection in the upper path is referred as IN-PHASE coherent detector or I-CHANNEL, and lower path is referred as QUADRATURE-PHASE coherent detector or Q-CHANNEL..

Operation:

Suppose the oscillator signal is of same phase as carrier wave used in generation of incoming DSC-SCwave, then 1- channel output contains the desired demodulation signal met). where as the Q- channel output is zero Suppose the oscillator phase is having an error of *phi radians, then I-channel output* will not be maximum, but Q channel produces some output, *Thus combining this outputs in a phase discriminator (consists of* multiplier followed by a low pass filter), a DC control signal is obtained that automatically corrects for local phase errors in the Vco.



1.10 Quadrature carrier multiplexing (QCM)or Quadrature Amplitude modulation (QAM)

Quadrature carrier multiplexing is scheme in which two DSB-SC modulated waves with independent message signals occupy the same channel bandwidth and yet still be separated at receiver. It is therefore a bandwidth conservation scheme. The transmitter part consists of two separate product modulators that are supplied with two carrier waves of same frequency fc but -90 degree phase difference.

Two different messages ml(t) and m2(t) are applied to product modulators, the outputs of the product modulators are multiplexed to get s(t) = Ac mt(t) COS(2 Пfct)+ Ac m2(t) COS(2Пfct). The multiplexed signal occupies a channel bandwidth of 200 centred at carrier frequency fc

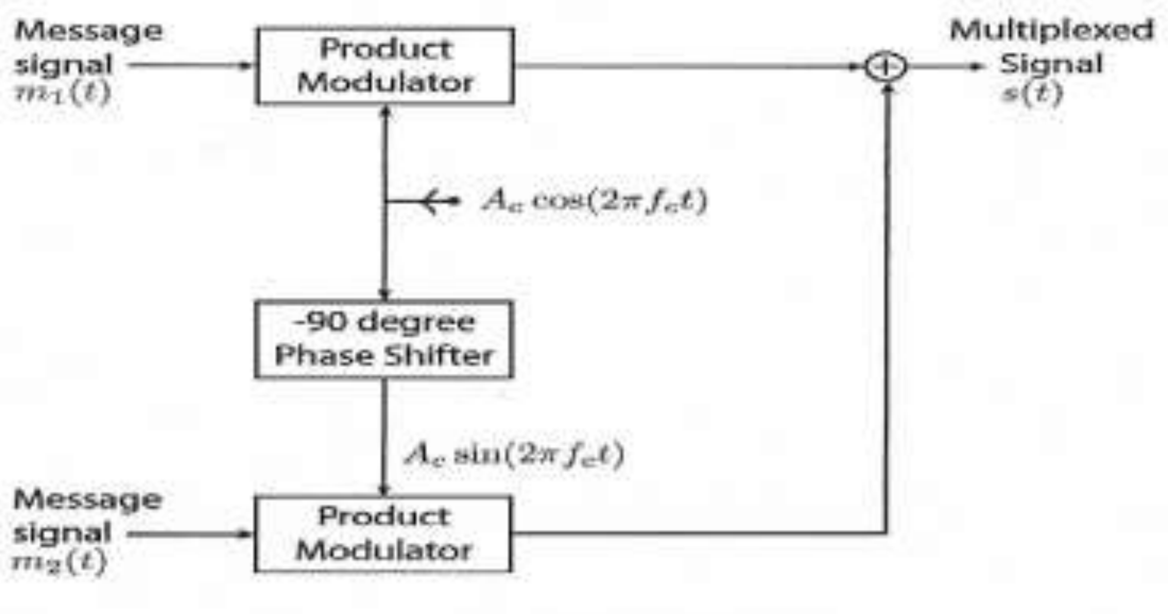


Fig: QCM TRANSMITTER

In the receiver part of the system, the multiplexed signal set) is applied simultaneously to two coherent detectors that are supplied with two local carriers of same frequency, but of -90 degree phase difference. The output of top detector is $\frac{1}{2} A_c A'_c m_1(t)$ and on bottom detector is $\frac{1}{2} A_c A'_c m_2(t)$. For the proper operation synchronization of local oscillators used in transmitter and receiver is must. To maintain synchronization a pilot signal of low power is used outside the pass-band of modulated signal.

