CHAPTER 2

AMPLITUDE MODULATION

1.0 PREREQUISTING ABOUT MODULATION:

In this chapter we discussed about Modulation is the process of varying one or more properties of a periodic waveform, called the carrier signal (high frequency signal), with a modulating signal that typically contains information to be transmitted.

- ✓ **Need for modulation:**
- Antenna Height
- Narrow Banding
- Poor radiation and penetration
- Diffraction angle
- Multiplexing.
- ✓ **Functions of the Carrier Wave:**

The main function of the carrier wave is to carry the audio or video signal from the transmitter to the receiver. The wave that is resulted due to superimposition of audio signal and carrier wave is called the modulated wave.

- ✓ **Types of modulation:**

The sinusoidal carrier wave can be given by the equation,

$v_c = V_c \sin(w_c t + \theta) = V_c \sin(2f_c t + \theta)$

V_c – Maximum Value

f_c – Frequency

θ – Phase Relation

Since the three variables are the amplitude, frequency, and phase angle, the modulation can be done by varying any one of them. Thus there are three modulation types namely:

- **Amplitude Modulation (AM)**
- **Frequency Modulation (FM)**
- **Phase Modulation (PM)**
- We have introduced linear modulation. In particular,
  - ✓ DSB-SC, Double sideband suppressed carrier
  - ✓ DSB-LC, Double sideband large carrier (AM)

- ✓ SSB, Single sideband
- ✓ VSB, Vestigial sideband

CONTENT:

- **AMPLITUDE MODULATION**
- **AM TRANSMITTER**
- **SSB - SC**
- **VSB - SC**
- **DSB - SC**
- **HILBERT TRANSFORM**
- **SUPER HETERODYNE RECEIVER**
- **COMPARISION OF VARIOUS AM TECHNIQUES**

1.1 AMPLITUDE MODULATION:

"**Modulation is the process of superimposing a low frequency signal on a high frequency carrier signal.**"

OR

"**The process of modulation can be defined as varying the RF carrier wave in accordance with the intelligence or information in a low frequency signal**."

OR

"**Modulation is defined as the precess by which some characteristics, usually amplitude, frequency or phase, of a carrier is varied in accordance with instantaneous value of some other voltage, called the modulating voltage.**"

- ✓ **Need For Modulation**

1. If two musical programs were played at the same time within distance, it would be difficult for anyone to listen to one source and not hear the second source. Since all musical sounds have approximately the same frequency range, form about 50 Hz to 10KHz. If a desired program is shifted up to a band of frequencies between 100KHz and 110KHz, and the second program shifted up to the band between 120KHz and 130KHz, Then both programs gave still 10KHz bandwidth and the listener can (by band selection) retrieve the program of his own choice. The receiver would down shift only the selected band of frequencies to a suitable range of 50Hz to 10KHz.
2. A second more technical reason to shift the message signal to a higher frequency is related to antenna size. It is to be noted that the antenna size is inversely proportional to the

frequency to be radiated. This is 75 meters at 1 MHz but at 15KHz it has increased to 5000 meters (or just over 16,000 feet) a vertical antenna of this size is impossible.

3. The third reason for modulating a high frequency carrier is that RF (radio frequency) energy will travel a great distance than the same amount of energy transmitted as sound power.

- ✓ **Types of Modulation**

The carrier signal is a sine wave at the carrier frequency. Below equation shows that the sine wave has three characteristics that can be altered.

$$\text{Instantaneous voltage (E)} = E_{c(max)} \text{Sin}(2\pi f_c t + \theta)$$

The term that may be varied are the carrier voltage Ec, the carrier frequency fc, and the carrier phase angle θ. So three forms of modulations are possible.

1. **AmplitudeModulation**

   Amplitude modulation is an increase or decrease of the carrier voltage (Ec), will all other factors remaining constant.

2. **FrequencyModulation**

   Frequency modulation is a change in the carrier frequency (fc) with all other factors remaining constant.

3. **PhaseModulation**

   Phase modulation is a change in the carrier phase angle (θ). The phase angle cannot change without also affecting a change in frequency. Therefore, phase modulation is in reality a second form of frequency modulation.

- ✓ **EXPLAINATION OF AM:**

The method of varying amplitude of a high frequency carrier wave in accordance with the information to be transmitted, keeping the frequency and phase of the carrier wave unchanged is called Amplitude Modulation. The information is considered as the modulating signal and it is superimposed on the carrier wave by applying both of them to the modulator. The detailed diagram showing the amplitude modulation process is given below.

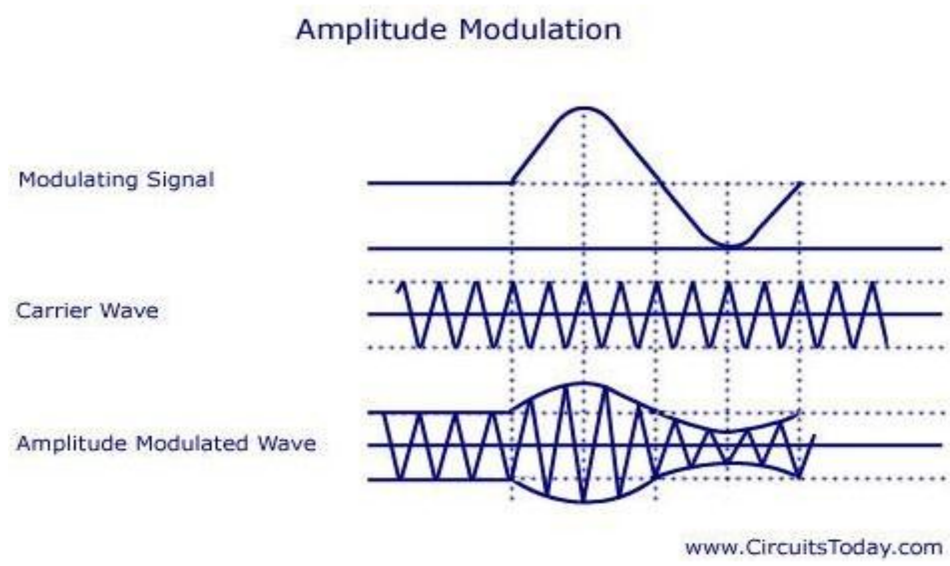

FIG 1.1 Amplitude Modulation

As shown above, the carrier wave has positive and negative half cycles. Both these cycles are varied according to the information to be sent. The carrier then consists of sine waves whose amplitudes follow the amplitude variations of the modulating wave. The carrier is kept in an envelope formed by the modulating wave. From the figure, you can also see that the amplitude variation of the high frequency carrier is at the signal frequency and the frequency of the carrier wave is the same as the frequency of the resulting wave.

- ✓ **Analysis of Amplitude Modulation Carrier Wave:**

Let $v_c = V_c \text{ Sin } w_c t$

$v_m = V_m \text{ Sin } w_m t$

v_c – Instantaneous value of the carrier

V_c – Peak value of the carrier

W_c – Angular velocity of the carrier

v_m – Instantaneous value of the modulating

signal V_m – Maximum value of the modulating

signal w_m – Angular velocity of the modulating

signal f_m – Modulating signal frequency

It must be noted that the phase angle remains constant in this process. Thus it can be ignored.

