Program : **B.Tech**

Subject Name: **Analog and Digital Communication**

Subject Code: **IT-404**

Semester: **4th**

UNIT-II

Amplitude modulation: Modulation, need of modulation, types of modulation techniques, amplitude modulation (DSB-FC), modulation index, frequency spectrum of AM wave, linear and over modulation, power relation in AM, transmission efficiency, modulation by a complex signal, bandwidth of AM, AM modulators, square law and switching modulator, advantages and disadvantages of AM. Demodulation of AM: Suppressed carrier amplitude modulation systems, DSB-SC, SSB-SC, VSB-SC systems, comparison of various amplitude modulation systems. Demodulation of AM, square law and envelope detector, synchronous detection of AM, Low and high power AM transmitters, AM receivers, TRF and superheterodyne receivers, sensitivity, selectivity and fidelity of receivers.

2.1. INTRODUCTION:

Communication is a process whereby information is enclosed in a package and is channelled and imparted by a sender to a receiver via some medium. The receiver then decodes the message and gives the sender a feedback. So the basic elements of communication systems are:

- Transmitter: originates the signal
- Receiver: receives transmitted signal after it travels over the medium
- Medium: guides the signal from the transmitter to the receiver.

In a data transmission system, the transmission medium is the physical path between transmitter and receiver. For guided media, electromagnetic waves are guided along a solid medium, such as copper twisted pair, copper coaxial cable, and optical fibre. For unguided media, wireless transmission occurs through the atmosphere, outer space, or water.

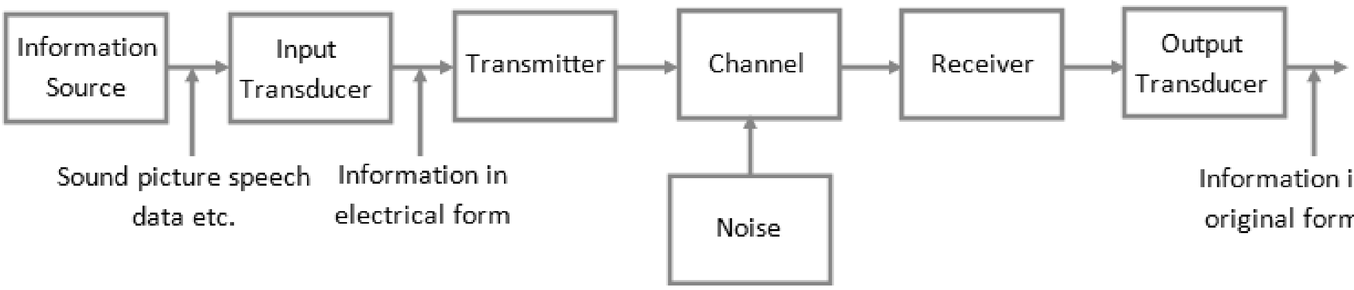


Figure2.1. Basic communication system

Elements of Communication system:

1. Information source: The message or information originates in the information source which has to be transmitted.

2. Input transducer: A transducer is the device which converts one form of energy to another form. In communication system transducer is usually required to convert the output of a source into an electrical signal that is suitable for transmission.

3. The Transmitter: The transmitter process the electrical signal into a form that is suitable for transmission through the transmission medium. The transmitter performs the signal processing of the message signal such as restriction of range of audio frequencies, amplification and modulation. All these processing are done to ease the transmission of the signal through the channel.

4. The Channel and the Noise: The communications 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 the free space. On the other hand, telephone channels usually employ a variety of physical media, including wire lines, optical fibre cables, and wireless microwave radio. Whatever the physical medium for signal transmission, transmitted signal is corrupted in a random manner by noise.

5. The Receiver: The function of the receiver is to recover or reproduce the message signal contained in the received signal. If the message signal is transmitted by carrier modulation, the receiver performs *carrier demodulation* in order to extract the message from the sinusoidal carrier.
6. Output transducer: It is the final stage use to convert an electrical message signal into its original form.

2.2. Modulation:

Modulation is a technique used to convert a low frequency message signal to a higher frequency modulated signal using a higher frequency carrier.

Definition: Modulation is the process of changing the parameters of the carrier signal, in accordance with the instantaneous values of the modulating signal.

Signals in the Modulation Process:

1. Message or Modulating Signal

The signal which contains a message to be transmitted is called as a message signal. It is a baseband signal, which has to undergo the process of modulation, to get transmitted. Hence, it is also called as the modulating signal.

Baseband signal: Baseband refers to the original frequency range of a transmission signal before it is converted, or modulated, to a different frequency range.

2. Carrier Signal

The high frequency signal which has a certain phase, frequency, and amplitude but contains no information is called a carrier signal. It is an empty signal. It is just used to carry the signal to the receiver after modulation.

3. Modulated Signal

The resultant signal after the process of modulation is called as the modulated signal. This signal is a combination of the modulating signal and the carrier signal.

Signal Bandwidth:

The bandwidth of a signal represents the range of its frequency components. A complex signal is made of a range of frequencies called spectrum. The Bandwidth of a signal is calculated by subtracting the highest frequency component from the lowest frequency component.

Demodulation: It is the reverse process of modulation, which is used to get back the original message signal. Modulation is performed at the transmitting end whereas demodulation is performed at the receiving end.

2.3. Need for modulation:

The baseband signals are incompatible for direct transmission. When the signal is transmitted without modulation they cannot travel longer distances as low frequency signal get it attenuates, so its strength has to be increased by modulating with a high frequency carrier wave, which doesn't affect the parameters of the modulating signal.

Modulation is needed to achieve the following basic needs:

1. Practicability of antennas: For the transmission of radio signals, the antenna height must be multiple of $\lambda/4$,where λ is the wavelength.

$\lambda = c/f$

Where c: is the velocity of light

f: is the frequency of the signal to be transmitted

The minimum antenna height required to transmit a baseband signal of f = 10 kHz is 7.5 Km.

The antenna of this height is practically impossible to install.

Now, let us consider a modulated signal at f = 1 MHz The minimum antenna height is 75 meters.

This antenna can be easily installed practically. Thus, modulation reduces the height of the antenna.

2. Avoids mixing of signals

If the baseband sound signals are transmitted without using the modulation by more than one transmitter, then all the signals will be in the same frequency range i.e. 0 to 20 kHz. Therefore, all the signals get mixed together and a receiver cannot separate them from each other. If each baseband sound signal is used to modulate a different carrier then they will occupy different slots in the frequency domain i.e. through different channels. Thus, modulation avoids mixing of signals.

3. Multiplexing is possible: Multiplexing is a process in which two or more signals can be transmitted over the same communication channel simultaneously. If transmitted without modulation, the different message signals over a single channel will interfere with each other. So multiplexing helps in transmitting a number of messages simultaneously over a single channel which reduces cost of installation and maintenance of more channels.

4. Narrow banding: The frequency translation through modulation converts a wideband signal to a narrowband, which is termed as narrow banding.

Let us assume a system is radiating directly with the frequency range from 50 Hz to 10 kHz, the ratio of highest to lowest wavelength is 200. If antenna is designed for 50 Hz, it will be too long for 10 kHz and vice versa. But if signal is translated to higher frequency of 1 MHz range using modulation, then the ratio of lowest to highest frequency will be $\frac{10^6 + 50}{10^6 + 10^4} \approx 1$ and the same antenna will be suitable for the entire band.

5. Improves Quality of Reception

6. Increase the Range of Communication

2.4. Types of Modulation:

The types of modulations are broadly classified into continuous-wave modulation and pulse modulation.

Continuous-wave Modulation

In the continuous-wave modulation, a high frequency sine wave is used as a carrier wave. This is further divided into amplitude and angle modulation.

- If the amplitude of the high frequency carrier wave is varied in accordance with the instantaneous amplitude of the modulating signal, then such a technique is called as Amplitude Modulation.
- If the angle of the carrier wave is varied, in accordance with the instantaneous value of the modulating signal, then such a technique is called as Angle Modulation.

The angle modulation is further divided into frequency and phase modulation.

- If the frequency of the carrier wave is varied, in accordance with the instantaneous value of the modulating signal, then such a technique is called as Frequency Modulation.
- If the phase of the high frequency carrier wave is varied in accordance with the instantaneous value of the modulating signal, then such a technique is called as Phase Modulation.

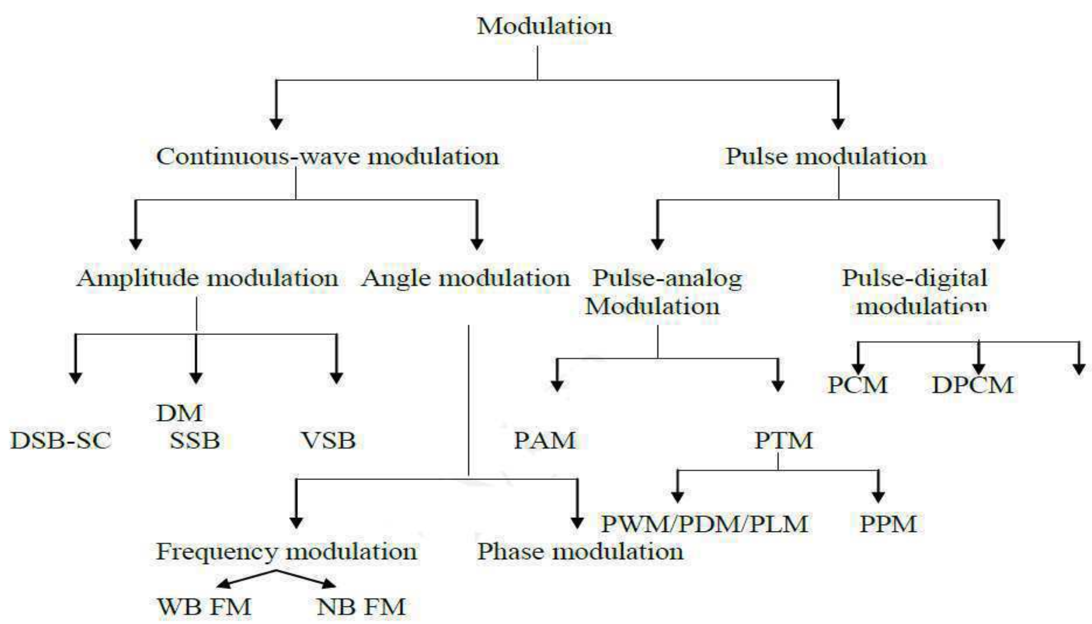


Figure 2.2 Types of modulation

Pulse Modulation

In Pulse modulation, a periodic sequence of rectangular pulses is used as a carrier wave. This is further divided into analog and digital modulation.

- In analog modulation technique, if the amplitude, duration or position of a pulse is varied in accordance with the instantaneous values of the baseband modulating signal, then such a technique is called as Pulse Amplitude Modulation (PAM) or Pulse Duration/Width Modulation (PDM/PWM), or Pulse Position Modulation (PPM).
- In digital modulation, the modulation technique used is Pulse Code Modulation (PCM) where the analog signal is converted into digital form of 1s and 0s. As the resultant is a coded pulse train, this is called as PCM. This is further developed as Delta Modulation (DM), which will be discussed in subsequent chapters. Hence, PCM is a technique where the analog signals are converted into a digital form.

2.5. Amplitude modulation

Definition:

The amplitude of the carrier signal varies in accordance with the instantaneous amplitude of the modulating signal i.e. the amplitude of the carrier signal containing no information varies as per the amplitude of the signal containing information, at each instant.

Mathematical expression:

Let m (t) is the baseband message and C (t) = A_c Cos (ω_ct) is called the carrier wave. The carrier frequency, f_c should be larger than the highest spectral component in m(t).

Consider a sinusoidal carrier signal C (t) is defined as

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

Where A_c= Amplitude of the carrier signal

f_c= frequency of the carrier signal

Φ = Phase angle.

For convenience, assume the phase angle of the carrier signal is zero. An amplitude-modulated (AM) wave, S(t) can be described as function of time is given by

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

Where the parameter k_a is a positive constant called the amplitude sensitivity of the modulator.

Let e(t) = $A_c|1 + k_a m(t)|$ is called the envelope of the AM signal. When f_c is large relative to the bandwidth of m(t), the envelope is a smooth signal that passes through the positive peaks of S(t) and it can be viewed as modulating the amplitude of the carrier wave in a way related to m(t) as shown in figure 2.3.

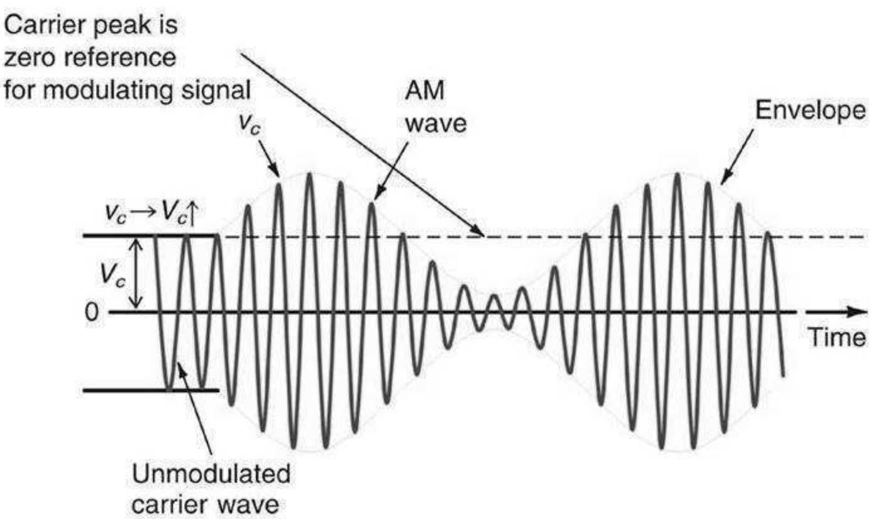


Figure 2.3.Amplitude modulation envelope in time domain

The amplitude modulated (AM) signal consists of both modulated carrier signal and un-modulated carrier signal. There are two requirements to maintain the envelope of AM signal is same as the shape of base band signal.