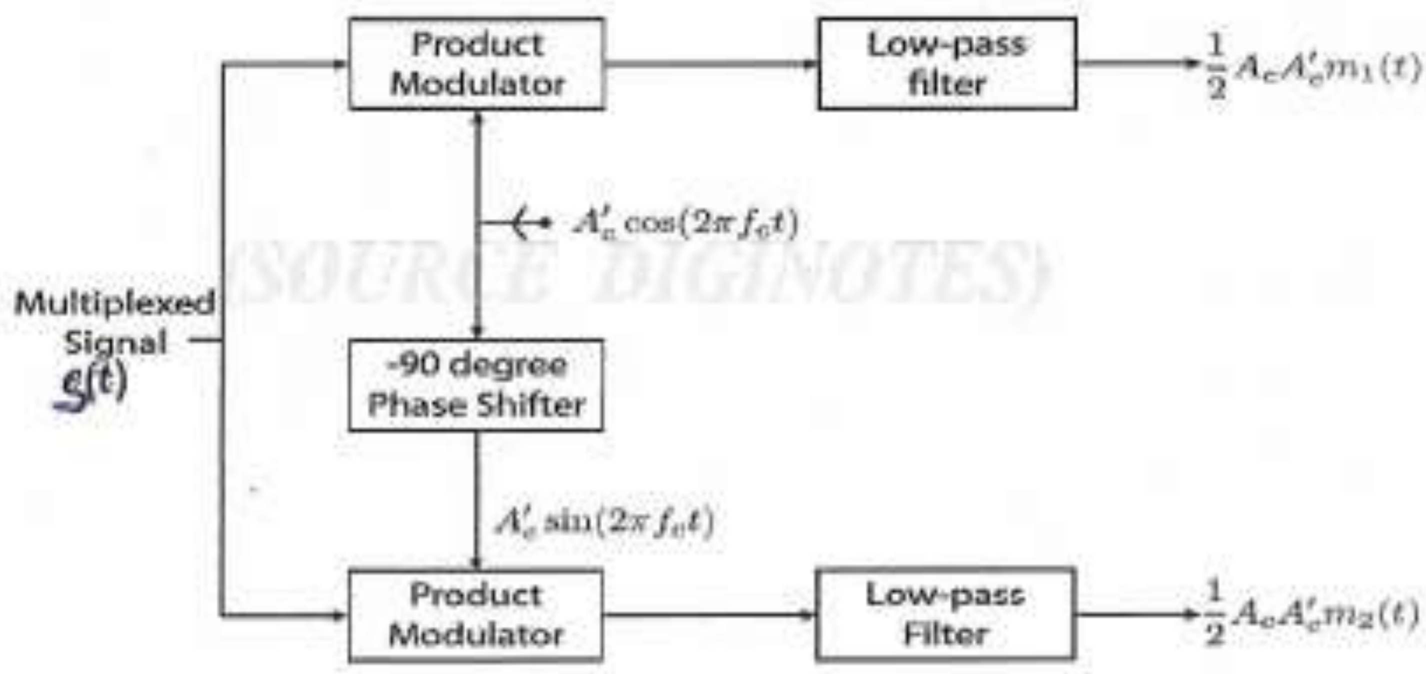


Fig : QCM receiver

1.11 Single Side Band Suppressed Carrier (SSB-SC) Modulation

The transmission bandwidth of standard AM as well as DSB-SCmodulated wave is 2 *w* Hz i.e., twice the message bandwidth co, Therefore, both these systems are bandwidth inefficient systems.

In both these systems, one half of the transmission bandwidth is occupied by the upper sideband (USB) and the other half is occupied by the lower sideband (LSB) as shown in fig.1.

The information contained in the USBis exactly identical to that carried by the LSB. So, by transmitting both the sidebands we are transmitting the same information twice. Hence, we can transmit only one sideband (USB or LSB) without any loss of information. So, it is possible to suppress the carrier and one sideband completely to conserve the bandwidth.

When only one sideband is transmitted, the modulation is called as single sideband modulation. It is also known as SSBor SSB-SCmodulation.