The amplitude of the carrier wave varies at f_m.The amplitude modulated wave is given by the

equation $A = V_c + v_m = V_c + V_m \text{ Sin } w_m t = V_c [1+ (V_m/V_c \text{ Sin } w_m t)]$

$= V_c (1 + m\text{Sin } w_m t)$

m – Modulation Index. The ratio of V_m/V_c.

Instantaneous value of amplitude modulated wave is given by the equation

$v = A \sin w_ct = Vc\,(1 + m \sin w_mt) \sin wct$

$= V_c \sin w_ct + mVc\,(\sin w_mt \sin w_ct)$

$v = V_c \sin wct + [mV_c/2 \cos (wc\text{-}wm)t – mVc/2 \cos (wc + wm)t]$

The above equation represents the sum of three sine waves. One with amplitude of Vc and a frequency of $w_c/2$, the second one with an amplitude of $mV_c/2$ and frequency of $(w_c – w_m)/2$ and the third one with an amplitude of $mV_c/2$ and a frequency of $(w_c + w_m)/2$.

In practice the angular velocity of the carrier is known to be greater than the angular velocity of the modulating signal ($w_c >> w_m$). Thus, the second and third cosine equations are more close to the carrier frequency. The equation is represented graphically as shown below.

- ✓ **Frequency Spectrum of AM Wave:**

Lower side frequency – $(w_c – w_m)/2$

Upper side frequency – $(w_c +w_m)/2$

The frequency components present in the AM wave are represented by vertical lines approximately located along the frequency axis. The height of each vertical line is drawn in proportion to its amplitude. Since the angular velocity of the carrier is greater than the angular velocity of the modulating signal, the amplitude of side band frequencies can never exceed half of the carrier amplitude.

Thus there will not be any change in the original frequency, but the side band frequencies $(w_c – w_m)/2$ and $(w_c +w_m)/2$ will be changed. The former is called the upper side band (USB) frequency and the later is known as lower side band (LSB) frequency.

Since the signal frequency $w_m/2$ is present in the side bands, it is clear that the carrier voltage component does not transmit any information.

Two side banded frequencies will be produced when a carrier is amplitude modulated by a single frequency. That is, an AM wave has a band width from $(w_c – w_m)/2$ to $(w_c +w_m)/2$, that is, $2w_m/2$ or twice the signal frequency is produced. When a modulating signal has more than one frequency, two side band frequencies are produced by every frequency. Similarly for two frequencies of the modulating signal 2 LSB‘s and 2 USB‘s frequencies will be produced.

The side bands of frequencies present above the carrier frequency will be same as the ones present below. The side band frequencies present above the carrier frequency is known to be the upper side band and all those below the carrier frequency belong to the lower side band. The USB frequencies represent the some of the individual modulating frequencies and the LSB frequencies represent the difference between the modulating frequency and the carrier frequency. The total bandwidth is represented in terms of the higher modulating frequency and is equal to twice this frequency.

- ✓ **Modulation Index (m):**

The ratio between the amplitude change of carrier wave to the amplitude of the normal carrier wave is called modulation index. It is represented by the letter ‗m'.

It can also be defined as the range in which the amplitude of the carrier wave is varied by the modulating signal. $m = V_m/V_c$.

Percentage modulation, $\%m = m*100 = V_m/V_c * 100$

The percentage modulation lies between 0 and 80%.

Another way of expressing the modulation index is in terms of the maximum and minimum values of the amplitude of the modulated carrier wave. This is shown in the figure below.

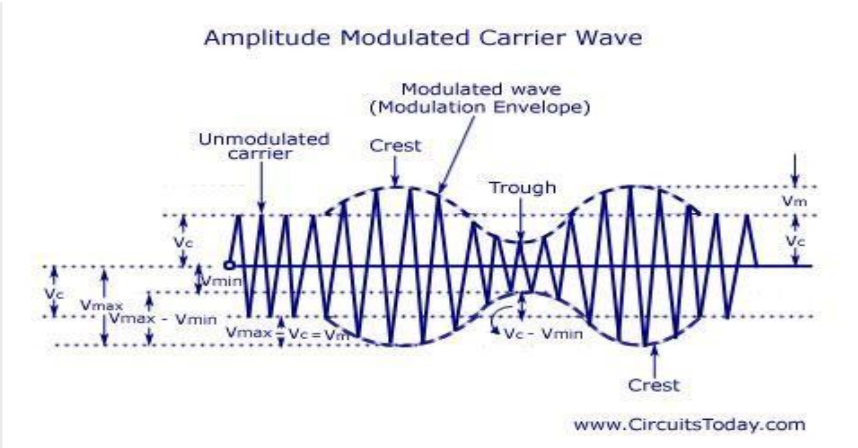

FIG 1.2 Amplitude Modulation Carrier Wave

$$2 V_{in} = V_{max} – V_{min}$$

$$V_{in} = (V_{max} – V_{min})/2$$

$$V_c = V_{max} – V_{in}$$

$$= V_{max} – (V_{max}-V_{min})/2$$

$$=(V_{max} + V_{min})/2$$

Substituting the values of Vm and Vc in the equation m = Vm/Vc , we get

$$M = V_{max} – V_{min}/V_{max} + V_{min}$$

As told earlier, the value of ‗m' lies between 0 and 0.8. The value of m determines the strength and the quality of the transmitted signal. In an AM wave, the signal is contained in the variations of the carrier amplitude. The audio signal transmitted will be weak if the carrier wave is only modulated to a very small degree. But if the value of m exceeds unity, the transmitter output produces erroneous distortion.

- ✓ **Power Relations in an AM wave:**

A modulated wave has more power than had by the carrier wave before modulating. The total power components in amplitude modulation can be written as:

$$P_{total} = P_{carrier} + P_{LSB} + P_{USB}$$

Considering additional resistance like antenna resistance R.

$$P_{carrier} = [(V_c/\surd 2)/R]^2 = V^2{}_C/2R$$

Each side band has a value of m/2 V_c and r.m.s value of $mV_c/2\surd 2$. Hence power in LSB and USB can be written as

$P_{LSB} = P_{USB} = (mV_c/2\surd 2)^2/R = m^2/4*V^2C/2R = m_2/4\ P_{carrier}$

$P_{total} = V^2{}_C/2R + [m^2/4*V^2C/2R] + [m^2/4*V^2C/2R] = V^2{}_C/2R\ (1 + m^2/2) = P_{carrier}\ (1 + m^2/2)$

In some applications, the carrier is simultaneously modulated by several sinusoidal modulating signals. In such a case, the total modulation index is given as

$$Mt = \surd(m1^2 + m2^2 + m3^2 + m4^2 + \ldots..$$

If Ic and It are the r.m.s values of unmodulated current and total modulated current and R is the resistance through which these current flow, then

$$P_{total}/P_{carrier} = (It.R/Ic.R)^2 = (It/Ic)^2$$

$$P_{total}/P_{carrier} = (1 + m^2/2)$$

$$It/Ic = 1 + m^2/2$$

- ✓ **Limitations of Amplitude Modulation:**

1. Low Efficiency- Since the useful power that lies in the small bands is quite small, so the efficiency of AM system is low.
2. Limited Operating Range – The range of operation is small due to low efficiency. Thus, transmission of signals is difficult.
3. Noise in Reception – As the radio receiver finds it difficult to distinguish between the amplitude variations that represent noise and those with the signals, heavy noise is prone to occur in its reception.