1. The amplitude of the $k_a\, m(t)$ is always less than unity i.e., $|k_a\, m(t)|<1$ for all 't'.
2. The carrier signal frequency f_c is far greater than the highest frequency component W of the message signal m (t) i.e., $f_c >> W$

Assume the message signal m (t) is band limited to the interval $-W < f < W$

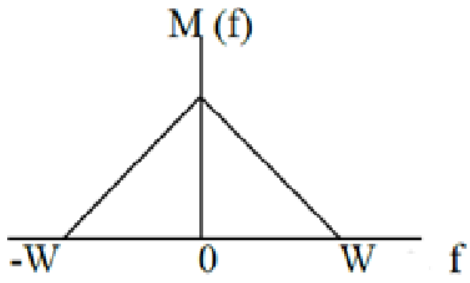


Fig. 2.4.Spectrum of message signal

The spectrum of AM is shown in fig. 3.5.The Fourier transform of AM signal S (t) is

S (f) = $\frac{Ac}{2}$ [δ(f-fc)+ δ (f+fc)]+ $\frac{K_a A_c}{2}$ [M(f-fc)+ M(f+fc)]

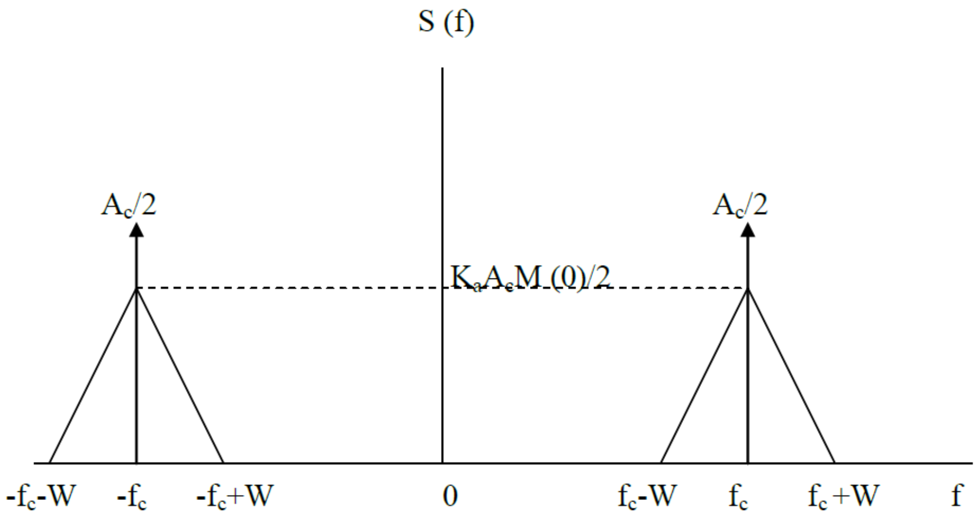


Fig.2.5. Spectrum of AM signal

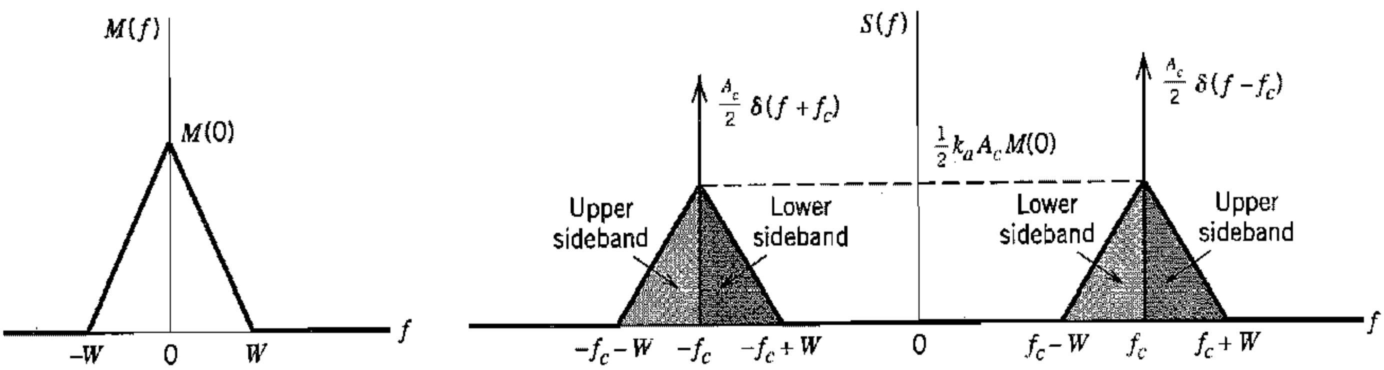


Fig.2.6. Spectrum of AM signal representing sidebands

The AM spectrum consists of two impulse functions which are located at f_c and $-f_c$ and weighted by $A_c/2$, two USBs, band of frequencies from f_c to f_c+W and band of frequencies from $-f_c-W$ to $-f_c$, and two LSBs, band of frequencies from f_c-W to f_c and $-f_c$ to $-f_c+W$.

The difference between highest frequency component and lowest frequency component is known as transmission bandwidth.

B = 2W

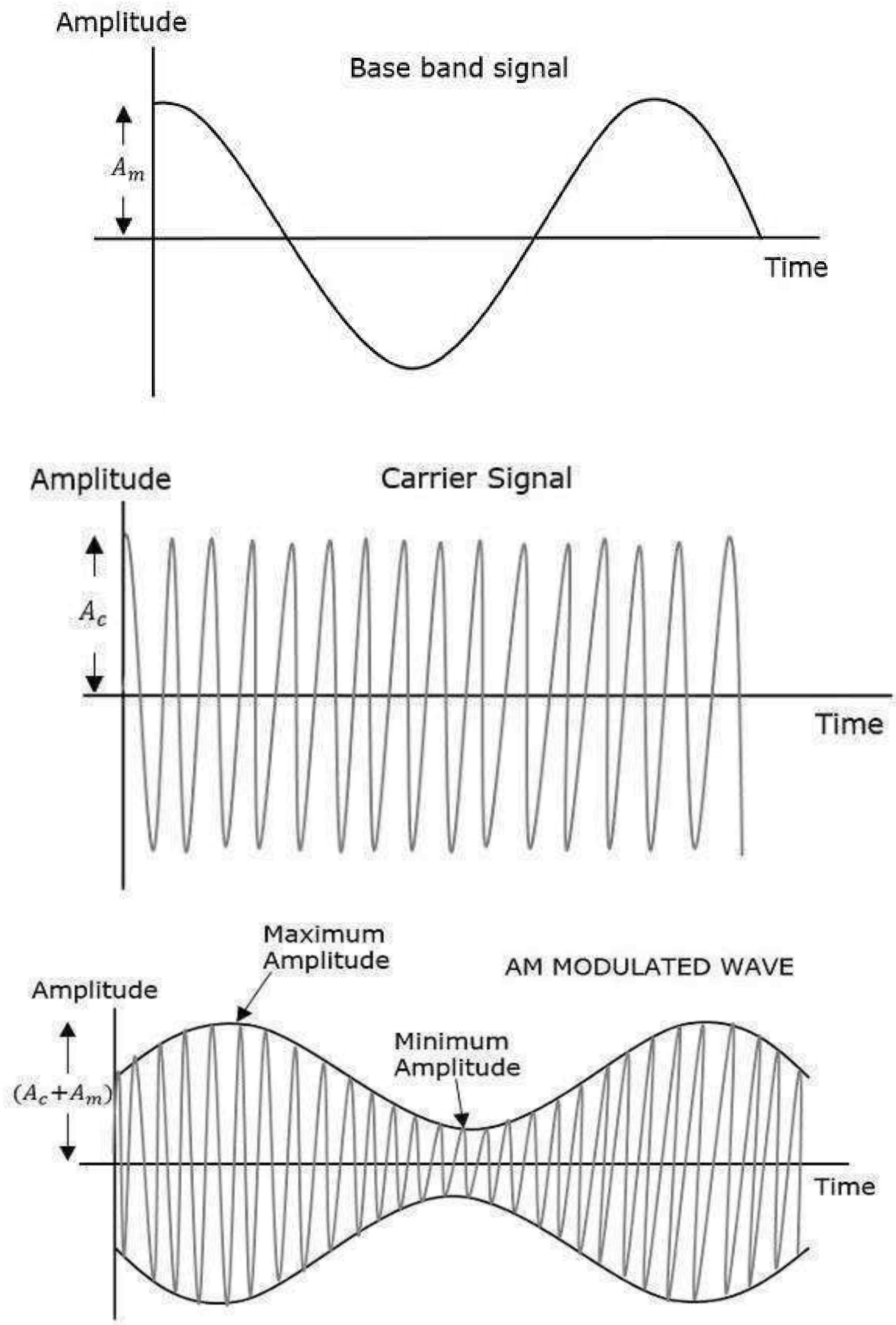


Figure 2.7.Amplitude modulation waveform in time domain

2.6. Single-tone modulation

In single-tone modulation modulating signal consists of only one frequency component where as in multi-tone modulation modulating signal consists of more than one frequency component.

Mathematical Expressions:

Following are the mathematical expressions for these waves.

Time-domain Representation of the Waves

Let the modulating signal be,

$$m(t) = A_m \cos 2\pi f_m t \qquad (2.1)$$

and the carrier signal be,

$$C(t)=A_c \cos(2\pi f_c t) \qquad (2.2)$$

Where,

A_m and A_c are the amplitude of the modulating signal and the carrier signal respectively.

f_m and f_c are the frequency of the modulating signal and the carrier signal respectively.

The equation for the overall modulated signal is obtained by multiplying the carrier and the modulating signal together.

$$S(t) = A_c [1+k_a m(t)] \cos(2\pi f_c t) \qquad (2.3)$$

Substituting in the individual relationships for the carrier and modulating signal in equation (3.3), the overall signal becomes:

$$S(t) = Ac [1+k_a A_m \cos 2\pi f_m t] \cos(2\pi f_c t)$$

Replace the term $k_a A_m$ by μ which is known as modulation index or modulation factor.

Or it can be written as

$$S(t)= [A_c+ A_m \cos(2\pi f_m t)] \cos(2\pi f_c t) \qquad (2.4)$$

Modulation Index:

A carrier wave, after being modulated, if the modulated level is calculated, then such an attempt is called as Modulation Index or Modulation Depth. Modulation index can be defined as the measure of extent of amplitude variation about an un-modulated carrier.

Rearrange the Equation 4 as below.

$$S(t) = A_c[1 +(A_m/A_c) \cos(2\pi f_m t)] \cos(2\pi f_c t) \qquad (2.5)$$

$$S(t) = A_c[1 +\mu \cos(2\pi f_m t)] \cos(2\pi f_c t) \qquad (2.6)$$

Where, μ is Modulation index or Amplitude sensitivity of the modulator and it is equal to the ratio of A_m and A_c. Mathematically, we can write it as

$$\mu = (A_m/A_c)$$

Calculating the modulation index from AM envelope:

With reference to the figure 3.7 and 3.8, we can calculate the modulation index from the modulated waveform. We know that $\mu = (A_m/A_c)$

$$A_m = (A_{max}-A_{min})/2 \qquad (2.8)$$

$$A_c = A_{max} - A_m \qquad (2.9)$$

By substituting (3.8) equation in equation (3.9) we get

$$A_c = A_{max} - (A_{max}-A_{min})/2 \qquad (2.10)$$

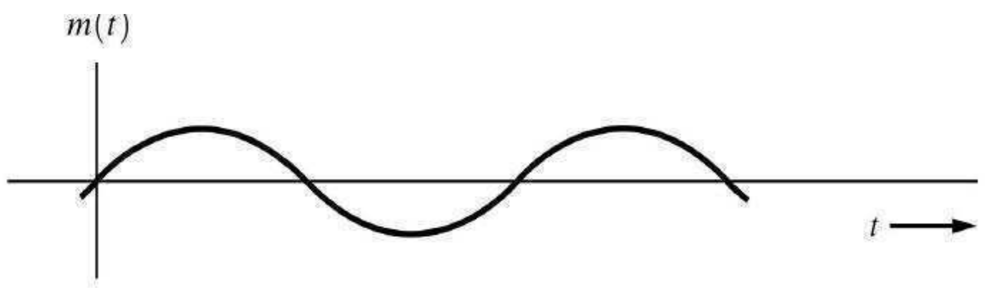
By diving (3.8) and (3.10) equation we get

$$\mu = (A_m/A_c)=\frac{A_{max}-A_{min}}{A_{max}+A_{min}} \qquad (2.11)$$

Where

A_{max} = maximum amplitude of the modulated carrier signal

A_{min} = minimum amplitude of the modulated carrier signal



(a) Sinusoidal Modulating Wave

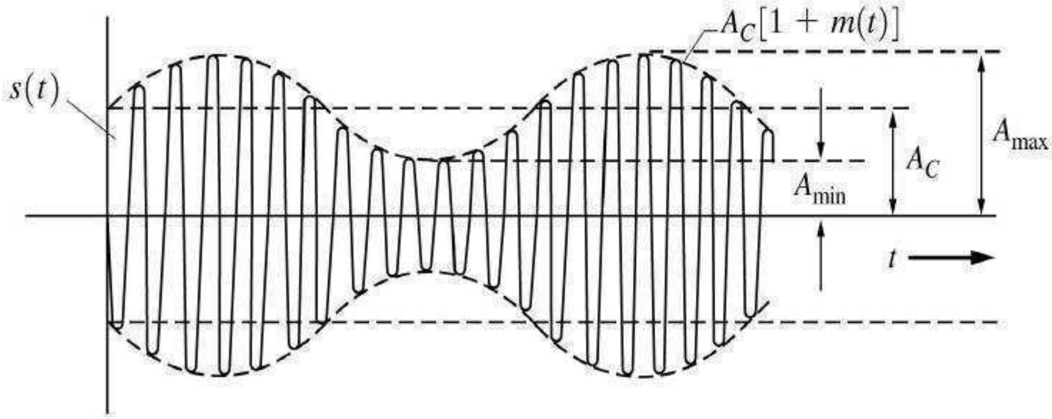


Figure 2.8.AM envelope

Modulation index μ has to be governed such that it is always less than unity; otherwise it results in a situation known as 'over-modulation' (μ >1). The over-modulation occurs, whenever the magnitude of the peak amplitude of the modulating signal exceeds the magnitude of the peak amplitude of the carrier signal. The signal gets distorted due to over modulation. Because of this limitation on'μ ', the system clarity is also limited. The AM waveforms for different values of modulation index m are as shown in figure 3.9.

If μ = 0 we haven't modulating wave, then no information is transmitted while engaging the channel with the carrier.

If μ= 1 we have the maximum of modulation. When the modulation index is 1, i.e. a modulation depth of 100%, the carrier level falls to zero and rise to twice its non-modulated level.
We are in optimal conditions if μ = 0.5.

If μ > 1 then we have strong crossover distortion. Any increase of the modulation index above 1.0, i.e. 100% modulation depth causes over-modulation. The carrier experiences 180° phase reversals where the carrier level would try to go below the zero point. These phase reversals give rise to additional sidebands resulting from the phase reversals (phase modulation) that extend out, in theory to infinity. This can cause interference to other users if not filtered.

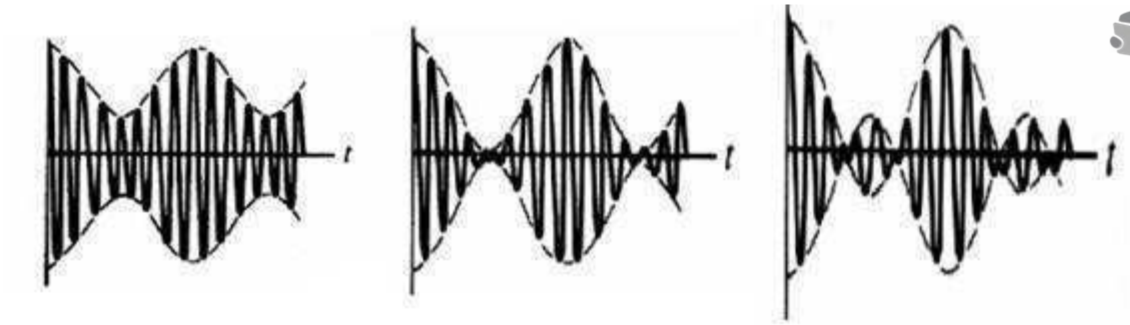


Figure 2.9.AM waveforms for different values of μ

$$S(t) = A_c \cos(2\pi f_c t) + A_c\mu/2[\cos 2\pi (f_c + f_m)t] + A_c\mu/2[\cos 2\pi (f_c - f_m)t] \quad (2.12)$$

- Looking at equation (3.12) we can say that 1st term represents un-modulated carrier and two additional terms represents two sidebands
- The frequency of the lower sideband (LSB) is $f_c - f_m$ and the frequency of the upper sideband (USB) is $f_c + f_m$

Fourier transform of S (t) is

$$S(f) = A_c/2[\delta(f-f_c) + \delta(f+f_c)] + A_c\mu/4[\delta(f-f_c-f_m) + \delta(f+f_c+f_m)] + A_c\mu/4[\delta(f-f_c+f_m) + \delta(f+f_c-f_m)] \quad (2.13)$$

Bandwidth of AM wave:

- We know bandwidth can be measured by subtracting lowest frequency of the signal from highest frequency of the signal
- For amplitude modulated wave it is given by

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

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

$= 2 f_m$

Therefore the bandwidth required for the amplitude modulation is twice the frequency of the modulating signal.