Advantages of SSB-SC Modulation Over DSB-FC

1. Less bandwidth requirements . This allow more number of signals to be transmitted in the same frequency range.
2. Lots of power saving . This is due to the transmission of only one sideband component .At 100% modulation, the percentage of power saving is 83.33% .
3. Reduced interference of noise. This is due to the reduced bandwidth . As the bandwidth increases, the amount of noise added to the signal will increase.

Disadvantages of SSB-SCModulation

1. The generation and reception of SSBsignal is complicated
2. The SSBtransmitter and receiver need to have an excellent frequency stability. A
slight change in frequency will affect the quality of transmitted and received signal. Therefore, SSB is not generally used for the transmission of good quality music. It is used for speech transmission.

Application of SSB

1. SSB transmission is used in the applications where the power saving and low bandwidth requirements are important.
2. The application areas are land and air mobile communication, telemetry, military communications, navigation and amateur radio. Many of these applications are point to point communication application.

The generation of a SSB signal is a simple process, we first generate a DSB-SC and then apply an ideal band pass filter with a cutoff frequencies of fc and fc +*w for the* upper side band. But construction of ideal filter is very difficult.

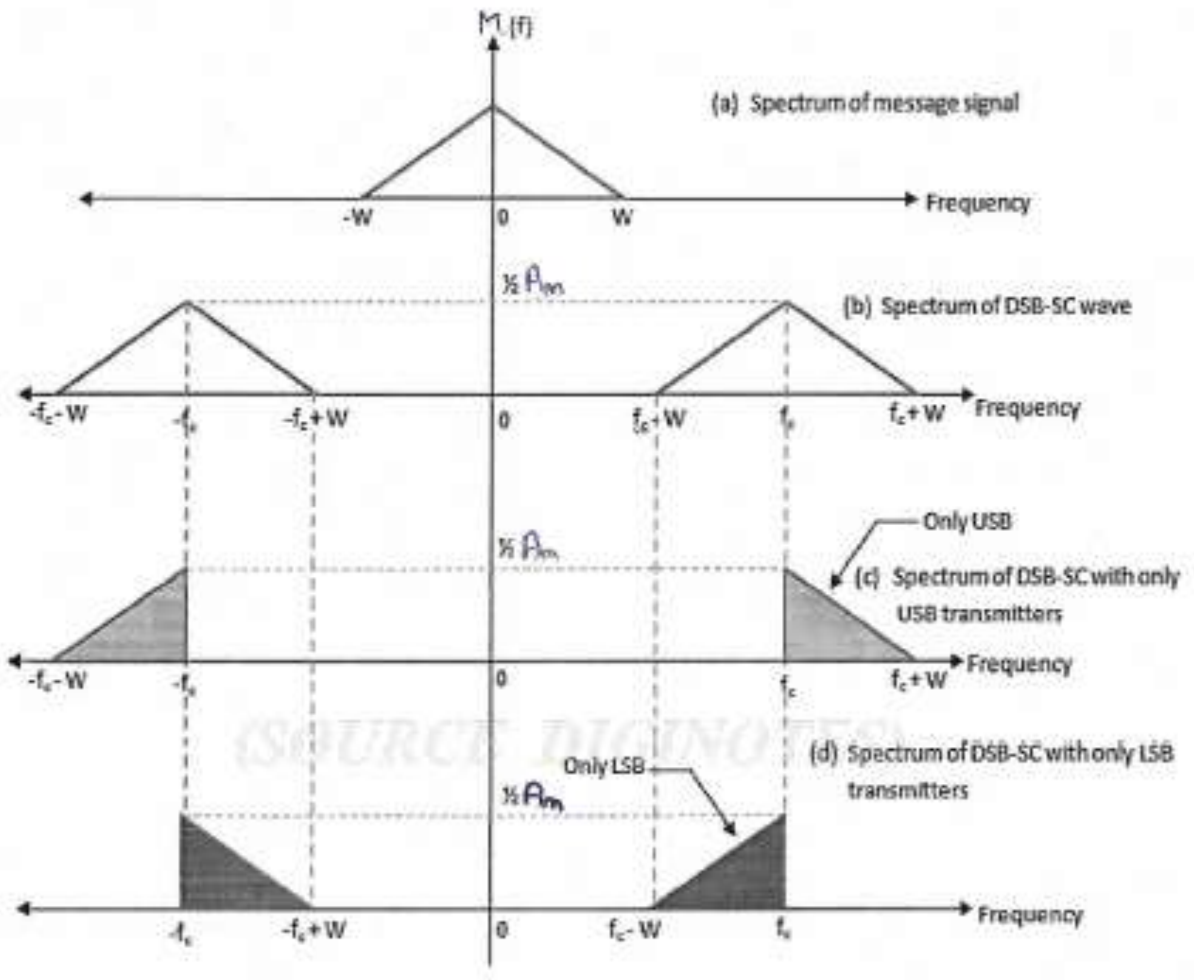


Fig 1

1.12 VSB modulation

Vestigial side band modulation (VSB) is a types of amplitude modulation in which one sideband and a part (vestige) of other side-band are transmitted.