4. Poor Audio Quality – To obtain high fidelity reception, all audio frequencies till 15 KiloHertz must be reproduced and this necessitates the bandwidth of 10 KiloHertz to minimise the interference from the adjacent broadcasting stations. Therefore in AM broadcasting stations audio quality is known to be poor.

1.2 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:

- High Level
- Low Level

High level transmitters use high level modulation, and low level transmitters use low level modulation. The choice between the two modulation schemes depends on the transmitting power of the AM transmitter. 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 and Low-Level Transmitters Below figure's show the block diagram of high-level and low-level transmitters. The basic difference between the two transmitters is the power amplification of the carrier and modulating signals

Figure (a) shows the block diagram of high-level AM transmitter.

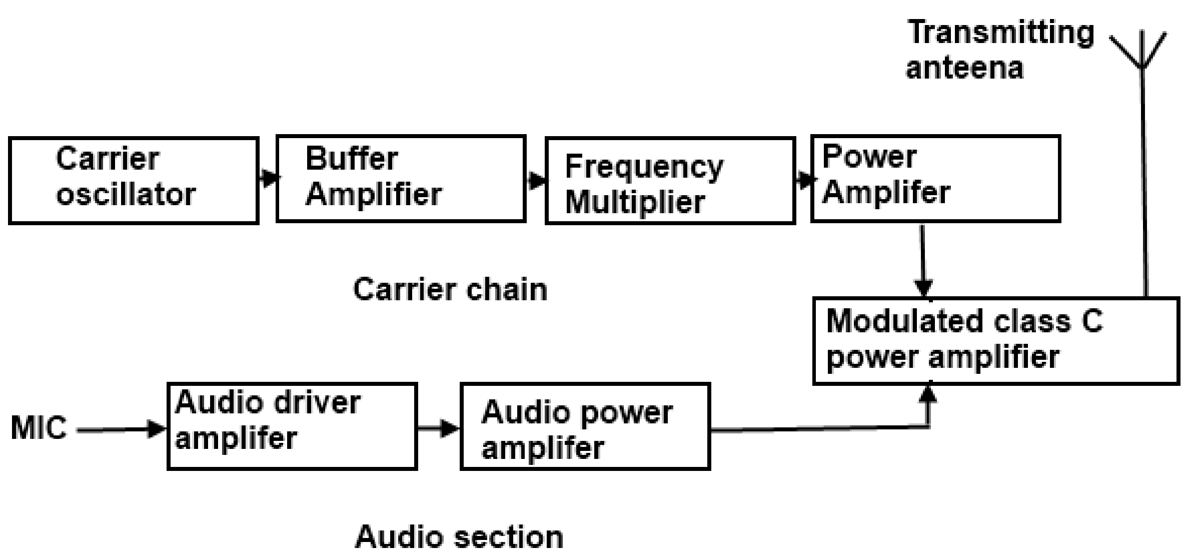

Figure (a) Block diagram of high level AM transmitter

Figure (a) is drawn for audio transmission. 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 (a). 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 various sections of the figure (a) are:

- Carrier oscillator
- Buffer amplifier
- Frequency multiplier
- Power amplifier
- Audio chain
- Modulated class C power amplifier

✓ **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. Further, a crystal oscillator can be used in this stage to generate a low frequency carrier with the best frequency stability. The frequency multiplier stage then increases the frequency of the carrier to its requirements.

✓ **Buffer Amplifier**

The purpose of the buffer amplifier is twofold. It first matches 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.

This is required so that the multiplier does not draw a large current from the carrier oscillator. If this occurs, the frequency of the carrier oscillator will not remain stable.

✓ **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. The frequency multiplier is a tuned circuit that can be tuned to the requisite carrier frequency that is to be transmitted.

- **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.

- **Audio Chain**

The audio signal to be transmitted is obtained from the microphone, as shown in figure (a). 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.

- **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 reacquired transmitting power. This signal is finally passed to the antenna., which radiates the signal into space of transmission.

Figure (b) shows the block diagram of a low-level AM transmitter.

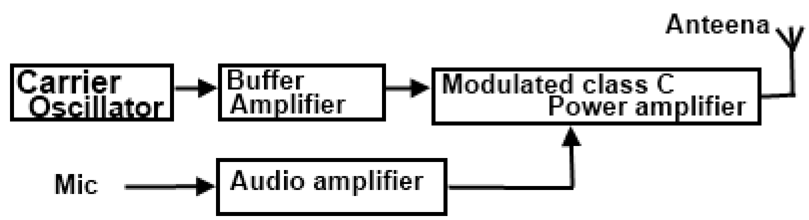

Figure (b) Block diagram of Low-level AM transmitter

The low-level AM transmitter shown in the figure (b) 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.

- **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. As the matching is required at different frequencies, inductors and capacitors offering different impedance at different frequencies are used in the matching networks.

The matching network must be constructed using these passive components. This is shown in figure ©

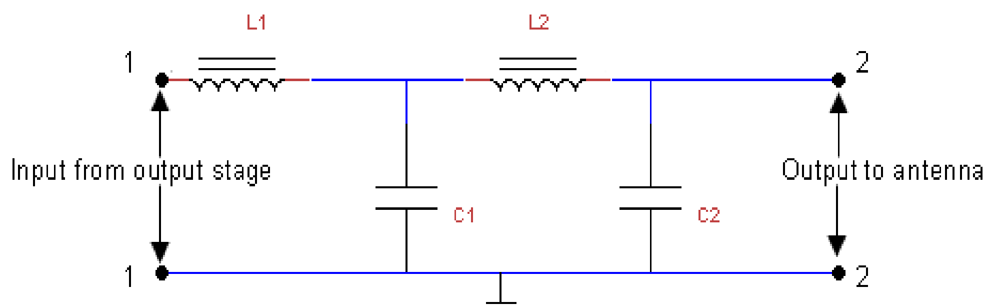

Figure (c) Double Pi Matching network

The matching network used for coupling the output stage of the transmitter and the antenna is called double π-network. This network is shown in figure (c). It consists of two inductors , L_1 and L_2 and two capacitors, C_1 and C_2. The values of these components are chosen such that the input impedance of the network between 1 and 1'. Shown in figure (c) is matched with the output impedance of the output stage of the transmitter. Further, the output impedance of the network is matched with the impedance of the antenna.