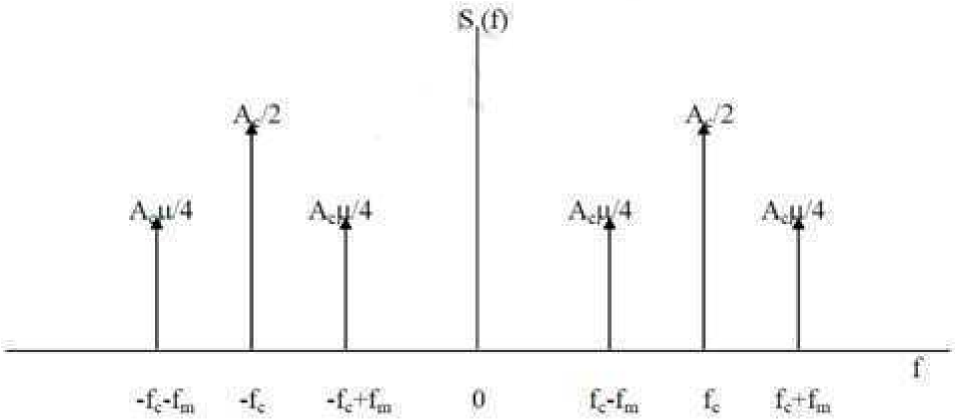


Figure 2.10. Spectrum of Single tone AM signal

Power calculations of single-tone AM signal:

The standard time domain equation for single-tone AM signal is given by equation 2.12

$$S(t) = A_c \cos(2\pi f_c t) + A_c\mu/2[\cos 2\pi (f_c + f_m)t] + A_c\mu/2[\cos 2\pi (f_c - f_m)t] \quad (2.12)$$

We have seen that AM wave has three components:

- Un-modulated carrier
- Lower sideband
- Upper sideband

Therefore the total power of AM wave is the sum of the carrier power Pc and Power in the two sidebands P_{USB} and P_{LSB}. It is given as

Power of any signal is equal to the mean square value of the signal
Carrier power $P_c = A_c^2 /2$
Upper Side Band power $P_{USB} = A_c^2 \mu^2 /8$
Lower Side Band power $P_{LSB} = A_c^2\mu^2 /8$
Total power $P_T = P_c + P_{LSB} + P_{USB}$
Total power $P_T = A_c^2 /2 + A_c^2 \mu^2 /8 + A_c^2 \mu^2 /8$
$P_T = P_c [1+ \mu^2 /2]$

2.7. Multi-tone modulation:
In multi-tone modulation modulating signal consists of more than one frequency component where as in single-tone modulation modulating signal consists of only one frequency component.

Mathematical Expression
Let us consider that a carrier signal $A_c \cos(2\pi f_c t)$ is modulated by a baseband or modulating signal m(t) which is expressed as :

$$m(t) = A_{m1} \cos(2\pi f_{m1} t) + A_{m1} \cos(2\pi f_{m2} t) \qquad (2.14)$$

We know that the general expression for AM wave is

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

Putting the value of x(t), we get

$$S(t) = A_c \cos(2\pi f_c t) + [A_{m1} \cos(2\pi f_{m1} t) + A_{m2} \cos(2\pi f_{m2} t)] \cos(2\pi f_c t) \qquad (2.15)$$

or it can be written as

$$S(t) = A_c [1 + K_a A_{m1} \cos(2\pi f_{m1} t) + K_a A_{m2} \cos(2\pi f_{m2} t)] \cos(2\pi f_c t) \qquad (2.16)$$

Replace $K_a A_{m1}$ by μ_1 and $K_a A_{m2}$ by μ_2
So finally we get

$$S(t) = A_c \cos(2\pi f_c t) + \frac{A_c\mu_1}{2}[\cos 2\pi (f_c + f_{m1})t] + \frac{A_c\mu_1}{2}[\cos 2\pi(f_c - f_{m1})t] + \frac{A_c\mu_2}{2}[\cos 2\pi (f_c + f_{m2})t] + \frac{A_c\mu_2}{2}[\cos 2\pi (f_c - f_{m2})t] \qquad (2.17)$$

Power of multi-tone AM signal is given by:

$$P_T = P_c [1+ \mu_1^2 /2 + \mu_2^2 /2 + \ldots\ldots\ldots\ldots + \mu_n^2/2]$$

Where P_t = Total power
P_c = Carrier power

$$P_T = P_c [1+ \mu_t^2 /2]$$

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

Fourier transform of S(t) is

$$S(f) = \frac{A_c}{2}[\delta(f-f_c)+ \delta(f+f_c)] + \frac{A_c\mu_1}{4}[\delta(f-f_c-f_{m1})+ \delta(f+f_c+f_{m1})] + \frac{A_c\mu_1}{4}[\delta(f-f_c+f_{m1})+ \delta(f+f_c-f_{m1})] + \frac{A_c\mu_2}{4}[\delta(f-f_c-f_{m2})+ \delta(f+f_c+f_{m2})] + \frac{A_c\mu_2}{4}[\delta(f-f_c+f_{m2})+ \delta(f+f_c-f_{m2})]$$

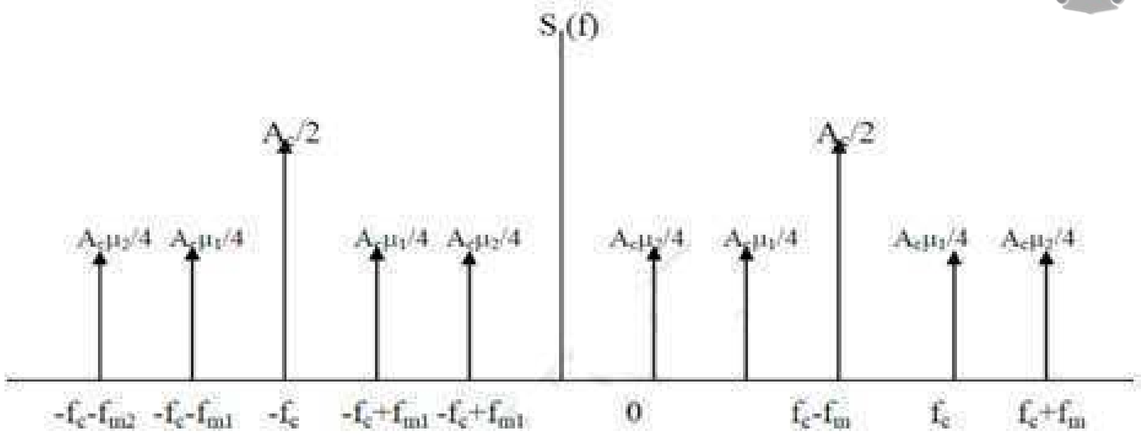


Figure 2.11. Spectrum of Multi tone AM signal

Transmission efficiency:

Transmission efficiency is defined as the ratio of total side band power to the total transmitted power.

The yield of modulation is defined therefore as the ratio between the transmitted information signal strength content in one of the two side lines, divided by all the power you must transmit.

$$\eta = \frac{P_{LSB}+P_{USB}}{P_T}$$

$$\eta = \frac{\mu^2}{(2+\mu^2)} \text{ X } 100\,\% \qquad (2.18)$$

The transmission efficiency (η) of AM wave is defined as the percentage of total power contributed by side bands of the AM signal. The maximum transmission efficiency of an AM signal is 33.33%, i.e., only one third of the total transmitted power is carried by the side bands in an AM wave. The remaining two third of the total transmitted power gets wasted.

Advantages of Amplitude modulation:

Generation and detection of AM signals are very easy

It is very cheap to build, due to this reason it is most commonly used in AM radio broad casting

Disadvantages of Amplitude of modulation:

Amplitude modulation is wasteful of power

Amplitude modulation is wasteful of band width

2.8. Modulation by a complex signal

A complex carrier signal c(t), at a carrier frequency ω_c , is described mathematically as the complex exponential

$C(t) = e^{(j\omega_c t+\,\delta)}$

For convenience we choose the initial time so that the phase (δ) is zero. Then, if m(t) is the signal or information that is to be transmitted by the carrier, the signal m(t) is encoded onto the carrier by multiplying the carrier by m(t)

S(t) = m(t) c(t)

$S(t) = m(t)e^{(j\omega_c t)}$

The carrier's amplitude is modulated by the signal m(t). Now we know that multiplication in the time domain is equivalent to convolution in the frequency domain. Thus, the Fourier transform of the signal s(t) is the convolution of the Fourier transforms of m(t) and c(t).

S(ω) = M(jω) * C(jω)

$$S(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} M(j\omega)C(j(\omega-\omega_0))d\omega_0$$

Earlier we took the Fourier transform of a complex exponential and determined it is a delta function

$C(j\omega) = 2\pi\ \delta(\omega-\omega_c)$

and upon substitution into the convolution equation we obtain

$S(\omega) = M(j(\omega-\omega_c))$

Thus, as a result of modulation, the transform of the signal m(t) is shifted on the frequency axis by the carrier frequency. We can visualize the situation by considering the magnitude of M (jω). We suppose that the signal m(t) is a real function of time and that its frequency content is bounded by some maximum frequency ω_m . Hence, all of the signal power lies in the range ± ω_m, as depicted in the figure 2.12 below. The second figure depicts the delta function at ω_c and the third figure shows the result of amplitude modulation.

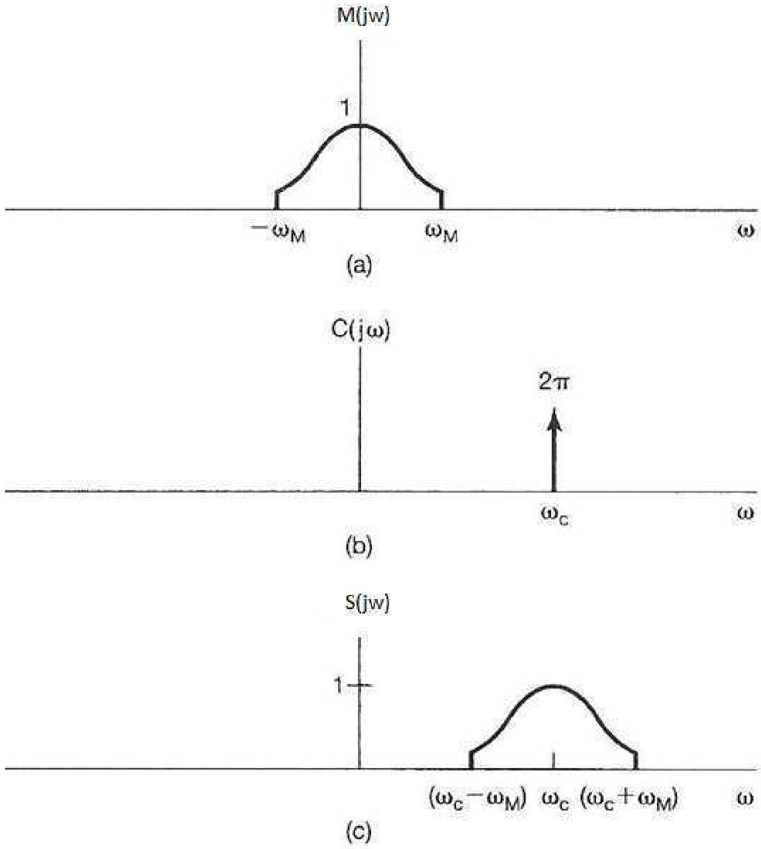


Figure 2.12 Complex AM spectrum

2.9. Generation of AM waves

The amplitude modulator is a circuit which generates amplitude modulated signal. In the process of modulation the frequency spectrum gets translated. The output of the modulator contains the frequencies which are different from those present in the input signal. The amplitude modulator therefore must be time varying linear systems such as switching or chopping circuit are a non linear time in varying system. The reason for this is that a linear time invariant system cannot produce new frequencies in its output. Here two methods for generating AM waves:

1. The square law are power law modulator
2. Switching modulator.

These two methods require non linear element as active device for generating AM signals. These two methods are use full in the low power generation of amplitude modulated waves.

Square-law modulator:

It consists of the following:

1. A non-linear device
2. A band pass filter
3. A carrier source and modulating signal

The modulating signal and carrier are connected in series with each other and their sum $V_1(t)$ is applied at the input of the non-linear device semi-conductor diodes and transistors are the most common nonlinear devices used for implementing square law modulators. The filtering requirement is usually satisfied by using a single or double tuned filters.
When a nonlinear element such as a diode is suitably biased and operated in a restricted portion of its characteristic curve, that is ,the signal applied to the diode is relatively weak, we find that transfer characteristic of diode-load resistor combination can be represented closely by a square law.

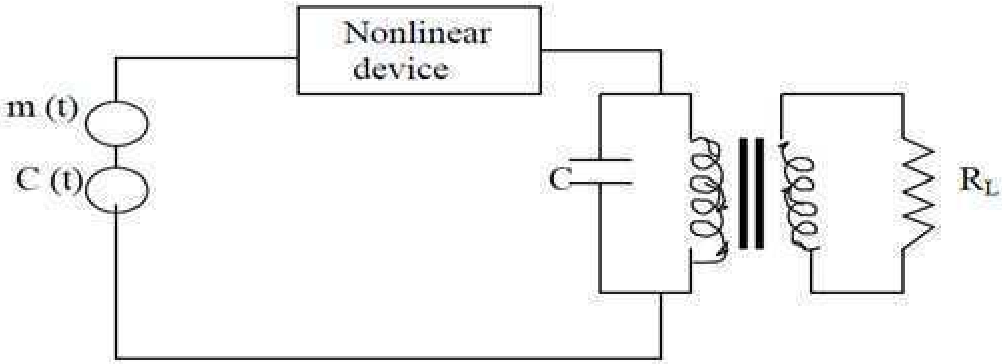


Figure 2.13.Square law modulator

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

$$V_0 (t) = a_1 V_i (t) + a_2 V_i^2 (t) \qquad (2.19)$$

Where a_1, a_2 are constants now, the input voltage V_i (t) is the sum of both carrier and message signals

$$\text{i.e., } V_i (t) = A_c \cos (2\pi f_c t)+m (t) \qquad (2.20)$$

Substitute equation (2.20) in equation (2.19) we get

$$V_0 (t) = a_1 A_c \cos (2\pi f_c t) + a_1 m (t) + a_2 [A_c \cos (2\pi f_c t)+m (t)]^2 \qquad (2.21)$$

$$V_0 (t) = a_1 A_c \cos(2\pi f_c t) + a_1 m (t) + a_2 A_c^2 \cos^2 (2\pi f_c t) + a_2 m^2 (t) + 2 a_2 A_c \cos (2\pi f_c t) m(t) \quad (2.22)$$

The five terms in the expression for $V_0(t)$ are as under :
Term 1: $a_1 m (t)$: Modulating Signal
Term 2: $a_1 A_c \cos (2\pi f_c t)$: Carrier Signal
Term 3: $a_2 m^2 (t)$: Squared modulating Signal
Term 4: $2 a_2 A_c \cos (2\pi f_c t) m(t)$: AM wave with only sidebands
Term 5: $a_2 A_c^2 \cos^2 (2\pi f_c t) + a_2 m^2 (t)$: Squared Carrier
Out of these five terms, terms 2 and 4 are useful whereas the remaining terms are not useful.

Let us combine terms 2, 4 and 1, 3, 5 as follows to get,

$$V_0 (t) = \{a_1 m (t) + a_2 A_c^2 \cos^2 (2\pi f_c t) + a_2 m^2 (t)\} + \{a_1 A_c \cos(2\pi f_c t) + 2 a_2 A_c \cos (2\pi f_c t) m(t)\} \quad (2.23)$$

Now design the tuned filter /Band pass filter with center frequency f_c and pass band frequency width 2W. We can remove the unwanted terms by passing this output voltage $V_0(t)$ through the band pass filter and finally we will get required AM signal.

$$V_0 (t) = a_1 A_c [1+ 2\frac{a_2}{a_1} m(t)] \cos(2\pi f_c t) \qquad (2.24)$$

Where $K_a = 2\frac{a_2}{a_1}$

Assume the message signal m (t) is band limited to the interval $-W \le f \le W$

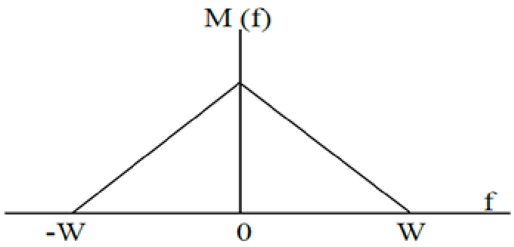


Figure 2.14.Spectrum of message signal

Spectrum of AM can represented a one shown in figure 2.15.The Fourier transform of output voltage V_O (t) is given by

$$V_O(f) = a_1A_C/2[(f-f_c) + (f+f_c)] + a_2 A_C [M(f-f_c) + M(f+f_c)] \quad (2.25)$$

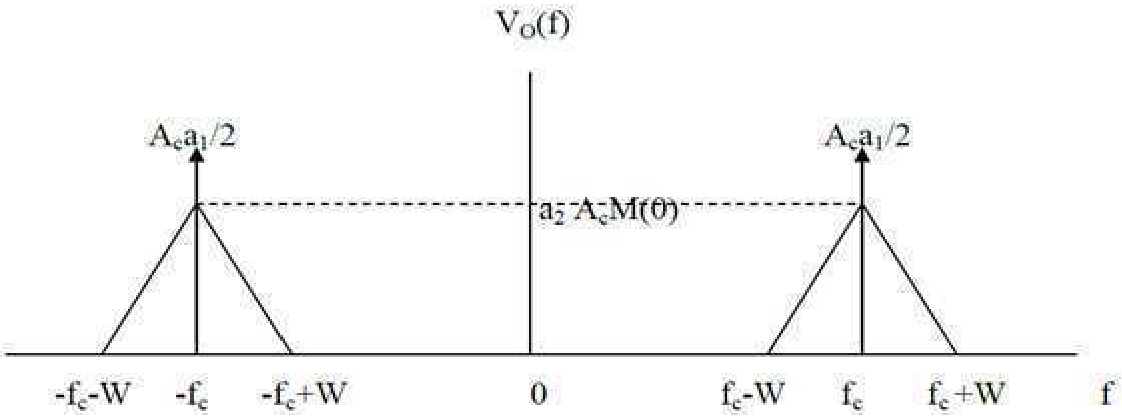


Figure 2.15.Spectrum of AM

The AM spectrum consists of two impulse functions which are located at f_c & $-f_c$ and weighted by $A_ca_1/2$ & $a_2A_c/2$, two USBs, band of frequencies from f_c to f_c +W and band of frequencies from $-f_c$-W to $-f_c$, and two LSBs, band of frequencies from f_c-W to f_c & $-f_c$ to $-f_c$+W.