VSB can be done for a higher frequency signal where there is no energy gap at the origin. It allows to have a non zero transition band, so this allows the use of non- ideal filter.

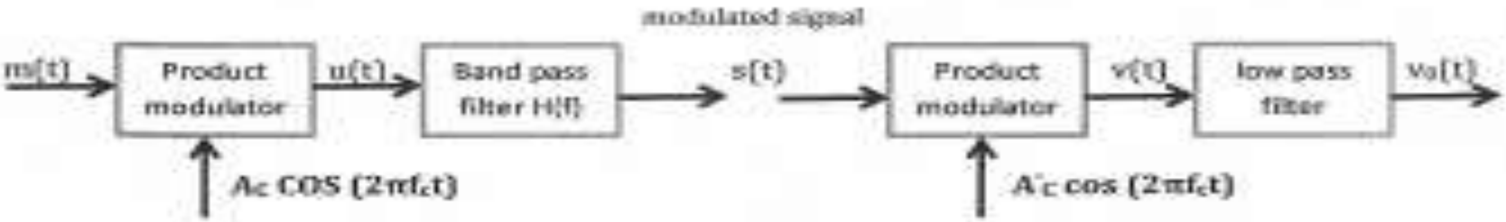


Fig: *Filtering scheme at transmitter* fig: *coherent detection for recovering of msg signal*

The generation of VSB includes product modulator, local oscillator and a band shaping filter with a transfer function **H(f)** as shown in the figure. The output of the product modulator **u(t)** is an frequency shifted signal which is passed through the filter to get modulated signal **s(t)**.

$$U(t) = m(t) \cdot c(t)$$

$$U(t) = m(t). A_c \cos(2\pi f_c t)$$

Taking fourier transform

$$U(f) = \frac{A_c}{2}[M(f-f_c) + M(f+f_c)] \quad \text{.......................(1)}$$

The demodulated output s(t) in frequency domain is, **S(f)= u(f).H(f)**

using eq (1) $S(f) = \frac{A_c}{2}[M(f-f_c) + M(f+f_c)]\ H(f)$ ....(2)

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

$$S(f-f_c) = \frac{A_c}{2}[M(f-2f_c) + M(f)]\ H(f-f_c) \quad \text{.......................(3)}$$

|||ly $S(f+f_c) = \frac{A_c}{2}[M(f+f_c-f_c) + M(f+f_c+f_c)]\ H(f+f_c)$

$$S(f+f_c) = \frac{A_c}{2}[M(f) + M(f+2f_c)]\ H(f+f_c) \quad \text{.......................(4)}$$

Using eq (3)&(4) in eq (5) we get

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

$$v(f) = \frac{A_c A_c'}{4} M(f-2f_c)\, H(f-f_c) + \frac{A_c A_c'}{4} M(f)\ H(f-f_c) + \frac{A_c A_c'}{4} M(f)\, H(f+f_c) + \frac{A_c A_c'}{4} M(f+2f_c)\ H(f+f_c)$$