The double π matching network also filters unwanted frequency components appearing at the output of the last stage of the transmitter. The output of the modulated class C power amplifier may contain higher harmonics, such as second and third harmonics, that are highly undesirable. The frequency response of the matching network is set such that these unwanted higher harmonics are totally suppressed, and only the desired signal is coupled to the antenna.

✓ **Comparision of Am and Fm Signals**

Both AM and FM system are used in commercial and non-commercial applications. Such as radio broadcasting and television transmission. Each system has its own merits and demerits. In a Particular application, an AM system can be more suitable than an FM system. Thus the two are equally important from the application point of view.

✓ **Advantage of FM systems over AM Systems**

The advantages of FM over AM systems are:

- The amplitude of an FM wave remains constant. This provides the system designers an opportunity to remove the noise from the received signal. This is done in FM receivers by employing an amplitude limiter circuit so that the noise above the limiting amplitude is suppressed. Thus, the FM system is considered a noise immune system. This is not possible in AM systems because the baseband signal is carried by the amplitude variations it self and the envelope of the AM signal cannot be altered.

- Most of the power in an FM signal is carried by the side bands. For higher values of the modulation index, mc, the major portion of the total power is contained is side bands, and the carrier signal contains less power. In contrast, in an AM system, only one third of the total power is carried by the side bands and two thirds of the total power is lost in the form of carrier power.
- In FM systems, the power of the transmitted signal depends on the amplitude of the unmodulated carrier signal, and hence it is constant. In contrast, in AM systems, the power depends on the modulation index ma. The maximum allowable power in AM systems is 100 percent when ma is unity. Such restriction is not applicable int case of FM systems. This is because the total power in an FM system is independent of the modulation index, mf and frequency deviation fd. Therefore, the power usage is optimum in an FM system.
- In an AM system, the only method of reducing noise is to increase the transmitted power of the signal. This operation increases the cost of the AM system. In an FM system, you can increase the frequency deviation in the carrier signal to reduce the noise. if the frequency deviation is high, then the corresponding variation in amplitude of the baseband signal can be easily retrieved. if the frequency deviation is small, noise 'can overshadow this variation and the frequency deviation cannot be translated into its corresponding amplitude variation. Thus, by increasing frequency deviations in the FM signal, the noise effect can he reduced. There is no provision in AM system to reduce the noise effect by any method, other than increasing itss transmitted power.
- In an FM signal, the adjacent FM channels are separated by guard bands. In an FM system there is no signal transmission through the spectrum space or the guard band. Therefore, there is hardly any interference of adjacent FM channels. However, in an AM system, there is no guard band provided between the two adjacent channels. Therefore, there is always interference of AM radio stations unless the received signalis strong enough to suppress the signal of the adjacent channel.

✓ **The disadvantages of FM systems over AM systems**

- There are an infinite number of side bands in an FM signal and therefore the theoretical bandwidth of an FM system is infinite. The bandwidth of an FM system is limited by

Carson's rule, but is still much higher, especially in WBFM. In AM systems, the bandwidth is only twice the modulation frequency, which is much less than that of WBFN. This makes FM systems costlier than AM systems.

- The equipment of FM system is more complex than AM systems because of the complex circuitry of FM systems; this is another reason that FM systems are costlier AM systems.
- The receiving area of an FM system is smaller than an AM system consequently FM channels are restricted to metropolitan areas while AM radio stations can be received anywhere in the world. An FM system transmits signals through line of sight propagation, in which the distance between the transmitting and receiving antenna should not be much. in an AM system signals of short wave band stations are transmitted through atmospheric layers that reflect the radio waves over a wider area.

1.3 SSB TRANSMISSION:

There are two methods used for SSB Transmission.

1. Filter Method
2. Phase Shift Method
3. Block diagram of SSB

✓ **Filter Method:**

This is the filter method of SSB suppression for the transmission. Fig 1.3

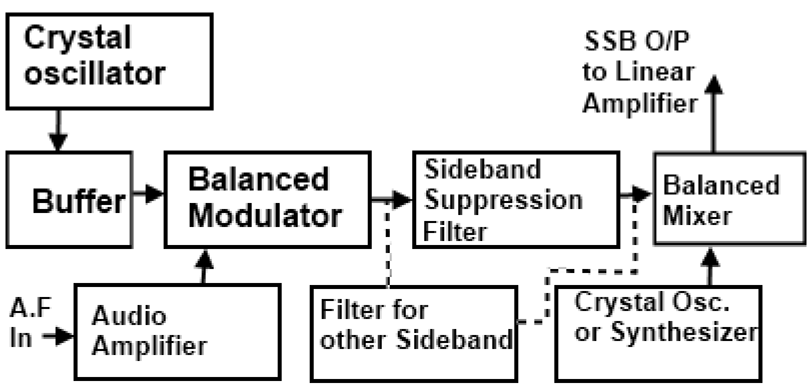

FIG 1.3 Filter Method

1. A crystal controlled master oscillator produces a stable carrier frequency fc (say 100 KHz)
2. This carrier frequency is then fed to the balanced modulator through a buffer amplifier which isolates these two satges.
3. The audio signal from the modulating amplifier modulates the carrier in the balanced modulator. Audio frequency range is 300 to 2800 Hz. The carrier is also suppressed in this stage but allows only to pass the both side bands. (USB & LSB).

4. A band pass filter (BPF) allows only a single band either USB or LSB to pass through it. It depends on our requirements.
5. This side band is then heterodyned in the balanced mixer stage with 12 MHz frequency produced by crystal oscillator or synthesizer depends upon the requirements of our transmission. So in mixer stage, the frequency of the crystal oscillator or synthersizer is added to SSB signal. The output frequency thus being raised to the value desired for transmission.
6. Then this band is amplified in driver and power amplifier stages and then fed to the aerial for the transmission.

✓ **Phase Shift Method:**

The phaseing method of SSB generation uses a phase shift technique that causes one of the side bands to be conceled out. A block diagram of a phasing type SSB generator is shown in fig 1.4.

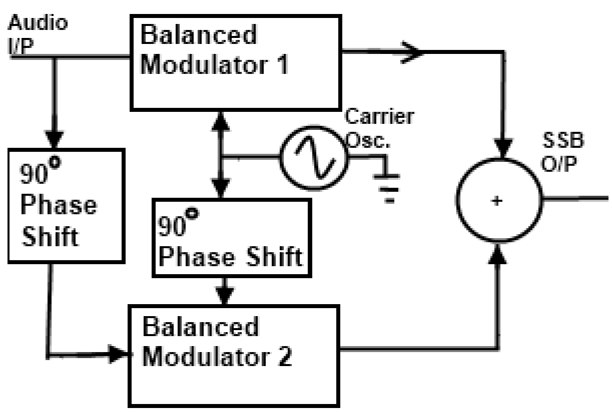

FIG 1.4 Phase Shift Method

It uses two balanced modulators instead of one. The balanced modulators effectively eliminate the carrier. The carrier oscillator is applied directly to the upper balanced modulator along with the audio modulating signal. Then both the carrier and modulating signal are shifted in phase by 90^o and applied to the second, lower, balanced modulator. The two balanced modulator output are then added together algebraically. The phase shifting action causes one side band to be canceled out when the two balanced modulator outputs are combined.