Switching Modulator:

In switching modulator the diode has to operate as an ideal switch as one shown in figure 2.16. Let the modulating and carrier signals be denoted as m(t) and $c(t)=A_c\,Cos(2\pi f_ct)$ respectively.

Working of circuit:

- The two signals i.e. modulating and carrier signals are applied as inputs to the summer (adder) block.
- Assume that carrier wave C(t) applied to the diode is large in amplitude, so that it swings right across the characteristic curve of the diode and also the diode acts as an ideal switch, that is, it presents zero impedance when it is forward-biased and infinite impedance when it is reverse-biased.
- We may thus approximate the transfer characteristic of the diode-load resistor combination by a piecewise-linear characteristic. Summer block produces an output, which is the addition of modulating and carrier signals.
- During the positive half cycle of the carrier signal i.e. if C (t)>0, the diode is forward biased, and then the diode acts as a closed switch. Now the output voltage V_o (t) is same as the input voltage V_i (t) .
- During the negative half cycle of the carrier signal i.e. if C (t) <0, the diode is reverse biased, and then the diode acts as an open switch. Now the output voltage V_O (t) is zero i.e. the output voltage varies periodically between the values input voltage V_i (t) and zero at a rate equal to the carrier frequency f_c.

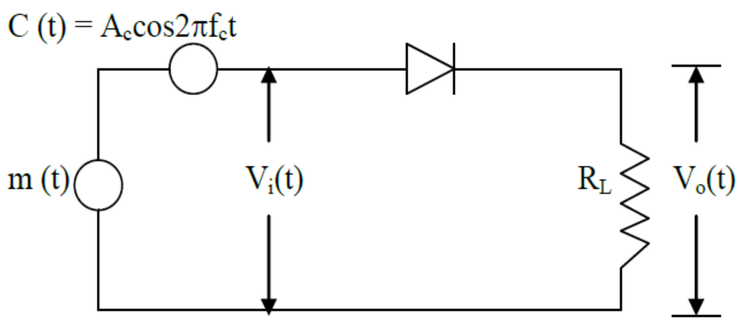


Figure 2.16.Switching modulator

Mathematically, we can write it as

The input voltage applied V_i (t) applied to the diode is the sum of both carrier and message signals.

$$V_i(t) = A_c \cos(2\pi f_c t) + m(t) \qquad (2.26)$$

$$V_o(t) = [A_c \cos(2\pi f_c t) + m(t)]\, g_P(t) \qquad (2.27)$$

Where $g_p(t)$ is the periodic pulse train with duty cycle one-half and period $T_c=1/f_c$ and which is given by

$$g_p(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos[2\pi f_c t(2n-1)] \qquad (2.28)$$

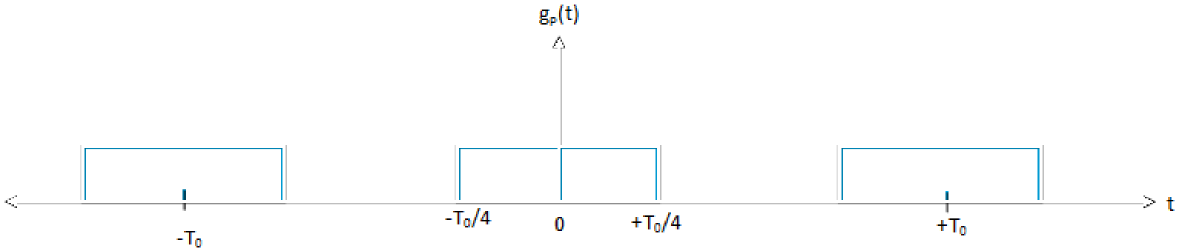


Figure 2.17 Pulse train

Substituting $g_p(t)$ into equation (2.27), we get

$$V_o(t) = \frac{1}{2}m(t) + \frac{1}{2}A_c \cos(2\pi f_c t) + \frac{2}{\pi}m(t)\cos(2\pi f c t) + \frac{2A_c}{\pi}\cos^2(2\pi f_c t) \qquad (2.29)$$

The odd harmonics in this expression are unwanted, and therefore, are assumed to be eliminated. In this expression, the first and the fourth terms are unwanted terms whereas the second and third terms together represent the AM wave.

Combining the second and third terms together, we obtain

$$V_o(t) = \frac{A_c}{2}\left[1 + \frac{4}{\pi A_c}m(t)\right]\cos(2\pi f_c t) + \text{unwanted terms} \qquad (2.30)$$

This is the required expression for the AM wave with μ= [4/πE_c].

The unwanted terms can be eliminated using a band-pass filter (BPF). Now design the tuned filter /Band pass filter with center frequency f_c and pass band frequency width 2W.We can remove the unwanted terms by passing this output voltage V0(t) through the band pass filter and finally we will get required AM signal.

Assume the message signal m(t) is band limited to the interval –W ≤f ≤W as one shown in figure 2.18

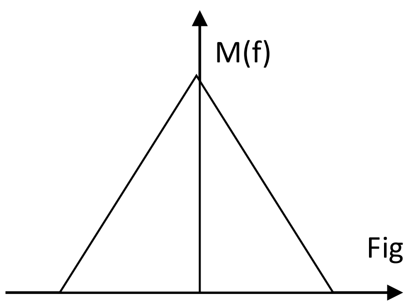


Figure 2.18 Spectrum of message signal

The spectrum of Am signal is shown in figure 2.19.The Fourier transform of output voltage V_O (t) is given by

$V_O (f) = A_C/4[\delta(f-f_c) + \delta(f+fc)] + A_C/\pi [M (f-f_c) + M (f+f_c)]$ (2.31)

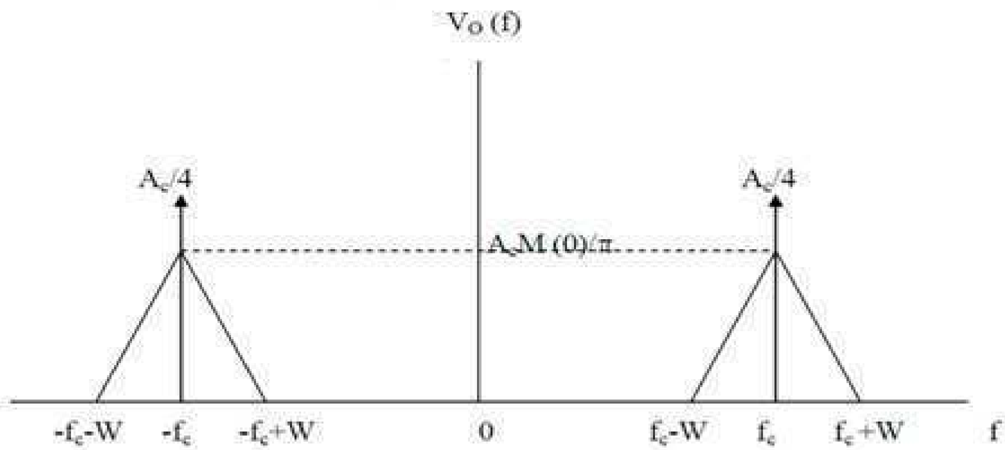


Figure 2.19. Spectrum of AM signal

The AM spectrum consists of two impulse functions which are located at fc & -fc and weighted by $A_c a_1/2$ & $a_2 A_c/2$, two USBs, band of frequencies from fc to fc +W and band of frequencies from -fc-W to –fc, and two LSBs, band of frequencies from fc-W to fc & -fc to -fc+W.

2.10. Advantages:

1. It is very simple to design and implement
2. It can be demodulated using a circuit consisting of very few components
3. AM receivers are very cheap as no specialised components are needed.
4. AM signal are reflected back to earth from ionosphere layer. Due to this fact, AM signals can reach far places which are thousands of miles from source. Hence AM radio has coverage wider compare to FM radio.

Disadvantage:

1. Due to large time constant, some distortion occurs which is known as diagonal clipping i.e., selection of time constant is somewhat difficult
2. The most natural as well as man-made radio noise are of AM type. The AM receivers do not have any means to reject this kind of noise.
3. Weak AM signals have low magnitude compare to strong signals. This requires AM receiver to have circuitry to compensate for signal level difference.
4. It is not efficient in terms of its use of bandwidth, requiring a bandwidth equal to twice that of the highest audio frequency

Application:

- **Broadcast transmissions:** AM is still widely used for broadcasting on the long, medium and short wave bands.

- **Air band radio:** VHF transmissions for many airborne applications still use AM. . It is used for ground to air radio communications as well as two way radio links for ground staff as well.

2.11. Suppressed carrier Amplitude modulation systems:

Objective: In full AM (DSB-AM), the carrier wave C (t) is completely independent of the message signal m(t), which means that the transmission of carrier wave represents a waste of power. This points to a shortcoming of amplitude modulation, that only a fraction of the total transmitted power is affected by m(t).Thus, the carrier signals and one of the two sidebands may be removed or attenuated so the resulting signals will require less transmitted power and will occupy less bandwidth, and yet perfectly acceptable communications will be possible.

2.12. Double Sideband-Suppressed Carrier (DSBSC) Modulation

Double sideband-suppressed (DSB-SC) modulation, in which the transmitted wave consists of only the upper and lower sidebands. Transmitted power is saved through the suppression of the carrier wave, but the channel bandwidth requirement is same as in AM that is twice the bandwidth of the message signal. In power calculation of AM signal, it has been observed that for single-tone sinusoidal modulation, the ratio of the total power and carrier power is

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

$\frac{P_c}{P_t} = \frac{2}{3}$ x 100 % = 67%(for $\mu = 1$)

So for 100% modulation that is $\mu = 1$, about 67% of the total power is wasted for transmitting carrier which does not contain any information. So if carrier is suppressed, saving of two-third power may be achieved at 100% modulation.

Let m (t) be a band-limited baseband message signal with cutoff frequency W. The DSBSC-AM signal corresponding to m (t) consists of the product of both the message signal m (t) and the carrier signal C (t), as follows:

S (t) =C (t) m (t)

S (t) =A_c Cos ($2\pi f_c t$) m (t)

This is the same as AM except with the sinusoidal carrier component is eliminated.

The modulated signal S (t) undergoes a phase reversal whenever the message signal m (t) crosses zero. The envelope of a DSB-SC modulated signal is different from the message signal. The transmission bandwidth required by DSB-SC modulation can be seen from figure 2.21 which is same as that for amplitude modulation that is twice the bandwidth of the message signal 2W.

Assume that the message signal is band-limited to the interval –W ≤f≤ W.

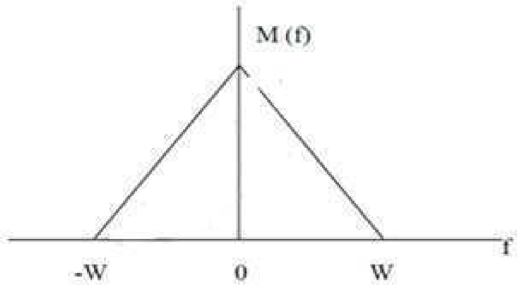


Figure 2.20 Spectrum of message signal

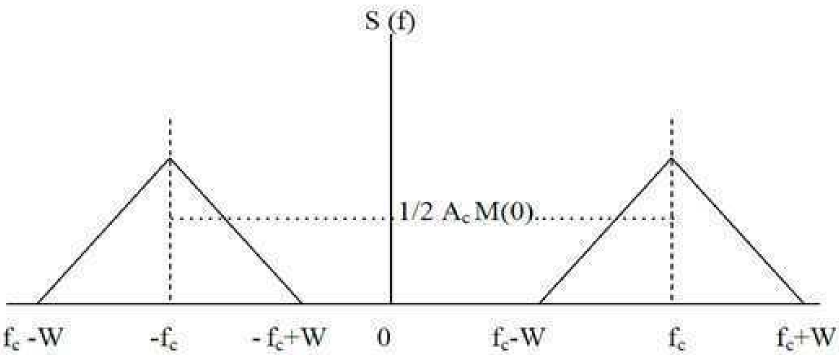


Figure 2.21.Spectrum of DSBSC signal

Single-tone modulation:

In single-tone modulation modulating signal consists of only one frequency component where as in multi-tone modulation modulating signal consists of more than one frequency components.

The standard time domain equation for the DSB-SC modulation is given by

S (t) =A_c Cos ($2\pi f_c t$) m (t) (1)

m (t) =A_m Cos ($2\pi f_m t$) (2)

Substitute equation (2) in equation (1) we will get

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

S (t) = $\frac{A_c A_m}{2}$ [Cos 2π (f_c-f_m) t + Cos 2π (f_c+f_m) t] (3)

The Fourier transform of S (t) is

S (f) = $\frac{A_c A_m}{4}$ [δ (f-f_c-f_m) + δ (f+f_c+f_m)] +$\frac{A_c A_m}{4}$ [δ (f-f_c+ f_m) + δ(f+f_c+f_m)]

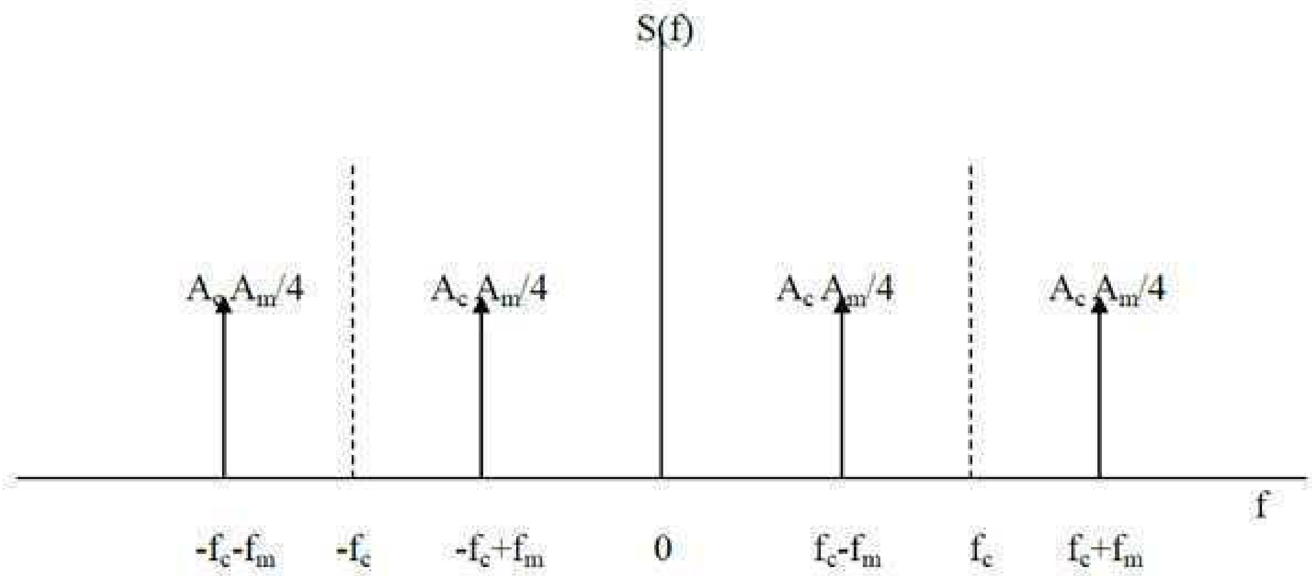


Figure 2.22.Spectrum of single tone DSBSC

Bandwidth:

The DSBSC modulated wave has only two frequencies. So, the maximum and minimum frequencies are f_c+f_m and f_c−f_m respectively.

f_{max}=f_c+f_m and f_{min}=f_c−f_m

Substitute, f_{max} and f_{min} values in the bandwidth formula.