Taking common,

$$v(f) = \frac{A_c A_c'}{4} M(f)\, [H(f-f_c) + H(f+f_c)] + \frac{A_c A_c'}{4} \{M(f-2f_c)\, H(f-f_c) + M(f+2f_c)\ H(f+f_c)\} \ldots\ldots(6)$$

the second term indicates the high frequency component, which is removed by the low pass filter to produce an output $v_0(t)$, so the spectrum remaining component's are

$$v_0(f) = \frac{A_c A_c'}{4} M(f)\, [H(f-f_c) + H(f+f_c)] \ \ldots\ldots\ldots(7)$$

for a distortion less reproduction of original message signal at detector, the transfer function H(f) must satisfy condition $[H(f-f_c) + H(f+f_c)] = 2H(f_c)$

where $H(f_c)$, the value of H(f) @ $f=f_c$, is a constant equal to 0.5

thus $[H(f-f_c) + H(f+f_c)] = 2(0.5) = 1,$ $\quad -\omega \le f \le \omega$

then output will be $v_0(f) = \frac{A_c A_c'}{4} M(f)$

In time domain it is $v_0(t) = \frac{A_c A_c'}{4} M(t)$ hence output is a scaled value of msg signal

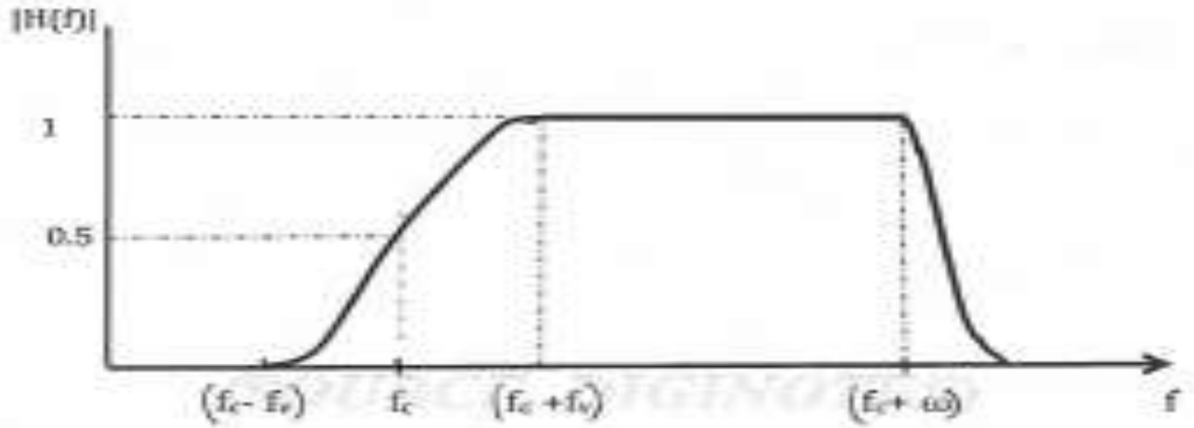
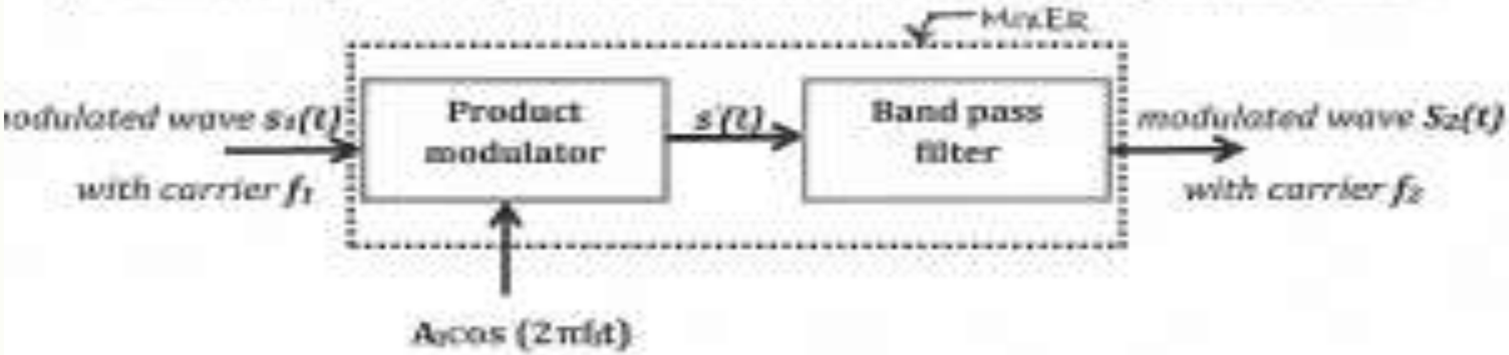


fig: amplitude response of VSB filter for positive frequency

1.13Frequency translation/ changing/ mixing/heterodyning

Frequency translation is the process of moving a signal from one part of the **frequency** axis, to another part of the axis. i.e., a message spectrum occupying the band from f_a to f_b for positive frequencies is shifted upward to (f_c+f_a) to (f_c+f_b). The message spectrum for negative frequencies is translated downwards in symmetric fashion.