- **Block diagram of SSB:**

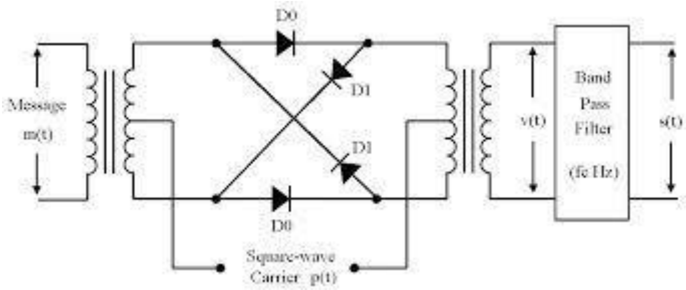

FIG 1.5 Balance Ring Modulator

- **Operation of Balance Ring Modulator:**

- Ring modulation is a signal-processing function in electronics, an implementation of amplitude modulation or frequency mixing, performed by multiplying two signals, where one is typically a sine-wave or another simple waveform. It is referred to as "ring" modulation because the analog circuit of diodes originally used to implement this technique took the shape of a ring. This circuit is similar to a bridge rectifier, except that instead of the diodes facing "left" or "right", they go "clockwise" or "anti-clockwise". A ring modulator is an effects unit working on this principle.
- The carrier, which is AC, at a given time, makes one pair of diodes conduct, and reverse-biases the other pair. The conducting pair carries the signal from the left transformer secondary to the primary of the transformer at the right. If the left carrier terminal is positive, the top and bottom diodes conduct. If that terminal is negative, then the "side" diodes conduct, but create a polarity inversion between the transformers. This action is much like that of a DPDT switch wired for reversing connections.
- Ring modulators frequency mix or heterodyne two waveforms, and output the sum and difference of the frequencies present in each waveform. This process of ring modulation produces a signal rich in partials. As well, neither the carrier nor the incoming signal is prominent in the outputs, and ideally, not at all.
- Two oscillators, whose frequencies were harmonically related and ring modulated against each other, produce sounds that still adhere to the harmonic partials of the notes, but contain a very different spectral make up. When the oscillators' frequencies are not harmonically related, ring modulation creates inharmonic, often producing bell-like or otherwise metallic sounds.

- ✓ If the same signal is sent to both inputs of a ring modulator, the resultant harmonic spectrum is the original frequency domain doubled (if $f_1 = f_2 = f$, then $f_2 - f_1 = 0$ and $f_2 + f_1 = 2f$). Regarded as multiplication, this operation amounts to squaring. However, some distortion occurs due to the forward voltage drop of the diodes.
- ✓ Some modern ring modulators are implemented using digital signal processing techniques by simply multiplying the time domain signals, producing a nearly-perfect signal output. Before digital music synthesizers became common, at least some analog synthesizers (such as the ARP 2600) used analog multipliers for this purpose; they were closely related to those used in electronic analog computers. (The "ring modulator" in the ARP 2600 could multiply control voltages; it could work at DC.)
- ✓ Multiplication in the time domain is the same as convolution in the frequency domain, so the output waveform contains the sum and difference of the input frequencies. Thus, in the basic case where two sine waves of frequencies f_1 and f_2 ($f_1 < f_2$) are multiplied, two new sine waves are created, with one at $f_1 + f_2$ and the other at $f_2 - f_1$. The two new waves are unlikely to be harmonically related and (in a well designed ring modulator) the original signals are not present. It is this that gives the ring modulator its unique tones.
- ✓ Inter modulation products can be generated by carefully selecting and changing the frequency of the two input waveforms. If the signals are processed digitally, the frequency-domain convolution becomes circular convolution. If the signals are wideband, this will cause aliasing distortion, so it is common to oversample the operation or low-pass filter the signals prior to ring modulation.
- ✓ One application is spectral inversion, typically of speech; a carrier frequency is chosen to be above the highest speech frequencies (which are low-pass filtered at, say, 3 kHz, for a carrier of perhaps 3.3 kHz), and the sum frequencies from the modulator are removed by more low-pass filtering. The remaining difference frequencies have an inverted spectrum - High frequencies become low, and vice versa.

- ➢ **Advantages:**
- ➢ It allows better management of the frequency spectrum. More transmission can fit into a given frequency range than would be possible with double side band DSB signals.
  All of the transmitted power is message power none is dissipate as carrier power.
- ➢ **Disadvantages:**

1. The cost of a single side band SSB receiver is higher than the double side band DSB counterpart be a ratio of about 3:1.

2. The average radio user wants only to flip a power switch and dial a station. Single side band SSB receivers require several precise frequency control settings to minimize distortion and may require continual readjustment during the use of the system.

1.4 VESTIGIAL SIDE BAND (VSB) MODULATION:

• The following are the drawbacks of SSB signal generation:

1. Generation of an SSB signal is difficult.
2. Selective filtering is to be done to get the original signal back.
3. Phase shifter should be exactly tuned to 90°.

• To overcome these drawbacks, VSB modulation is used. It can view as a compromise between SSB and DSB-SC. Figure1.5 shows all the three modulation schemes.