BW=f_c+f_m− (f_c−fm)

BW=2f_m

Power calculations of DSB-SC waves:-

Consider the following equation of DSBSC modulated wave

S (t) = $\frac{A_c A_m}{2}$ [cos 2π (f_c-f_m) t + Cos 2π (f_c+f_m) t]

Power of DSBSC wave is equal to the sum of powers of upper sideband and lower sideband frequency components.

P_T=P_{USB}+P_{LSB}

We know the standard formula for power of cosine signal is

P = $\frac{{V_{rms}}^2}{R}$

Average power delivered to a 1ohm resistor can be calculated as,

P_{USB} = ($\frac{A_m A_c}{2\sqrt{2}}$)^2

P_{USB} = $A_m^2 A_c^2/8$

Similarly; P_{LSB} = ($\frac{A_m A_c}{2\sqrt{2}}$)^2 = $A_m^2 A_c^2/8$

So total power P_T =$A_c^2 A_m^2/4$

$\frac{P_{USB}}{P_T}$ = $\frac{P_{LSB}}{P_T}$ = $\frac{A_m^2 A_c^2/_8}{A_m^2 A_c^2/_4}$ x 100 % = 50%

For the sinusoidal modulation, the average power in the lower or upper side-frequency with respect to the total power in the DSB-SC modulated wave is 50%.

Generation of DSB-SC waves:

The generation of a DSB-SC modulated wave consists simply of the product of the message signal m(t) and the carrier wave A_c Cos ($2\pi f_c t$). Devices for achieving this requirement is called a product modulator. There are two methods to generate DSB-SC waves. They are:

- Balanced modulator
- Ring modulator

Balanced Modulator:

1. Balanced modulator consists of two identical AM modulators which are arranged in a balanced configuration in order to suppress the carrier signal. Hence, it is called as balanced modulator as shown in figure 4.4.
2. Assume that two AM modulators are identical, except for the sign reversal of the modulating signal applied to the input of one of the modulators.
3. The same carrier signal C (t) = A_c Cos(2πfct) is applied as one of the inputs to these two AM modulators.
4. The modulating signal m(t) is applied as another input to the upper AM modulator. Whereas, the modulating signal with opposite polarity, −m(t) is applied as another input to the lower AM modulator.

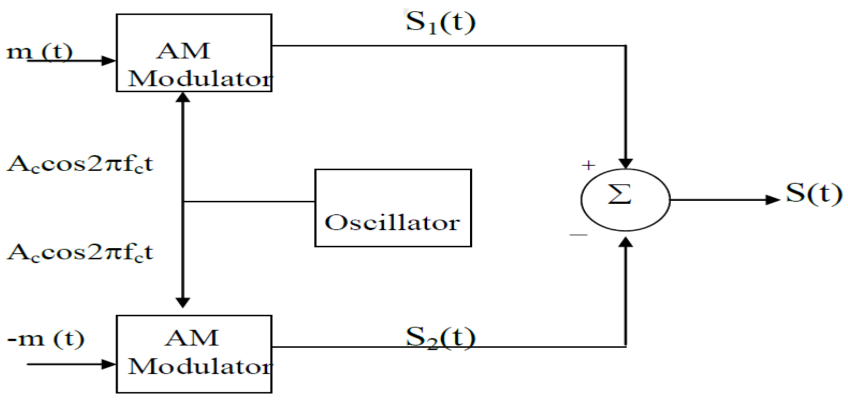


Figure 2.23.Balanced modulator

Mathematical analysis:

The outputs of the two AM modulators can be expressed as follows:

$S_1(t) = A_c [1+k_a m(t)] \cos 2\pi f_c t$

$S_2(t) = A_c [1- k_a m(t)] \cos 2\pi f_c t$

Subtracting $S_2(t)$ from $S_1(t)$, we obtain

$S(t) = S_1(t) - S_2(t)$

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

Hence, except for the scaling factor $2k_a$ the balanced modulator output is equal to product of the modulating signal and the carrier signal. The Fourier transform of S (t) is

$S(f) = k_a A_c [M(f-f_c) + M(f+f_c)]$

Assume that the message signal is band-limited to the interval $-W \le f \le W$ as shown in figure 2.24 and its DSB-SC modulated spectrum is shown in figure 4.6.

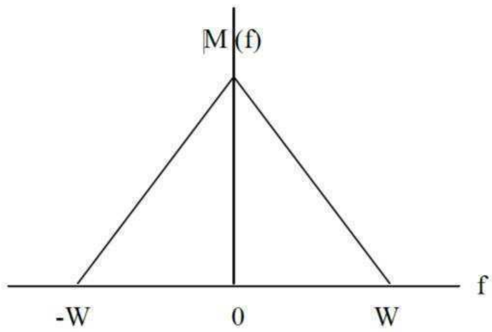


Figure 2.24.Spectrum of Baseband signal

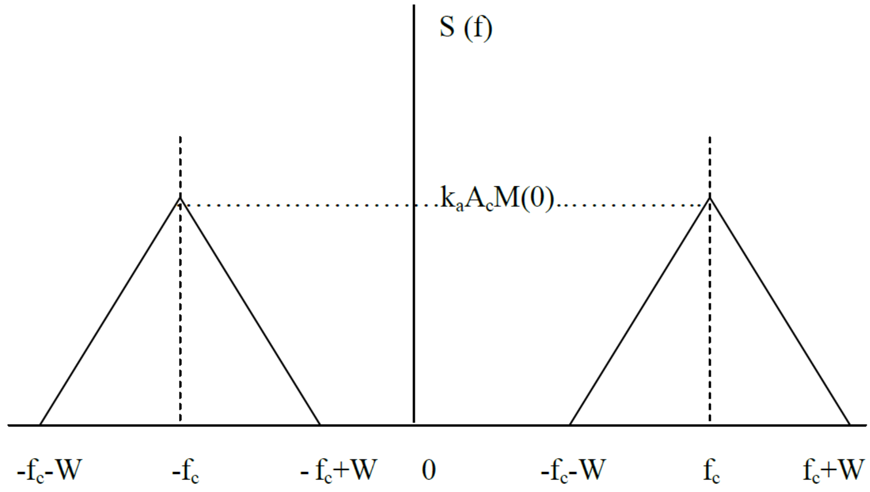


Figure 2.25.Spectrum of DSBSC wave

Ring modulator:

One of the most useful product modulator, for generating a DSBSC wave, is the ring modulator shown in figure 2.26.

1. In this diagram, the four diodes D1,D2,D3 and D4 are connected in the ring structure. Hence, this modulator is called as the ring modulator.
2. The diodes are controlled by a square-wave carrier C (t) of frequency f_c, which applied longitudinally by means of to center-tapped transformers. If the transformers are perfectly balanced and the diodes are identical, there is no leakage of the modulation frequency into the modulator output.
3. The message signal m(t) is applied to the input transformer. Whereas, the carrier signals C (t) is applied between the two centre-tapped transformers.
4. For positive half cycle of the carrier signal, the diodes D1 and D3 are switched ON and the other two diodes D2 and D4 are switched OFF. In this case, the message signal is multiplied by +1.
5. For negative half cycle of the carrier signal, the diodes D2 and D4 are switched ON and the other two diodes D1 and D3 are switched OFF. In this case, the message signal is multiplied by -1. This results in 180^0 phase shift in the resulting DSBSC wave.

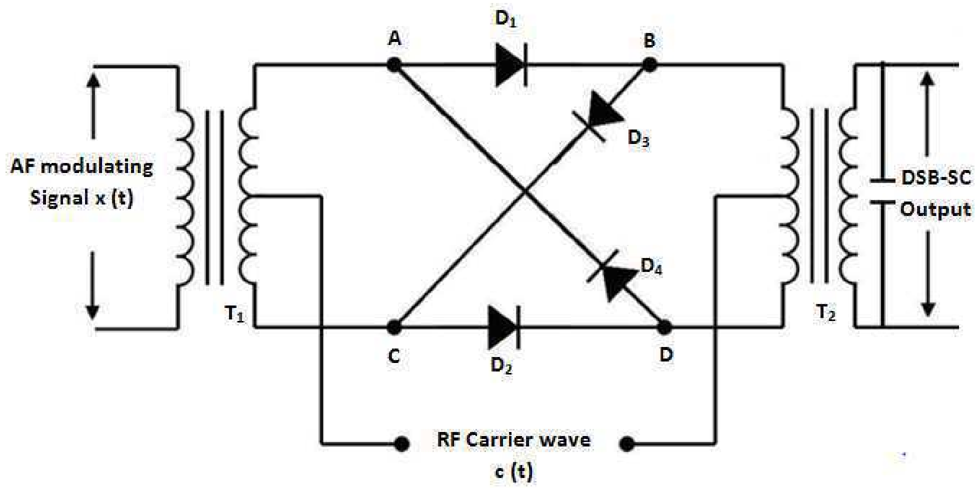


Figure 2.26.Ring modulator

Mathematical Analysis:

The square wave carrier c (t) can be represented by a Fourier series as follows:

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

= 4/π Cos(2πfct) + higher order harmonics(n=1)

Now, the Ring modulator output is the product of both message signal m (t) and carrier signal c (t).

S (t) =c (t) m (t)

$$S(t) == \frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n-1}}{2n-1}\cos 2\pi f_c t(2n-1)\ m(t) \qquad \text{For } n=1$$

$S(t) = 4/\pi \cos(2\pi f_c t)\, m(t)$

There is no output from the modulator at the carrier frequency i.e the modulator output consists of modulation products. The ring modulator is also called as a double-balanced modulator, because it is balanced with respect to both the message signal and the square wave carrier signal.

The Fourier transform of S (t) is

$S(f) = 2/\pi\, [M(f-fc) + M(f+fc)]$

Assume that the message signal is band-limited to the interval $-W \leq f \leq W$ as shown in figure 2.27 and its DSB-SC modulated spectrum in figure 2.28.

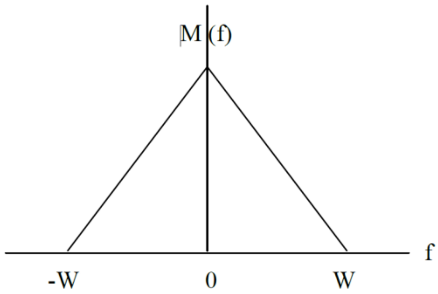


Figure 2.27. Spectrum of Baseband signal

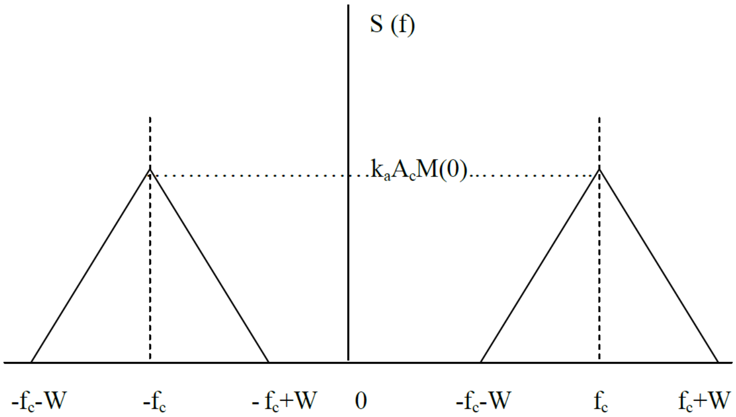


Figure 2.28.Spectrum of DSBSC wave

Coherent Detection of DSB-SC Waves:

The base band signal can be recovered from a DSB-SC signal by multiplying DSB-SC wave S (t) with a locally generated sinusoidal signal and then low pass filtering the product. It is assumed that local oscillator signal is coherent or synchronized, in both frequency and phase, with the carrier signal C (t) used in the product modulator to generate S (t). This method of demodulation is known as coherent detection or synchronous demodulation.

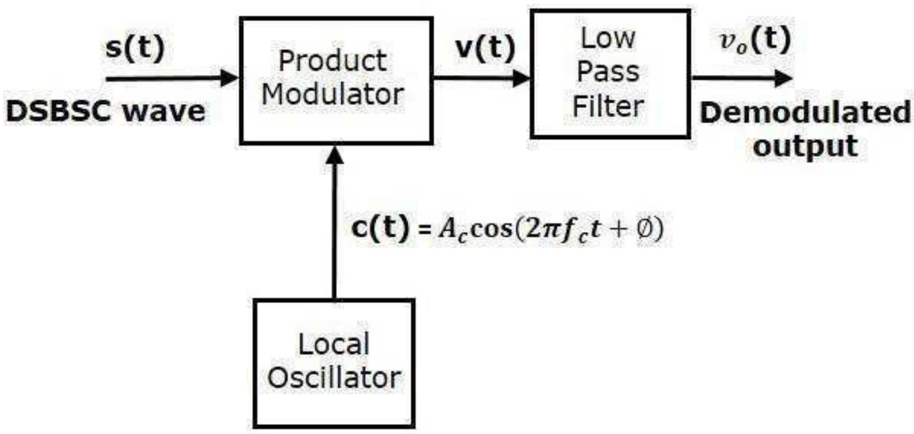


Figure 2.29.Coherent detection of DSB-SC signal

Analysis of coherent detection:

The product modulator produces the product of both input signal s(t) and local oscillator signal and the output of the product modulator is v (t).

$S(t) = A_c \cos(2\pi f c t)\, m(t)$

$C(t) = A_c \cos(2\pi f c t + \emptyset)$

$V(t) = C(t)\, S(t)$

$V(t) = A_c \cos(2\pi f_c t + \emptyset)\, S(t)$

$V(t) = A_c \cos(2\pi f_c t + \emptyset)\, A_c \cos(2\pi f_c t)\, m(t)$

$V(t) = A_c^2 \cos(2\pi f_c t + \emptyset) \cos(2\pi f_c t)\, m(t)$

$V(t) = \frac{A_c^2}{2} \cos\emptyset\; m(t) + \frac{A_c^2}{2} \cos(4\pi f_c t + \emptyset)\, m(t)$

In the above equation, the first term is the scaled version of the message signal. It can be extracted by passing the above signal through a low pass filter. Therefore, the output of low pass filter is

$V_o(t) = \frac{A_c^2}{2} \cos\emptyset\; m(t)$

The Fourier transform of V_o (t) is

$V_O(f) = \frac{A_c^2}{2} \cos\emptyset\; M(f)$

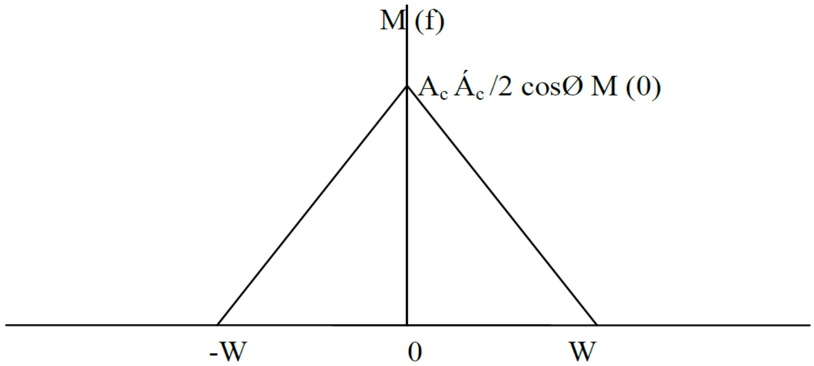


Figure 2.30.DSB-SC demodulated output

The demodulated signal is proportional to the message signal m (t) when the phase error is constant. The amplitude of this demodulated signal is maximum when Ø=0, the local oscillator signal and the carrier signal should be in phase, i.e., there should not be any phase difference between these two signals. The demodulated signal amplitude will be zero, when Ø=±π/2. This effect is called as **quadrature null effect**.