Suppose a modulated wave $s_1(t)$ which is centred at carrier frequency f_1 need to be translated in upward to new frequency f_2 , then a mixer is used as shown in fig . mixer is a device that consist of product modulator followed by a band-pass filter , a local oscillator with a carrier frequency f_L is used to as input to product modulator. Then the output of modulator is $S'(t) = s_1(t) \cdot A_l \cos(2\pi f_l t)$

But $s_1(t) = m(t) \cos(2\pi f_1 t)$

Therefore $\quad S'(t) = m(t) \cos(2\pi f_1 t) A_l \cos(2\pi f_l t)$

$$S'(t) = \frac{1}{2} A_l\, m(t)[\cos(2\pi(f_1+f_l)t) + \cos(2\pi(f_1-f_l)t)]$$

Hence we get new frequency as $f_2 = f_1 + f_l$

$f_l = f_2 - f_L \qquad$ for $f_2 > f_1$ frequency translation is upwards

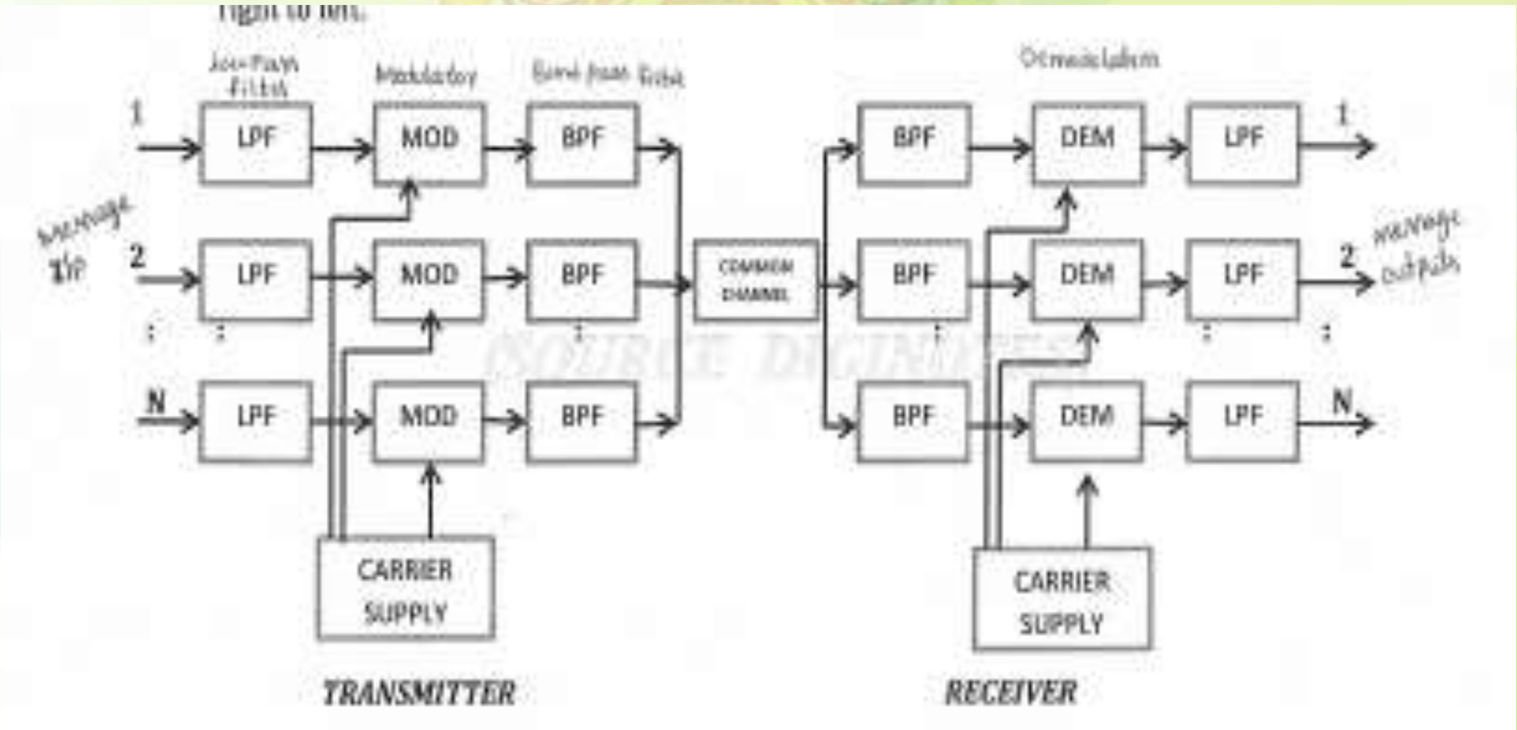
similarly for down translation $f_1 > f_2$