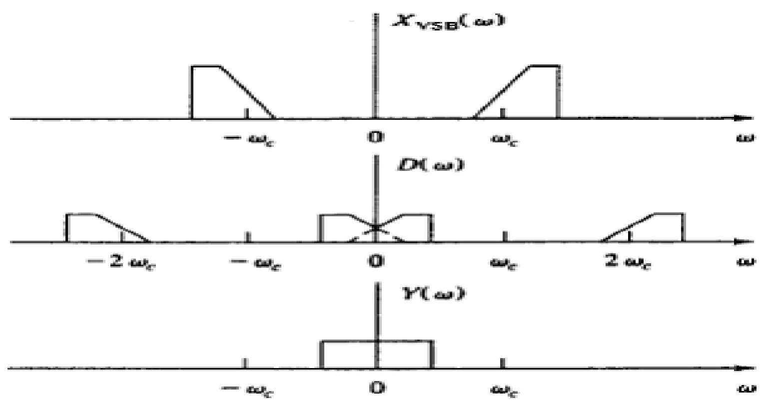

Fig. 3-13 Synchronous demodulation of VSB signals

- **Spectrum of VSB Signals:**

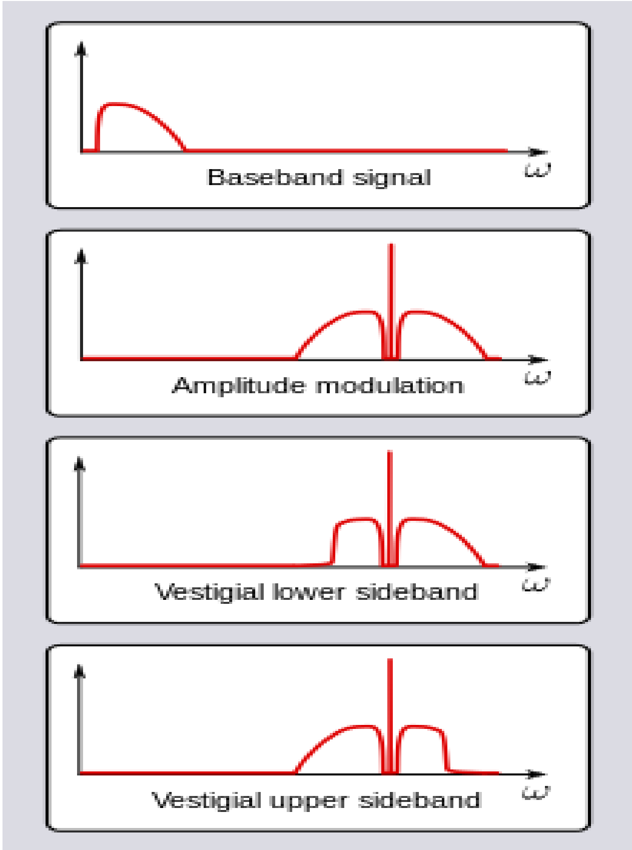

FIG 1.6 Spectrum of VSB Signals

- **Vestigial sideband (VSB) transmission is a compromise between DSB and SSB**

- In VSB modulation, one passband is passed almost completely whereas only a residual portion of the other sideband is retained in such a way that the demodulation process can still reproduce the original signal.
- VSB signals are easier to generate because some roll-off in filter edges is allowed. This results in system simplification. And their bandwidth is only slightly greater than that of SSB signals (-25 %).
- The filtering operation can be represented by a filter H(f) that passes some of the lower (or upper) sideband and most of the upper (or lower) sideband.

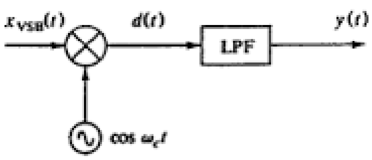

Fig. 3-11 VSB demodulator

- Heterodyning means the translating or shifting in frequency.
- By heterodyning the incoming signal at ωRF with the local oscillator frequency
  ωLO, the message is translated to an intermediate frequency
  ωIF, which is equal to either the sum or the difference of ωRF and ωIF.
- If ωIF = 0, the bandpass filter becomes a low-pass filter and the original baseband signal is presented at the output. This is called homodyning

➢ **Heterodyning: Image Response:**

Methods to solve the image response in heterodyne receiver

1. Careful selection of intermediate frequency ωIF for a given frequency band.
2. Attenuate the image signal before heterodyning.

✓ **Advantages:**

- VSB is a form of amplitude modulation intended to save bandwidth over regular AM. Portions of one of the redundant sidebands are removed to form a vestigial side band signal.
- The actual information is transmitted in the sidebands, rather than the carrier; both sidebands carry the same information. Because LSB and USB are essentially mirror images of each other, one can be discarded or used for a second channel or for diagnostic purposes.

✓ **Disadvantages:**

- VSB transmission is similar to (SSB) transmission, in which one of the sidebands is completely removed. In VSB transmission, however, the second sideband is not completely removed, but is filtered to remove all but the desired range of frequencies.

1.5 DSB-SC:

Double-sideband suppressed-carrier transmission (DSB-SC) is transmission in which frequencies produced by amplitude modulation (AM) are symmetrically spaced above and below the carrier frequency and the carrier level is reduced to the lowest practical level, ideally being completely suppressed.

✓ **Spectrum:**

DSB-SC is basically an amplitude modulation wave without the carrier, therefore reducing power waste, giving it a 50% efficiency. This is an increase compared to normal AM transmission (DSB), which has a maximum efficiency of 33.333%, since 2/3 of the power is in the carrier which carries no intelligence, and each sideband carries the same information. Single Side Band (SSB) Suppressed Carrier is 100% efficient.

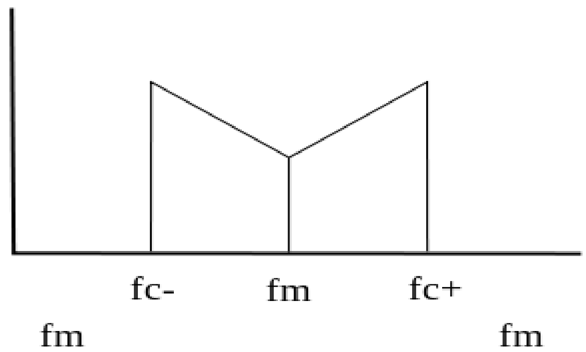

FIG 1.7 Spectrum plot of an DSB-SC signal

- **Generation:**

DSB-SC is generated by a mixer. This consists of a message signal multiplied by a carrier signal. The mathematical representation of this process is shown below, where the product-to-sum trigonometric identity is used.

$$\underbrace{V_m \cos(\omega_m t)}_{\text{Message}} \times \underbrace{V_c \cos(\omega_c t)}_{\text{Carrier}} = \underbrace{\frac{V_m V_c}{2}\left[\cos\left((\omega_m + \omega_c)\, t\right) + \cos\left((\omega_m - \omega_c)\, t\right)\right]}_{\text{Modulated Signal}}$$

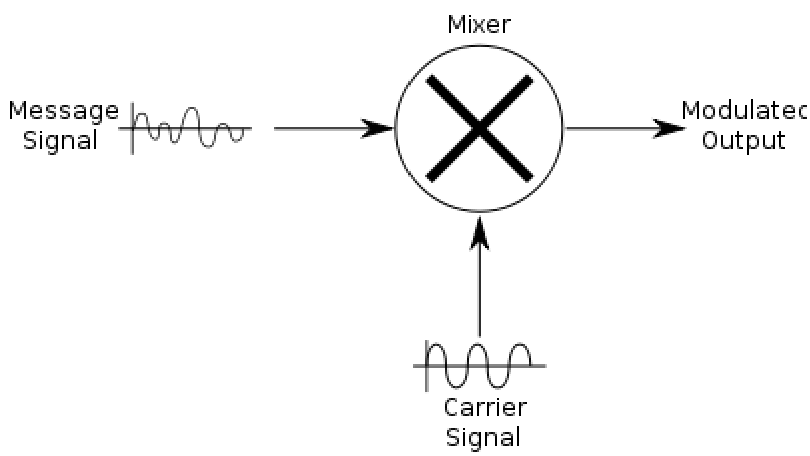

FIG 1.8 Generation of DSB-SC signal

- **Demodulation:**

Demodulation is done by multiplying the DSB-SC signal with the carrier signal just like the modulation process. This resultant signal is then passed through a low pass filter to produce a scaled version of original message signal. DSB-SC can be demodulated if modulation index is less than unity.

$$\overbrace{\frac{V_m V_c}{2}\left[\cos\left(\left(\omega_m+\omega_c\right)t\right)+\cos\left(\left(\omega_m-\omega_c\right)t\right)\right]}^{\text{Modulated Signal}} \times \overbrace{V_c' \cos\left(\omega_c t\right)}^{\text{Carrier}}$$
$$= \left(\frac{1}{2}V_c V_c'\right) \underbrace{V_m \cos(\omega_m t)}_{\text{original message}} + \frac{1}{2}V_c V_c' V_m \left[\cos((\omega_m+2\omega_c)t)+\cos((\omega_m-2\omega_c)t)\right]$$

The equation above shows that by multiplying the modulated signal by the carrier signal, the result is a scaled version of the original message signal plus a second term. Since $\omega_c \gg \omega_m$, this second term is much higher in frequency than the original message.