Costa's loop detection:

1. The receiver consists of two coherent detectors supplied with same DSB-SC wave while the other input for both product modulators is taken from Voltage Controlled Oscillator (VCO) with -90^0 phase shift to one of the product modulator as shown in figure 2.29.
2. The frequency of the local oscillator is adjusted to be the same as the carrier frequency f_c. The two detector are coupled together to form a negative feedback system designed in such a way as to maintain the local oscillator synchronous with the carrier wave.
3. The detector in the upper path is referred to as the in-phase coherent detector or I-channel, and that in the lower path is referred to as the quadrature-phase coherent detector or Q-channel.
4. The output of product modulator is applied as an input of the lower low pass filter.
5. The output of lower Low pass filter has -90^0 phase difference with the output of the upper low pass filter. The outputs of these two low pass filters are applied as inputs of the phase discriminator. Based on the phase difference between these two signals, the phase discriminator produces a DC control signal.
6. This signal is applied as an input of VCO to correct the phase error in VCO output. Therefore, the carrier signal (used for DSBSC modulation) and the locally generated signal (VCO output) are in phase.

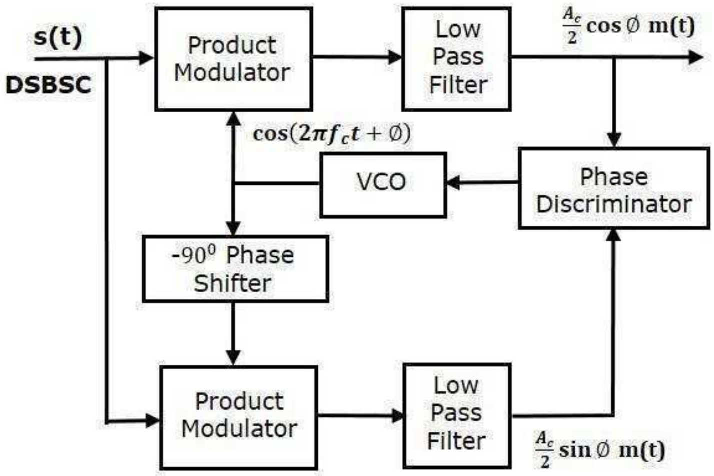


Figure 2.31.Costa's receiver

Mathematical Analysis: We know that the equation of DSBSC wave is

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

Let the output of VCO be $c_1(t) = \cos(2\pi f_c t+\varphi)$

This output of VCO is applied as the carrier input of the upper product modulator. Hence, the output of the upper product modulator is

$v_1(t) = S(t)\, c_1(t)$

Substitute, S(t) and $c_1(t)$ values in the above equation.

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

$v_1(t) = \frac{A_c^2}{2} \cos\phi\ m(t) + \frac{A_c^2}{2} \cos(4\pi f_c t + \varphi)\, m(t)$

This signal is applied as an input of the upper low pass filter. The output of this low pass filter is

$v_{01}(t) = A_c^2 \cos\varphi\ m(t)$

Therefore, the output of this low pass filter is the scaled version of the modulating signal.The output of -90^0 phase shifter is

$c_2(t) = \cos(2\pi f_c t+\varphi-90^0)=\sin(2\pi f_c t+\varphi)$

This signal is applied as the carrier input of the lower product modulator. The output of the lower product modulator is

$v_2(t) = S(t)\, c_2(t)$

Substitute, S(t) and $c_2(t)$ values in the above equation.

$v_2(t) = A_c \cos(2\pi f_c t) m(t) \sin(2\pi f_c t+\varphi)$

After simplifying, we will get $v_2(t)$ as

$v_2(t) = A_c^2 \sin\varphi m(t)+A_c^2 \sin(4\pi fct+\varphi) m(t)$

This signal is applied as an input of the lower low pass filter. The output of this low pass filter is

$v_{02}(t) = A_c^2 \sin\varphi\ m(t)$

The output of this Low pass filter has -90^0 phase difference with the output of the upper low pass filter.

2.13. Single Sideband Modulation

Single sideband modulation (SSB) is a form of amplitude modulation which uses only one sideband for a given message signal to provide the final signal. The process of suppressing one of the sidebands along with the carrier and transmitting a single sideband is called as Single Sideband Suppressed Carrier system or simply SSBSC.

SSB provides a considerably more efficient form of communication when compared to ordinary amplitude modulation in terms of the radio spectrum used a can be seen from figure 2.30, and also the power used to transmit the signal.

Depending on which half of DSB-SC signal is transmitted, there are two types of SSB modulation

1. Lower Side Band (LSB) Modulation
2. Upper Side Band (USB) Modulation

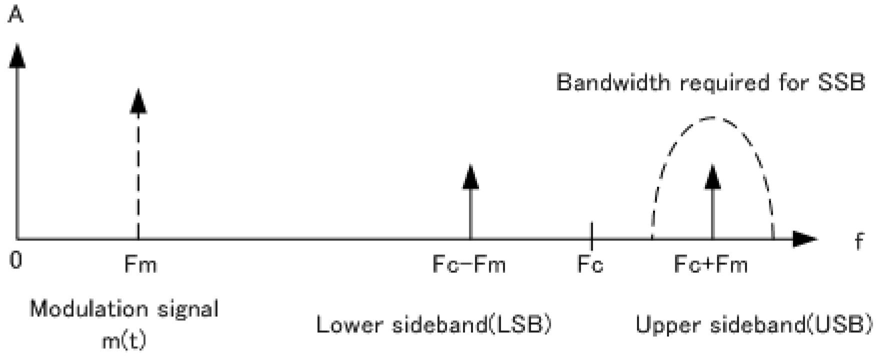


Figure 2.32.SSB-SC spectrum

Mathematical Expressions

Let us consider the mathematical expressions for the modulating and the carrier signals as follows

Modulating signal $m(t) = A_m \text{Cos}(2\pi f_m t)$

Carrier signal $c(t) = A_c \text{Cos}(2\pi f_c t)$

Mathematically, we can represent the equation of SSBSC wave as

$S(t) = \frac{A_m A_c}{2} \text{Cos}\,[2\pi(f_c+f_m)t]$ for the upper sideband

Or

$S(t) = \frac{A_m A_c}{2} \text{Cos}\,[2\pi(f_c-f_m)t]$ for the lower sideband

Bandwidth of SSBSC Wave

As can be seen in figure 2.33, the DSBSC modulated wave contains two sidebands and its bandwidth is $2f_m$. Since the SSBSC modulated wave contains only one sideband, its bandwidth is half of the bandwidth of DSBSC modulated wave. Therefore, the bandwidth of SSBSC modulated wave is f_m and it is equal to the frequency of the modulating signal.

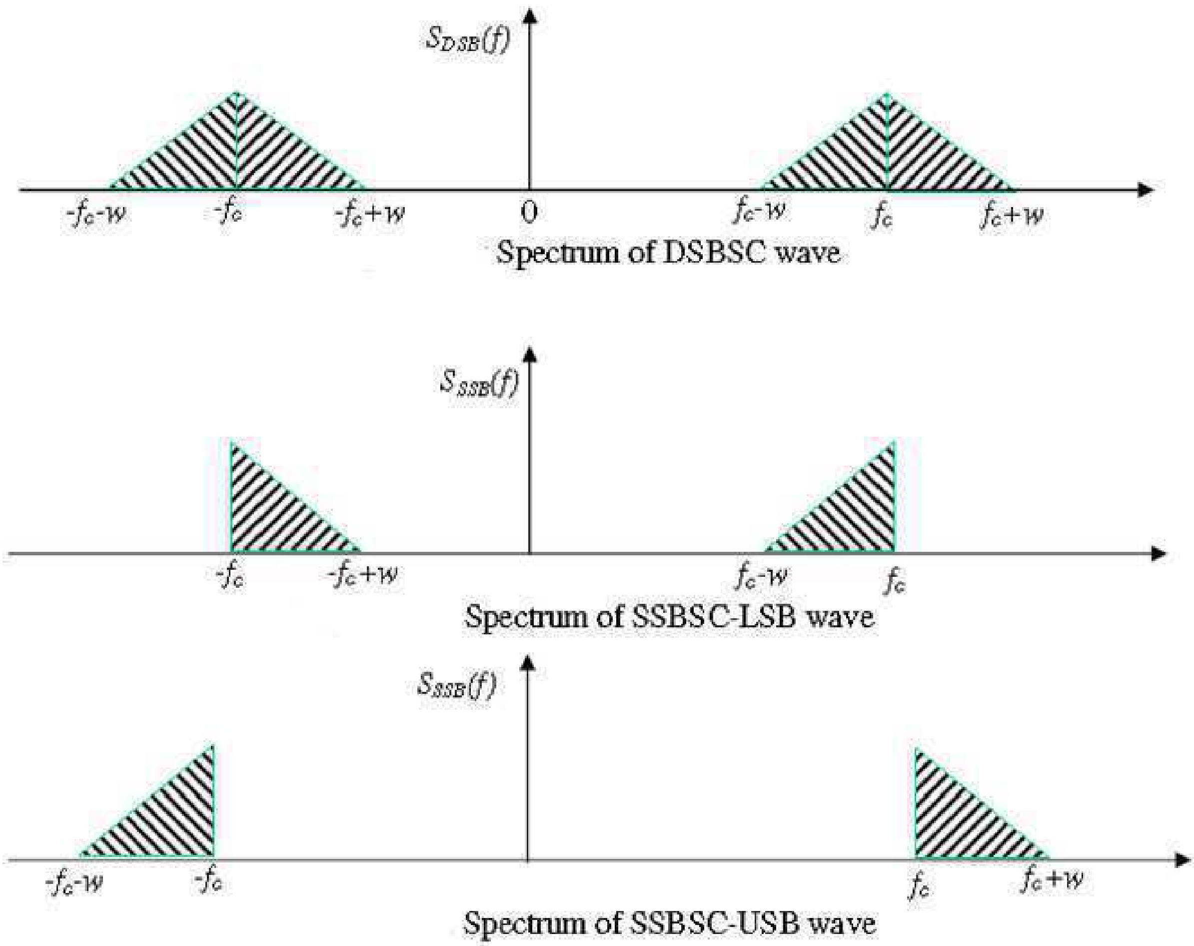


Figure 2.33 Spectrums of DSBSC and SSBSC

Power Calculations of SSBSC signal:

Consider the following equation of SSBSC modulated wave.

$s(t)=\frac{A_m A_c}{2}\cos[2\pi(f_c+f_m)t]$ for the upper sideband

Or

$s(t)=\frac{A_m A_c}{2}\cos[2\pi(f_c-f_m)t]$ for the lower sideband

Power of SSBSC wave is equal to the power of any one sideband frequency components.

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

We know that the standard formula for power of cosine signal is

$$P = \frac{V_{rms}^2}{R} = \frac{\left(V_m/\sqrt{2}\right)^2}{R}$$

In this case, the power of the upper sideband is

$$P_{USB}=\frac{(A_m A_c)^2}{8R}$$

Similarly, we will get the lower sideband power same as that of the upper side band power.

$$P_{LSB}=\frac{(A_m A_c)^2}{8R}$$

Therefore, the power of SSBSC wave for 1 ohm resistance is

$$P_t = P_{USB} = P_{LSB} = \frac{(A_m A_c)^2}{8}$$

Advantages

- Bandwidth or spectrum space occupied is lesser than AM and DSBSC waves.
- Transmission of more number of signals is allowed.
- Power is saved.
- High power signal can be transmitted.
- Less amount of noise is present.
- Signal fading is less likely to occur.

Disadvantages

- The generation and detection of SSBSC wave is a complex process.
- The quality of the signal gets affected unless the SSB transmitter and receiver have an excellent frequency stability.

Applications

- For power saving requirements and low bandwidth requirements.
- In land, air, and maritime mobile communications.
- In point-to-point communications.
- In radio communications.
- In television, telemetry, and radar communications.
- In military communications, such as amateur radio, etc.

2.14. Generation of SSB waves:

1. Frequency Discrimination Method

The frequency discrimination or filter method of SSB generation consists of a product modulator, which produces DSBSC signal and a band-pass filter to extract the desired side band and reject the other and is shown in the figure 2.34. Application of this method requires that the message signal satisfies two conditions:

1. The message signal m(t) has low or no low-frequency content. M(ω) has a "hole" at zero-frequency Example: - speech, audio, music.

2. The highest frequency component W of the message signal m(t) is much less than the carrier frequency.

Then, under these conditions, the desired side band will appear in a non-overlapping interval in the spectrum in such a way that it may be selected by an appropriate filter.

In designing the band pass filter, the following requirements should be satisfied:

1) The pass band of the filter occupies the same frequency range as the spectrum of the desired SSB modulated wave.

2. The width of the guard band of the filter, separating the pass band from the stop band, where the unwanted sideband of the filter input lies, is twice the lowest frequency component of the message signal.

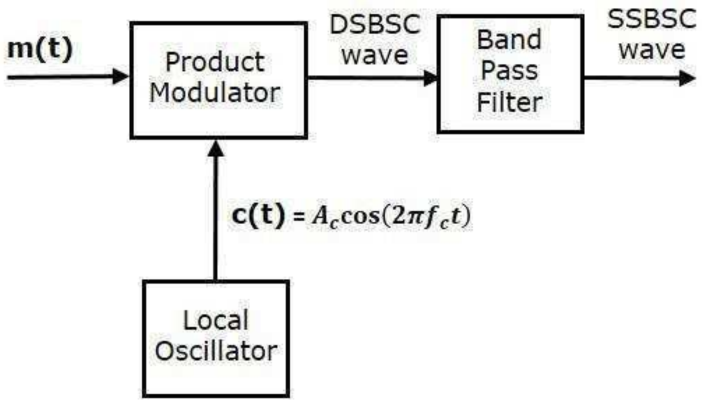


Figure 2.34.Filter method

2. Phase discrimination method

1. The phase discriminator consists of two product modulators I and Q, supplied with carrier waves in-phase quadrature to each other as shown in figure 2.35.
2. The incoming base band signal m(t) is applied to product modulator I, producing a DSBSC modulated wave that contains reference phase sidebands symmetrically spaced about carrier frequency fc.
3. The Hilbert transform mˆ(t) of m(t) is applied to product modulator Q, producing a DSBSC modulated that contains side bands having identical amplitude spectra to those of modulator I, but with phase spectra such that vector addition or subtraction of the two modulator outputs results in cancellation of one set of side bands and reinforcement of the other set.
4. The use of a plus sign at the summing junction yields an SSB wave with only the lower side band, whereas the use of a minus sign yields an SSB wave with only the upper side band. This modulator circuit is called Hartley modulator.

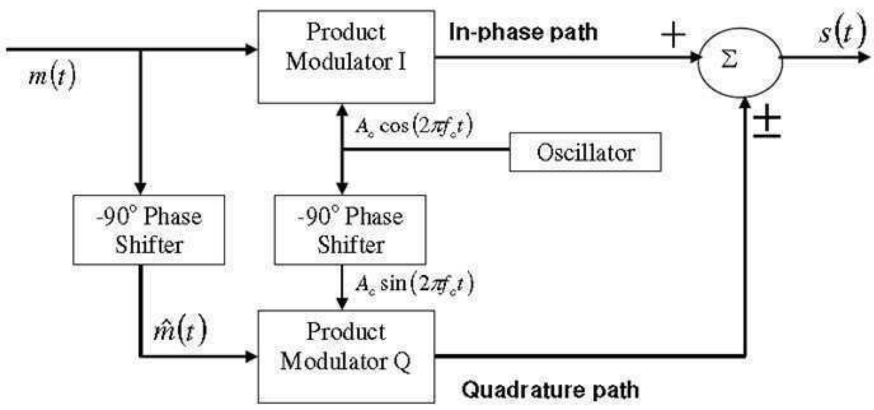


Figure 2.35.Phase discrimination method

Demodulation of SSB waves:

Coherent detection: It assumes perfect synchronization between the local carrier and that used in the transmitter both in frequency and phase. The carrier signal which is used for generating SSBSC wave is used to detect the message signal. Hence, this process of detection is called as coherent or synchronous detection. Following is the block diagram of coherent detector.

In this process, the message signal can be extracted from SSBSC wave by multiplying it with a coherent carrier and then the resulting signal is passed through a Low Pass Filter. The output of this filter is the desired message signal.