The band pass filter rejects the unwanted frequency and keeps the required one.

1.14 Frequency Division Multiplexing (FDM)

The incoming message signal are assumed to be of low-pass frequency. Each signals are passed through LPF to remove unwanted high frequency components, the filtered signals are applied to modulators that shift the frequency ranges of the signals so to occupy mutually exclusive intervals. The necessary carrier frequencies is generated from carrier supply, for analog signals SSBmodulation is used usually with a bandwidth of 4K Hz. The band pass filters are used to restrict the band of each modulated wave to its prescribed range. The band passed output are combined parallel to form input to common channel.

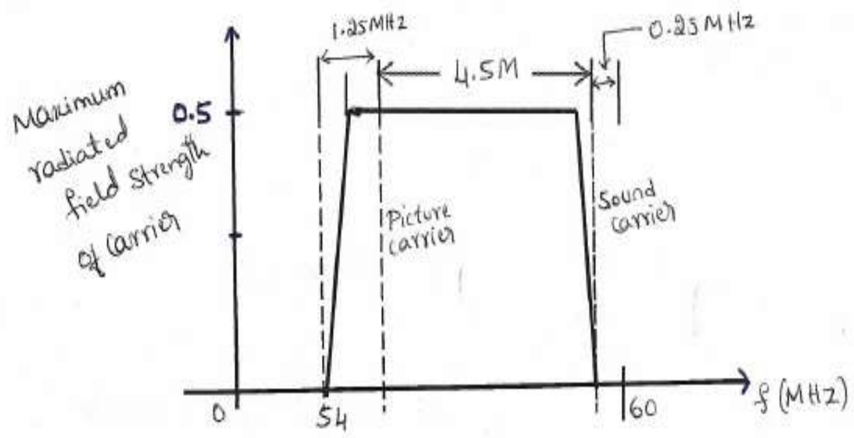
At the receiver side, a bank of parallel band pass filters are used to separate the modulated message signals then demodulator uses carrier to get the original message



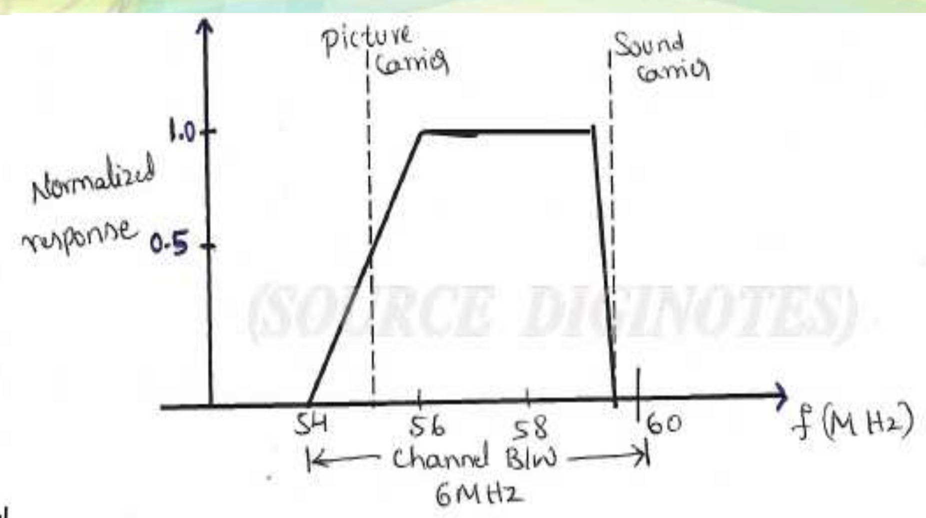
1.15 VSBTransmission OF Analog and Digital Television