Once this signal passes through a low pass filter, the higher frequency component is removed, leaving just the original message.

✓ **Distortion and Attentuation:**

For demodulation, the demodulation oscillator's frequency and phase must be exactly the same as modulation oscillator's, otherwise, distortion and/or attenuation will occur.

To see this effect, take the following conditions:

- Message signal to be transmitted: $f(t)$
- Modulation (carrier) signal: $V_c \cos(\omega_c)$
- Demodulation signal (with small frequency and phase deviations from the modulation signal): $V_c' \cos\left[(\omega_c+\Delta\omega)t+\theta\right]$

The resultant signal can then be given by

$$f(t) \times V_c \cos(\omega_c) \times V_c' \cos\left[(\omega_c+\Delta\omega)t+\theta\right]$$
$$= \frac{1}{2}V_c V_c' f(t) \cos\left(\Delta\omega \cdot t+\theta\right) + \frac{1}{2}V_c V_c' f(t) \cos\left[(2\omega_c+\Delta\omega)t+\theta\right]$$
$$\xrightarrow{\text{After low pass filter}} \frac{1}{2}V_c V_c' f(t) \cos\left(\Delta\omega \cdot t+\theta\right)$$

The $\cos\left(\Delta\omega \cdot t+\theta\right)$ terms results in distortion and attenuation of the original message signal. In particular, $\Delta\omega \cdot t$ contributes to distortion while θ adds to the attenuation.

1.6 HILBERT TRANSFORM:

$\hat{x}(t)$ of a signal x(t) is defined by the equation

$$\hat{x}(t) = \frac{1}{\pi}\int_{-\infty}^{\infty} \frac{x(s)}{t-s}\, ds,$$

where the integral is the Cauchy principal value integral. The reconstruction formula

$$x(t) = -\frac{1}{\pi}\int_{-\infty}^{\infty}\frac{\hat{x}(s)}{t-s}\,ds,$$

defines the Hilbert inverse transform.

- **Hilbert transformer:**

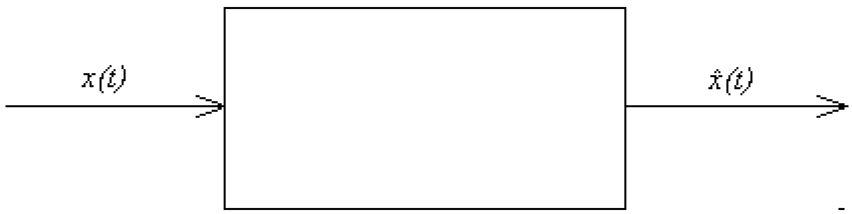

FIG 1.9 Block diagram of Hilbert Transform Pair

The pair x(t), $\hat{x}(t)$ is called a Hilbert transform pair is an LTI system whose transfer function is H(v) = - j · sgn v,because $\hat{x}(t) = (1/\pi t) * x(t)$ which, by taking the Fourier transform implies

$$\hat{X}(v) = -j\,(\text{sgn } v)\,X(v).$$

A Hilbert transformer produces a -90 degree phase shift for the positive frequency components of the input x(t), the amplitude doesn't change.

- **Properties of the Hilbert transform:**

A signal x(t) and its Hilbert transform $\hat{x}(t)$ have

1. the same amplitude spectrum
2. the same autocorrelation function
3. x(t) and $\hat{x}(t)$ are orthogonal
4. The Hilbert transform of $\hat{x}(t)$ is -x(t)

- **Pre envelope:**

The pre envelope of a real signal x(t) is the complex function

$$x_+(t) = x(t) + j\,\hat{x}(t).$$

The pre envelope is useful in treating band pass signals and systems. This is due to the result

$$X_+(v) = \begin{cases} 2X(v), & v > 0 \\ X(0), & v = 0 \\ 0, & v < 0 \end{cases}$$

- **Complex envelope:**

The complex envelope of a band pass signal x(t) is

$$\tilde{x}(t) = x_+(t)\ □^{-□\,2□□□□}.$$

1.7 SUPERHETERODYNE RECEIVER:

A superheterodyne receiver(often shortened to superhet) uses frequency mixing to convert a received signal to a fixed intermediate frequency (IF) which can be more conveniently processed than the original radio carrier frequency.

- ✓ **Basic Superheterodyne Block Diagram and Functionality:**

The basic block diagram of a basic superhet receiver is shown below. This details the most basic form of the receiver and serves to illustrate the basic blocks and their function.

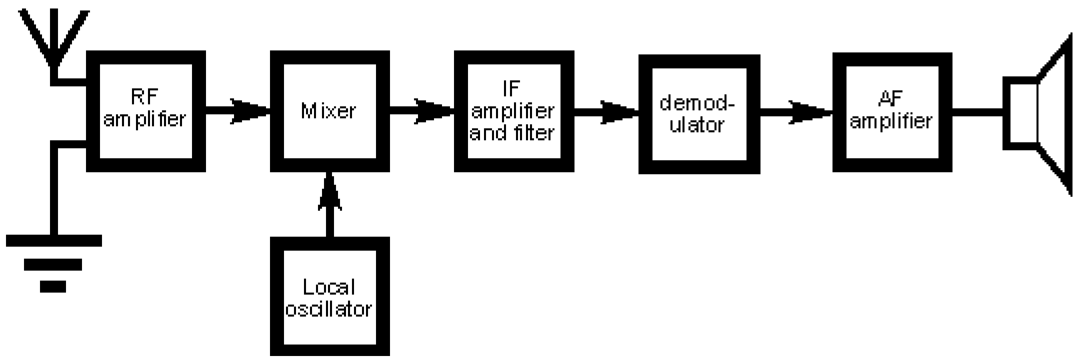

FIG 1.10 Block Diagram of a Basic Superheterodyne Radio Receiver

The way in which the receiver works can be seen by following the signal as is passes through the receiver.

- Front end amplifier and tuning block: Signals enter the front end circuitry from the antenna. This circuit block performs two main functions:
  - **Tuning:** Broadband tuning is applied to the RF stage. The purpose of this is to reject the signals on the image frequency and accept those on the wanted frequency. It must also be able to track the local oscillator so that as the receiver is tuned, so the RF tuning remains on the required frequency. Typically the selectivity provided at this stage is not high. Its main purpose is to reject signals on the image frequency which is at a frequency equal to twice that of the IF away from the wanted frequency. As the tuning within this block provides all the rejection for the image response, it must be at a sufficiently sharp to reduce the image to an acceptable level. However the RF tuning may also help in preventing strong off-channel signals from entering the receiver and overloading elements of the receiver, in particular the mixer or possibly even the RF amplifier.
  - **Amplification:** In terms of amplification, the level is carefully chosen so that it does not overload the mixer when strong signals are present, but enables the signals

to be amplified sufficiently to ensure a good signal to noise ratio is achieved. The amplifier must also be a low noise design. Any noise introduced in this block will be amplified later in the receiver.