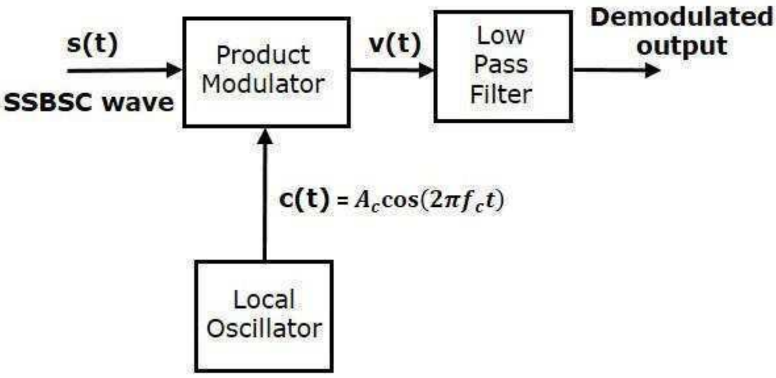


Figure 2.36.Coherent detection

Mathematical Analysis:

S (t) = A_m Ac/2 Cos[$2\pi(f_c - f_m)t$]

The output of the local oscillator is

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

From the figure, we can write the output of product modulator as

v(t) = s(t)c(t)

Substitute s(t) and c(t) values in the above equation

$$V(t) = \frac{A_m A_c}{2}\cos[2\pi(f_c+f_m)t] \quad A_c\cos(2\pi f_c t)$$

$$V(t) = \frac{A_m A_c^2}{4}\cos(2\pi f_m t) + \frac{A_m A_c^2}{4}\cos[2\pi(2f_c - f_m)t]$$

In the above equation, the first term is the scaled version of the message signal the scaling factor is $\frac{A_c^2}{4}$. It can be extracted by passing the above signal through a low pass filter.

Therefore, the output of low pass filter is

$$V_0(t) = \frac{A_m A_c^2}{4}\cos(2\pi f_m t)$$

2.15. Vestigial side band Modulation

Vestigial sideband is a type of Amplitude modulation in which one side band is completely passed along with trace or tail or vestige of the other side band. VSB is a compromise between SSB and DSBSC modulation. In SSB, we send only one side band, the bandwidth required to send SSB wave is w. SSB is not appropriate way of modulation when the message signal contains significant components at extremely low frequencies. To overcome this VSB is used. The word “vestige” means “a part” from which, the name is derived.

VSBSC Modulation is the process, where a part of the signal called as vestige is modulated along with one sideband. The frequency spectrum of VSBSC wave is shown in the figure 2.37. Along with the upper sideband, a part of the lower sideband is also being transmitted in this technique. Similarly, we can transmit the lower sideband along with a part of the upper sideband.

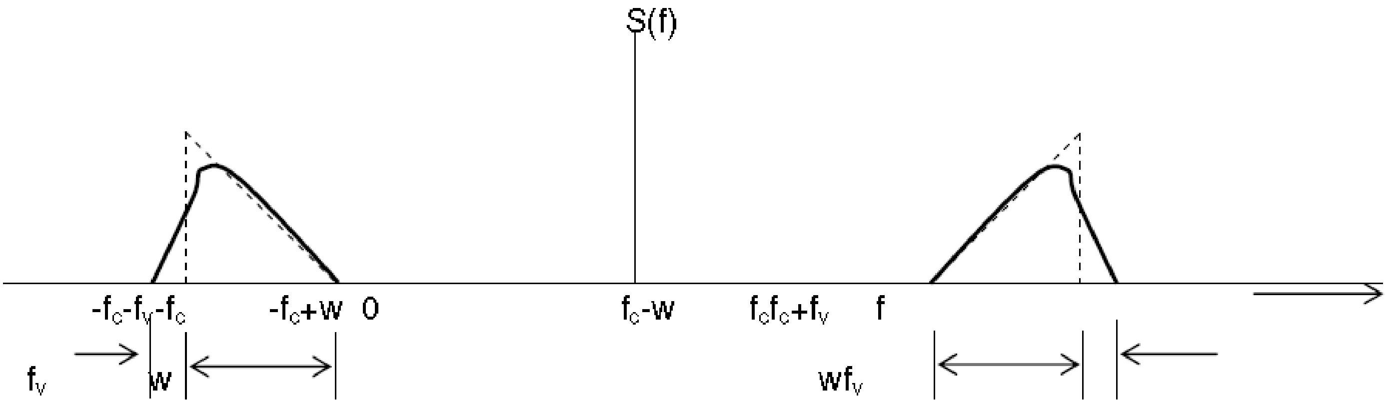


Figure 2.37.Spectrum of VSB containing vestige of USB

The vestige of the Upper sideband compensates for the amount removed from the Lower sideband. The bandwidth required to send VSB wave is

$B = w + f_v$

Where f_v is the width of the vestigial side band.

Therefore, VSB has the virtue of conserving bandwidth almost as efficiently as SSB modulation, while retaining the excellent low-frequency base band characteristics of DSBSC and it is standard for the transmission of TV signals.

Generation of VSB Modulated wave:

To generate a VSB modulated wave, we pass a DSBSC modulated wave through a sideband-shaping filter. The modulating signal m(t) is applied to a product modulator. The output of the local oscillator is also applied to the other input of the product modulator.

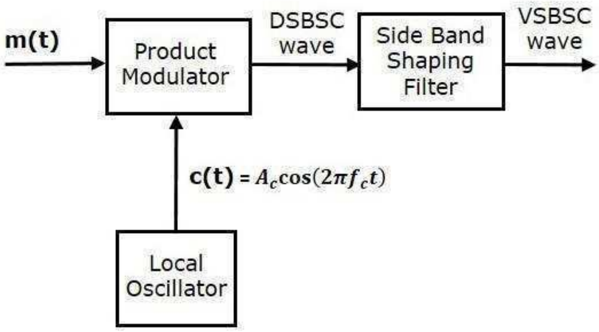


Figure 2.38.VSB modulator

Mathematical Analysis:

The output of the product modulator is then given by :

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

Apply Fourier transform on both sides

$P(f) = A_c/2[M(f-f_c)+M(f+f_c)]$

The above equation represents the equation of DSBSC frequency spectrum.

Let the transfer function of the sideband shaping filter be H(f). This filter has the input p(t) and the output is VSBSC modulated wave S(t).The Fourier transforms of p(t) and S(t) are P(f) and S(f) respectively.

$S(f)=P(f)H(f)$

Substitute P(f) in the above equation.

$S(f)=A_c/2[M(f-f_c)+M(f+f_c)]H(f)$

The above equation represents the equation of VSBSC frequency spectrum.

Demodulation of VSBSC

Demodulation of VSBSC wave is similar to the demodulation of SSBSC wave. Here, the same carrier signal which is used for generating VSBSC wave is used to detect the message signal. Hence, this process of detection is called as coherent or synchronous detection. The VSBSC demodulator is shown in the figure 2.39.In this process, the message signal can be extracted from VSBSC wave by multiplying it with a carrier, which is having the same frequency and the phase of the carrier used in VSBSC modulation. The resulting signal is then passed through a Low Pass Filter. The output of this filter is the desired message signal.

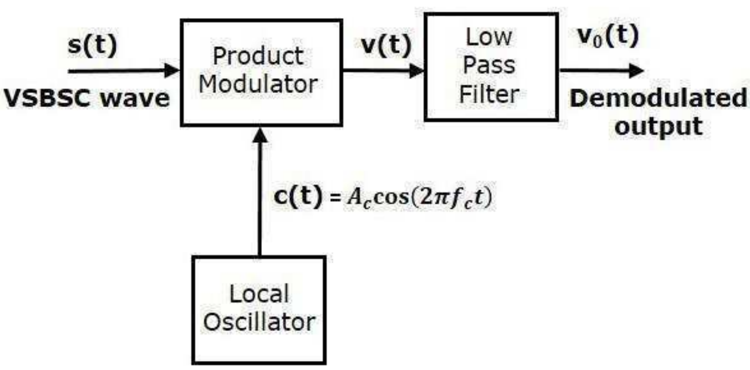


Figure 2.39.Demodulation of VSB-SC signal

Advantages of VSB

1. The main advantage of VSB modulation is the reduction in bandwidth. It is almost as efficient as the SSB.
2. Due to allowance of transmitting a part of lower sideband, the constraint on the filter has been relaxed. So practically, easy to design filters can be used.
3. It possesses good phase characteristics and makes the transmission of low frequency components possible.

Application of VSB

VSB modulation has become standard for the transmission of television signal. Because the video signal need a large transmission bandwidth if transmitted using DSB-FC or DSB-SC techniques.

2.16. Comparison of amplitude modulation techniques:

- In commercial AM radio broadcast systems standard AM is used in preference to DSBSC or SSB modulation.
- Suppressed carrier modulation systems require the minimum transmitter power and minimum transmission bandwidth. Suppressed carrier systems are well suited for point –to-point communications.
- SSB is the preferred method of modulation for long-distance transmission of voice signals over metallic circuits, because it permits longer spacing between the repeaters.
- VSB modulation requires a transmission bandwidth that is intermediate between that required for SSB or DSBSC.
- DSBSC, SSB, and VSB are examples of linear modulation. In Commercial TV broadcasting; the VSB occupies a width of about 1.25MHz, or about one-quarter of a full sideband.
- In standard AM systems the sidebands are transmitted in full, accompanied by the carrier. Accordingly, demodulation is accomplished by using an envelope detector or square law detector. On the other hand in a suppressed carrier system the receiver is more complex because additional circuitry must be provided for purpose of carrier recovery.
- Suppressed carrier systems require less power to transmit as compared to AM systems thus making them less expensive.
- SSB modulation requires minimum transmitter power and maximum transmission band with for conveying a signal from one point to other thus SSB modulation is preferred.
- VSB modulation requires a transmission band width that is intermediate of SSB or DSBSC.
- In SSB and VSB modulation schemes the quadrature component is only to interfere with the in phase component so that power can be eliminated in one of the sidebands.

Parameter of comparison	**AM**	**DSB-SC**	**SSB-SC**	**VSB**
Carrier suppression	NA	Fully	Fully	NA
Sideband suppression	NA	NA	One sideband completely	One sideband suppressed partially
Bandwidth	$2f_m$	$2f_m$	f_m	$f_m < BW > 2f_m$
Transmission efficiency	Minimum	Moderate	Maximum	moderate
Power requirement	More power is required for transmission	Power required is less than AM	Power required is less than Am and DSB-SC	Power required is less than DSB-SC but more than SSB-SC
Power saving (%)	0	66.67	83.33	Lies between DSB and SSB
Applications	Radio broadcasting	Radio broadcasting	Point to point mobile communication	TV

2.17. Demodulation of AM waves:

There are two methods to demodulate AM signals. They are:

1. Square-law detector
2. Envelope detector

Square-law detector:

Square-law detector is used to detect low level modulated signals (below 1v). A Square-law detector requires nonlinear element and a low pass filter for extracting the desired message signal. Semi-conductor diodes and transistors are the most common nonlinear devices used for implementing square law detectors as shown in figure 2.40. The filtering requirement is usually satisfied by using a single or double tuned filters.

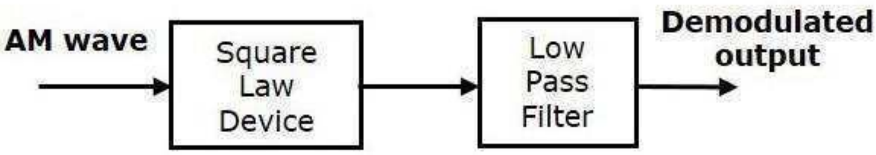


Figure 2.40.Square law detector

When a nonlinear element is suitably biased and operated in a restricted portion of its characteristic curve, we find that transfer characteristic of diode-load resistor combination can be represented closely by a square law :

$V_0 (t) = a_1 V_i (t) + a_2 V_i^{\,2} (t)$ (4)

Where a_1, a_2 are constants

Now, the input voltage V_i (t) is the sum of both carrier and message signals

$V_i (t) = A_c [1+k_a m (t)] \cos 2\pi f_c t$ (5)

Substitute equation (5) in equation (4) we get

$V_0 (t) = a_1 A_c [1+k_a m (t)] \cos 2\pi f_c t + 1/2\, a_2 A_c^2 [1+2 k_a m (t) + k_a^2 m^2 (t)] [\cos 4\pi f_c t]$ (6)

Now design the low pass filter with cutoff frequency f is equal to the required message signal bandwidth. We can remove the unwanted terms by passing this output voltage V_0 (t) through the low pass filter and finally we will get required message signal.

$V_0 (t) = A_c^2 a_2 m (t)$

The Fourier transform of output voltage V_O (t) is given by

$V_O (f) = Ac^2 a_2 M (f)$

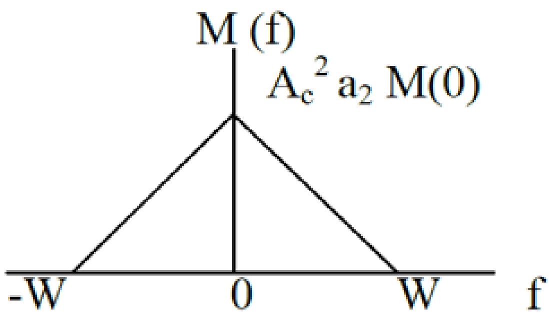


Figure 2.41.Spectrum of output signal

Envelope Detector:

Envelope detector is used to detect (demodulate) high level AM wave. Following figure 2.42 is the block diagram of the envelope detector. It is also based on the switching action or switching characteristics of a diode. It consists of a diode and a resistor-capacitor filter.

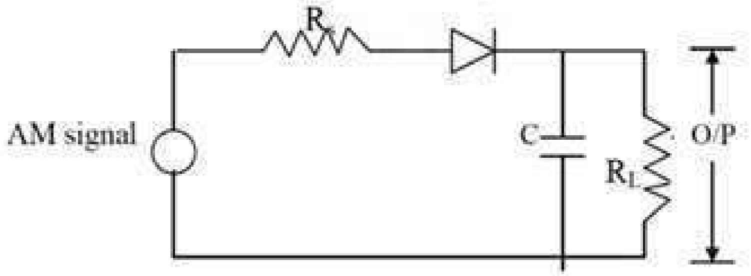


Figure 2.42.Envelope detector

The operation of the envelope detector is as follows.

1. On a positive half cycle of the AM signal, the diode is forward biased and the capacitor C charges up rapidly to the peak value of the input signal.
2. When the AM signal level falls below this value, the diode becomes reverse biased and the capacitor C discharges slowly through the load resistor R_L till the next positive cycle of AM signal.
3. When the input signal becomes greater than the voltage across the capacitor, the diode conducts again and the process is repeated.
4. The component values should be selected in such a way that the capacitor charges very quickly and discharges very slowly. As a result, we will get the capacitor voltage waveform same as that of the envelope of AM wave as shown in figure 2.43.

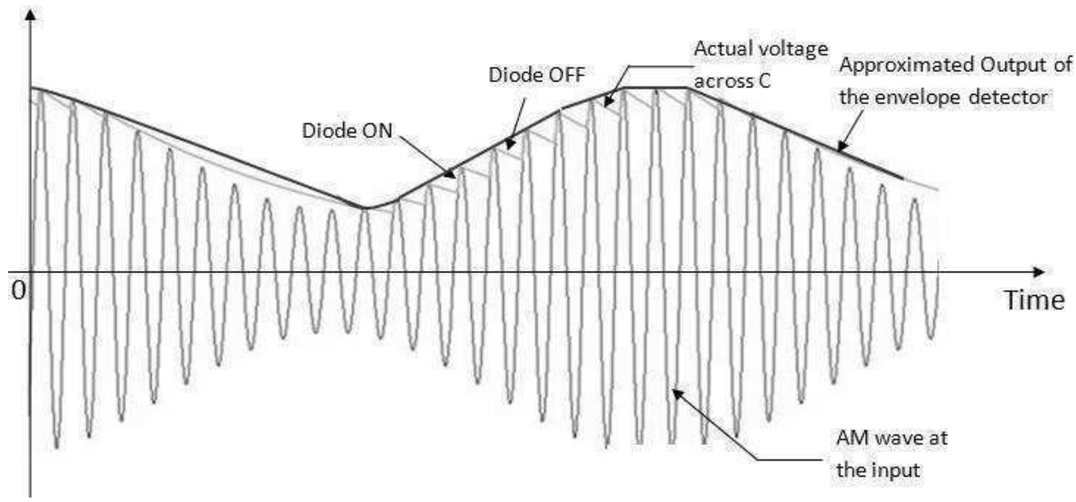


Figure 2.43.Input-output waveform for envelope detector

The charging time constant R_s C is very small when compared to the carrier period $1/f_c$, the capacitor C charges rapidly to the peak value of the signal.