VSB is used in commercial TV broadcasting of both analog and digital signals. The channel bandwidth used is 6M Hz, which consists of VSB modulated video signal and sound signal as shown in figure, the picture carrier is at 55.25 MHz and sound carrier is at 59.75 MHz. but base band spectrum is extending from 1.25 MHz below picture carrier to 4.SMHz above it.

Based on following two factors VSB modulation is used
1. The video signals has large bandwidth and significant low frequency content.
2. The demodulation circuit must be simple and cheap. So we have to use envelope
detector, which requires addition of carrier in VSB modulated signal. To fulfil above factors the transmitted wave must have high power level,



Idealized amplitude spectrum Of transmitted TV signal



Amplitude response of VSB shaping filter in the receiver

VSB technique can also be applied to digital signals for high definition television signals with following factors:

1. The transmitted signal must be compatible in terms of bandwidth with existing analog format. A data rate of more than 20 Mbps can be transmited in 6MHz bandwidth.
2. The receiver circuit must be simple and cheap, this is possible with the advancement in digital signal processing units.

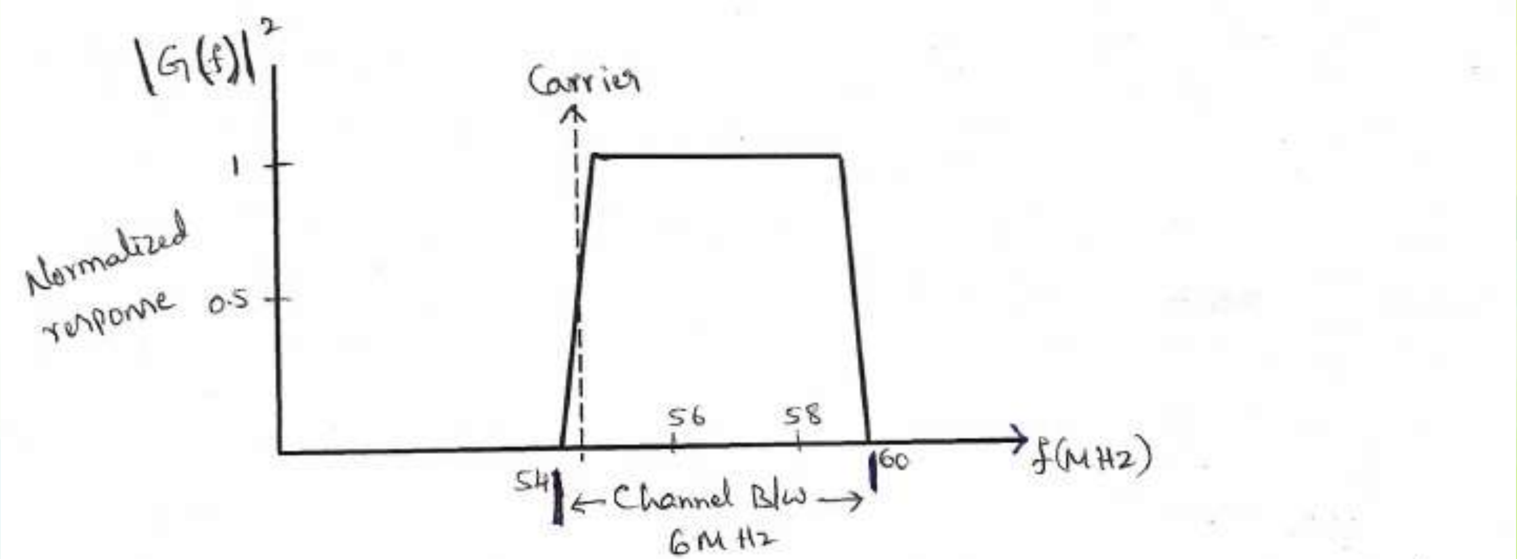


fig: Idealized amplitude response spectrum of VSB Modulated digital TV Signal.

Queries …?