- **Mixer / frequency translator block:** The tuned and amplified signal then enters one port of the mixer. The local oscillator signal enters the other port. The performance of the mixer is crucial to many elements of the overall receiver performance. It should eb as linear as possible. If not, then spurious signals will be generated and these may appear as 'phantom' received signals.
- **Local oscillator:** The local oscillator may consist of a variable frequency oscillator that can be tuned by altering the setting on a variable capacitor. Alternatively it may be a frequency synthesizer that will enable greater levels of stability and setting accuracy.
- **Intermediate frequency amplifier, IF block :** Once the signals leave the mixer they enter the IF stages. These stages contain most of the amplification in the receiver as well as the filtering that enables signals on one frequency to be separated from those on the next. Filters may consist simply of LC tuned transformers providing inter-stage coupling, or they may be much higher performance ceramic or even crystal filters, dependent upon what is required.
- **Detector / demodulator stage:** Once the signals have passed through the IF stages of the superheterodyne receiver, they need to be demodulated. Different demodulators are required for different types of transmission, and as a result some receivers may have a variety of demodulators that can be switched in to accommodate the different types of transmission that are to be encountered. Different demodulators used may include:
    - **AM diode detector:** This is the most basic form of detector and this circuit block would simple consist of a diode and possibly a small capacitor to remove any remaining RF. The detector is cheap and its performance is adequate, requiring a sufficient voltage to overcome the diode forward drop. It is also not particularly linear, and finally it is subject to the effects of selective fading that can be apparent, especially on the HF bands.
    - **Synchronous AM detector:** This form of AM detector block is used in where improved performance is needed. It mixes the incoming AM signal with another on the same frequency as the carrier. This second signal can be developed by passing the whole signal through a squaring amplifier. The advantages of the synchronous

AM detector are that it provides a far more linear demodulation performance and it is far less subject to the problems of selective fading.

- **SSB product detector:** The SSB product detector block consists of a mixer and a local oscillator, often termed a beat frequency oscillator, BFO or carrier insertion oscillator, CIO. This form of detector is used for Morse code transmissions where the BFO is used to create an audible tone in line with the on-off keying of the transmitted carrier. Without this the carrier without modulation is difficult to detect. For SSB, the CIO re-inserts the carrier to make the modulation comprehensible.
- **Basic FM detector:** As an FM signal carries no amplitude variations a demodulator block that senses frequency variations is required. It should also be insensitive to amplitude variations as these could add extra noise. Simple FM detectors such as the Foster Seeley or ratio detectors can be made from discrete components although they do require the use of transformers.
- **PLL FM detector:** A phase locked loop can be used to make a very good FM demodulator. The incoming FM signal can be fed into the reference input, and the VCO drive voltage used to provide the detected audio output.
- Quadrature FM detector: This form of FM detector block is widely used within ICs. IT is simple to implement and provides a good linear output.

- **Audio amplifier:** The output from the demodulator is the recovered audio. This is passed into the audio stages where they are amplified and presented to the headphones or loudspeaker.

1.8 COMPARISION OF VARIOUS AM:

PARAMETER	VSB - SC	SSB - SC	DSB-SC
Definition	A vestigial sideband (in radio communication) is a sideband that has been only partly cut off or suppressed.	Single-sideband modulation (SSB) is a refinement of amplitude modulation that more efficiently uses electrical power and bandwidth.	In radio communications, asidebandis a band of frequencies hig her than or lower thanthe carrier frequency, containing power as a result of the modulation process.
Application	Tv broadcastings & Radio broadcastings	Tv broadcastings & ShortwaveRadio broadcastings	Tv broadcastings & Radio broadcastings Garage door opens

			keyless remotes
Uses	Transmits TV signals	Short wave radio communications	Two way radio communications.

1.9 APPLICATION & ITS USES:

- Radio broadcastings
- Tv broadcastings
- Garage door opens keyless remotes
- Transmits TV signals
- Short wave radio communications
- Two way radio communication.

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GLOSSARY TERMS:

1. **Amplitude modulation:** The modulation of a wave by varying its amplitude, used especially as a means of broadcasting an audio signal by combining it with a radio carrier wave.
2. **The modulation index:** (modulation depth) of a modulation scheme describes by how much the modulated variable of the carrier signal varies around its unmodulated level.
3. **NarrowbandFM:** If the modulation index of *FM* is kept under 1, then the *FM* produced is regarded as narrow band *FM*.
4. **Frequency modulation (FM):** the encoding of information in a carrier wave by varying the instantaneous frequency of the wave.
5. **Amplication:** The level is carefully chosen so that it does not overload the mixer when strong signals are present, but enables the signals to be amplified sufficiently to ensure a good signal to noise ratio is achieved.
6. **Modulation:** The process by which some of the characteristics of carrier wave is varied in accordance with the message signal.

TUTORIAL PROBLEMS:

1. A 400 watts carrier is modulated to a depth of 75% calculate the total power in a double side band full carrier AM wave.

   Solution:

   Carrier power Pc = 400 watts, m= 0.75

   Total power in a DSB-FC AM Wave = pt = $P_c(1+\frac{m^2}{2})$

   $= 400(1+\frac{(0.75)^2}{2})$

   = 512.5 watts.

2. For the maximum envelope voltage Vmax = 20V and a minimum positive envelope voltage of Vmin = 6V Determine Modulation Index.

   Solution:
   Vmax = 20V ; Vmin = 6V

(a) Modulation index, m = $\frac{V_{max}-V_{min}}{V_{max}+V_{min}}$

= 14/26

= 0.538.

(b) Carrier Wave Vc:

Vmax = Vc+ Vm

20 = Vc+ Vm

Vmin = Vc - Vm

6 = Vc - Vm

Vc = 13V.

WORKED OUT PROBLEMS:

1. Calculate the % power saving when the carrier and one of the sidebands are suppressed in an am wave modulated to depth of 60%.

(a) Total transmitted power $P_t = P_c(1+\frac{m^2}{2})$

(b) $P_{SSB} = P_c(\frac{m^2}{4})$

(c) % power saving = $\frac{P_t-P_{SSB}}{P_t} \times 100$ Ans : 92.37%.

2. For an AM DSBFC envelope with Vmax = 40V and Vmin = 10V , determine the

(a) Unmodulated carrier wave ; Vmax = Vc +Vm ; Vmin = Vc –Vm Ans : Vc = 25V.

(b) % Modulation index = $\frac{(V_{max}-V_{min})}{(V_{max}+V_{min})}$ *100.