$R_s C << 1/f_c$

Where R_s = internal resistance of the voltage source, C = capacitor, f_c = carrier frequency

The discharging time constant R_L C is very large when compared to the charging time constant i.e., the capacitor discharges slowly through the load resistor.

i.e., $1/fc << R_L C << 1/W$

Where R_L = load resistance value, W = message signal bandwidth

Distortions in the Envelope Demodulator Output

There are two types of distortions which can occur in the detector output such as:

1. Diagonal clipping
2. Negative peak clipping

Diagonal Clipping: This type of distortion occurs when the RC time constant of the load circuit is too long. Due to this, the RC circuit cannot follow the fast changes in the modulating envelope.

Negative peak clopping: This distortion occurs due to a fact that the modulation index on the output side of the detector is higher than that on its input side. Hence, at higher depth of modulation of the transmitted signal, the over-modulation may takes place at the output of the detector. The negative peak clipping will take place as a result of this over-modulation as shown in figure 2.44.

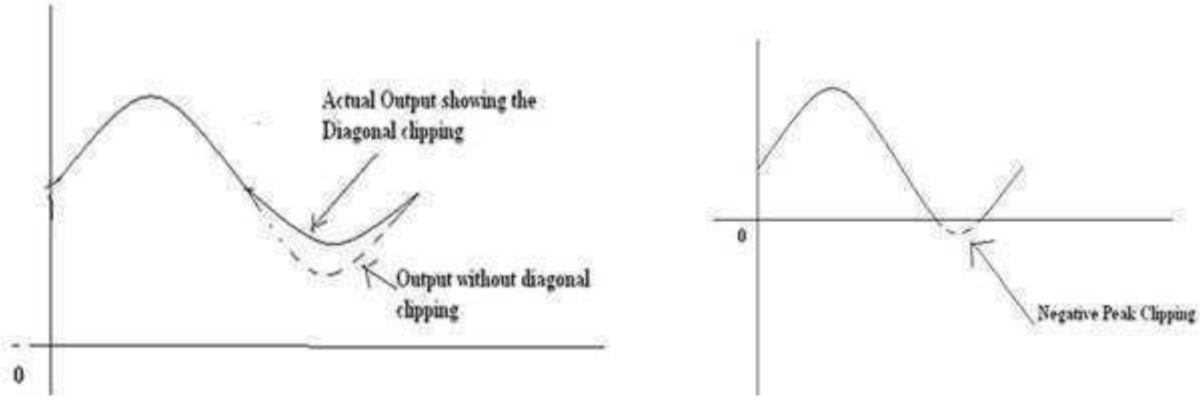


Figure 2.44.Ditortion in output of envelope detector

4.7. Low and high power AM transmitters:

Transmitters that transmit AM signals are known as AM transmitters. These transmitters are used in medium wave (MW) and short wave (SW) frequency bands for AM broadcast. The MW band has frequencies between 550 KHz and 1650 KHz, and the SW band has frequencies ranging from 3 MHz to 30 MHz The two types of AM transmitters that are used based on their transmitting powers are:

1. High Level
2. Low Level

The basic difference between the two transmitters is the power amplification of the carrier and modulating signals. High level transmitters use high level modulation, and low level transmitters use low level modulation. In broadcast transmitters, where the transmitting power may be of the order of kilowatts, high level modulation is employed. In low power transmitters, where only a few watts of transmitting power are required, low level modulation is used.

High-Level Transmitters:

In high-level transmission, the powers of the carrier and modulating signals are amplified before applying them to the modulator stage, as shown in figure 2.45.

1. **Carrier oscillator:** The carrier oscillator generates the carrier signal, which lies in the RF range. The frequency of the carrier is always very high. Because it is very difficult to generate high frequencies with good frequency stability, the carrier oscillator generates a sub multiple with the required carrier frequency. This sub multiple frequency is multiplied by the frequency multiplier stage to get the required carrier frequency.
2. **Buffer Amplifier:** The purpose of the buffer amplifier is to match the output impedance of the carrier oscillator with the input impedance of the frequency multiplier, the next stage of the carrier oscillator. It then isolates the carrier oscillator and frequency multiplier.
3. **Frequency Multiplier:** The sub-multiple frequency of the carrier signal, generated by the carrier oscillator, is now applied to the frequency multiplier through the buffer amplifier. This stage is also known as harmonic generator. The frequency multiplier generates higher harmonics of carrier oscillator frequency.
4. **Power Amplifier:** The power of the carrier signal is then amplified in the power amplifier stage. This is the basic requirement of a high-level transmitter. A class C power amplifier gives high power current pulses of the carrier signal at its output.
5. **Audio Chain:** The audio signal to be transmitted is obtained from the microphone. The audio driver amplifier amplifies the voltage of this signal. This amplification is necessary to drive the audio power amplifier. Next, a class A or a class B power amplifier amplifies the power of the audio signal.
6. **Modulated Class C Amplifier:** This is the output stage of the transmitter. The modulating audio signal and the carrier signal, after power amplification, are applied to this modulating stage. The modulation takes place at this stage. The class C amplifier also amplifies the power of the AM signal to the required transmitting power. This signal is finally passed to the antenna, which radiates the signal into space of transmission.

Low-Level Transmitters: In low-level modulation, the powers of the two input signals of the modulator stage are not amplified. The required transmitting power is obtained from the last stage of the transmitter, the class C power amplifier. The low-level AM transmitter shown in the figure 2.45 is similar to a high-level transmitter, except that the powers of the carrier and audio signals are not amplified. These two signals are directly applied to the modulated class C power amplifier. Modulation takes place at the stage, and the power of the modulated signal is amplified to the required transmitting power level. The transmitting antenna then transmits the signal.

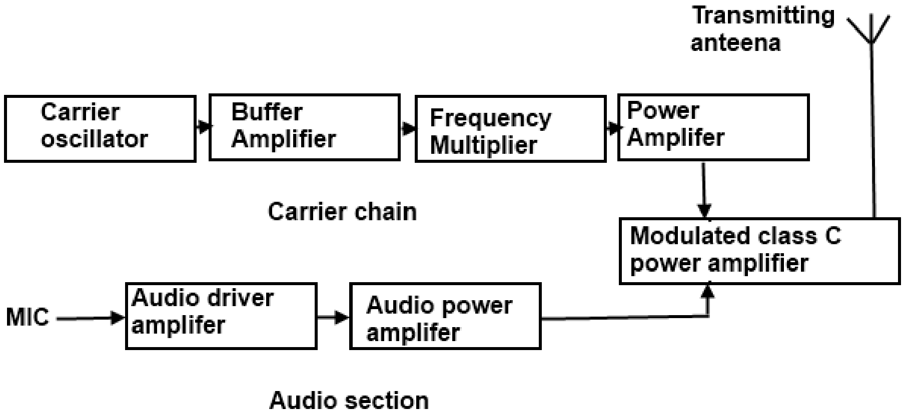


Figure 2.45.High level AM transmitter

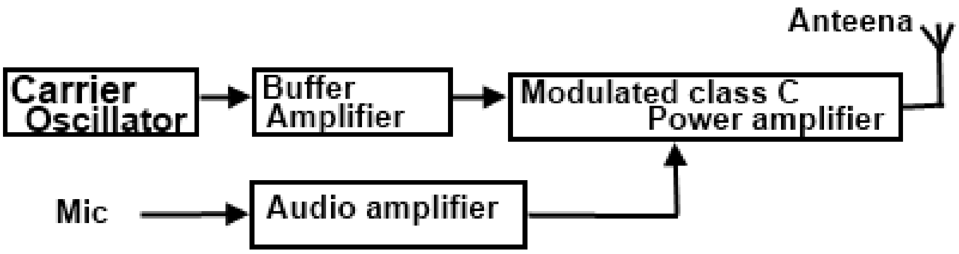


Figure 2.46.Low level AM transmitter

Coupling of Output Stage and Antenna

The output stage of the modulated class C power amplifier feeds the signal to the transmitting antenna. To transfer maximum power from the output stage to the antenna it is necessary that the impedance of the two sections match. For this, a matching network is required. The matching between the two should be perfect at all transmitting frequencies.

2.19. AM Receiver:

Radio receivers amplify and tune the radio signals. The receiver picks up the signals from the airwaves, and converts them to the original message signal. The radio signal that is transmitted into the air contains a carrier wave that is much higher in frequency than message siganl.

2.20. Tuned Radio Frequency Receiver:

A TRF receiver amplifies and tunes the raw radio signal as present in the air waves by means of an RF (radio frequency) amplifier. Some receivers will have as many 4 or 5 stages of RF amplification before the carrier signal is stripped away leaving only the audio portion of the signal. The process of removing the carrier signal is done by the detector circuit of a radio receiver. Afterwards the final process is amplifying the audio signal to a level strong enough to drive a speaker.

Typically a TRF receiver would consist of three main sections:

- **Tuned radio frequency stages:** The tuner circuit is an LC circuit, which is also called as resonant or tank circuit. It selects the frequency, desired by the AM receiver. This consisted of one or more amplifying and tuning stages. In a TRF receiver a series of loosely coupled tuned circuits are used to increase selectivity.
- **Signal detector:** The detector enabled the audio from the amplitude modulation signal to be extracted. It uses envelope detection.
- **Audio amplifier**: This is the power amplifier stage, which is used to amplify the detected audio signal. The processed signal is strengthened to be effective. This signal is passed on to the loudspeaker to get the original sound signal.

Drawbacks :

1. Instability
2. Poor selectivity at high frequencies
3. Bandwidth variation over the tuning range
4. Insufficient adjacent frequency rejection
5. In TRF receiver, amplification is not constant over the tuning range.

2.21. Superheterodyne AM Receiver:

In super heterodyne receiver the incoming RF signal is combined with local oscillator signal frequency through a mixer and converted into signal of lower fixed frequency known as intermediate frequency. It consists of RF section, frequency converter, IF amplifier, detector, audio amplifier.

RF section:

- RF section mainly consists of a tuneable filter and an amplifier which picks up the desired station by tuning the filter to the exact frequency band.
- The signal at the antenna has lower signal noise found anywhere in the receiver.
- Then RF amplifier provides gain to increase signal to noise ratio (SNR).

Frequency converter:

- It converts the carrier frequency f_c to a fixed IF frequency of 455 KHz.
- A constant frequency difference should be maintained between the local oscillator signal and incoming RF signal frequency. (Through capacitor tuning in which the capacitance are together and operated by a common knob.)
- For this purpose it uses local oscillator whose frequency f_{co} is exactly 455 KHz above the incoming carrier frequency f_c and $f_{co}=f_c+455$

IF amplifier:

- The intermediate frequency generated from the mixer/converter is amplified by IF amplifier. After the IF amplifier the signal is applied at the demodulator which extract the original modulated signal.
- The reason for translating all stations to a fixed carrier frequency of 455 KHz is to obtain adequate selectivity. The characteristics of the IF amplifier are not dependent on the incoming frequency to which the receiver is tuned. The selectivity and sensitivity of super-heterodyne receiver are quite uniform throughout its tuning range.
- The main function of the RF section is image frequency suppression. The mixer or converter output consists of components of difference between the incoming f_c and the local oscillator f_{co}.
- Audio amplifier: Once demodulated, the recovered audio is applied to an audio amplifier block to be amplified by a power amplifier to the required level for loudspeakers or headphones.

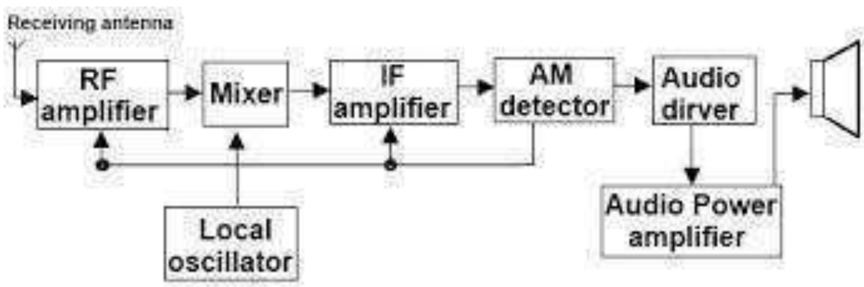


Figure 2.47.Superheterodyne AM receiver

Local oscillator frequency

At design level there are two choices for the local oscillator frequency:

$f_{LO} = f_{RF} + f_{IF}$ (high-side injection) or $f_{LO}= f_{RF} - f_{IF}$ (low-side injection)

Usually for medium wave AM receivers the frequency of the oscillator is higher than the desired RF frequency ($f_{LO} = f_{RF} + f_{IF}$).

Image frequency

When the receiver demodulates the incoming desired signal at f_{RF}, unfortunately it demodulates down to IF also an unwanted signal at $f_{RF}+2f_{IF}$.This frequency is called image frequency

To reduce the design complexity of the receivers the IF frequency is chosen in such a way that the signal at

$f_{image} = f_{RF}+2f_{IF}$ can be rejected by a simple tuneable RF band pass filter such as a tank circuit with a variable capacitor.

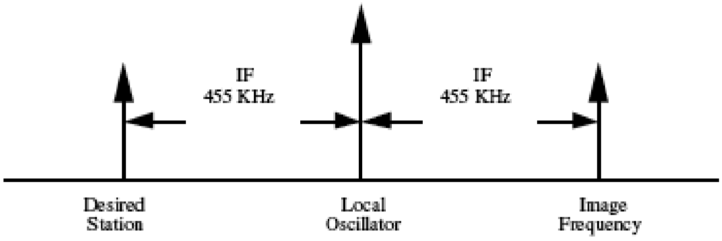


Figure 2.48.Concept of image frequency

2.22. Terminologies of Receiver:

1. Selectivity:

Selectivity is the measure of the ability of a radio receiver to select a particular frequency or particular band of frequencies and rejecting all other unwanted frequencies. The receiver selectivity performance determines the level of interference that may be experienced. It is the ability to reject unwanted signals. The signal bandwidth should be narrow for better selectivity.

The selectivity can be aimed at rejecting signals that may reach the receiver output in a variety of ways.

- **Adjacent channel selectivity:** Adjacent channel selectivity of the form of selectivity that rejects signals on nearby frequencies.
- **Image rejection selectivity:** When using a super heterodyne radio, it is possible for the image frequency to reach the final stages of the receiver. Rejecting these signals is important as they can cause significant levels of interference. The selectivity required to remove these signals is contained within the radio frequency stages of the radio.
- Image frequency rejection ratio is the ratio of gain at the signal frequency to the gain at the image frequency.Image frequency rejection ratio (α) is given by:

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

Where $\rho = f_{IF}/f_{RF} - f_{RF}/f_{IF}$; Q is the quality factor of the tuned circuit

2. Sensitivity:

The ability of the radio receiver to pick up the required level of radio signals will enable it to operate more effectively within its application.

- Sensitivity of a receiver is its ability to identify and amplify weak signals at the receiver output.
- It is often defined in terms of voltage that must be applied to the input terminals of the receiver to produce a standard output power which is measured at the output terminals.
- The higher value of receiver gain ensures smaller input signal necessary to produce the desired output power.
- Thus a receiver with good sensitivity will detect minimum RF signal at the input and still produce utilizable demodulated signal.
- Sensitivity is also known as receiver threshold.
- It is expressed in microvolt or decibels.
- Sensitivity of the receiver mostly depends on the gain of IF amplifier.
- It can be improved by reducing the noise level and bandwidth of the receiver.

3. Fidelity

- Fidelity of a receiver is its ability to reproduce the exact replica of the transmitted signals at the receiver output.
- For better fidelity, the amplifier must pass high bandwidth signals to amplify the frequencies of the outermost sidebands, while for better selectivity the signal should have narrow bandwidth. Thus a trade off is made between selectivity and fidelity.
- Low frequency response of IF amplifier determines fidelity at the lower modulating frequencies while high frequency response of the IF amplifier determines fidelity at the higher modulating frequencies.

