CHAPTER 7

Electronics Engineering

Communication Systems

Communication is a vital component in a progressive world. Communication systems, modulation and radio systems are discussed in this chapter. It closes with a treatise on Cathode Ray Oscilloscopes.

7.1. What is communication?

Communication is the process of transferring information meaningfully from one point to another. In general, electronic communication refers to the sending, receiving and processing of information by electronic means. Meaningful information may be in the form of voice, text, picture or a combination of these.

7.2. Explain briefly the important stages in a modern communication system.

A modern communication system involves the following stages:

Stage 1: Sorting, processing and storing of information prior to communication.

Stage 2: Actual transmission with further processing and filtering of noise or unwanted information

Stage 3: Reception of information, which includes processing steps to obtain an estimate or interpretation of the message or information.

7.3. List the various forms of communications.

The various forms of communication include

1. Radio telephony and telegraphy
2. Radio broadcasting
3. Point to point and mobile communication
4. Computer communication
5. Radar
6. Radio telemetry and radio aids to navigation.

7.4. What is radio communication? Give examples.

Radio communication is the process of sending information in the form of electrical signal from one place and receiving it in another place without using any connecting wires between the two places. It is also called *wireless communication*. Examples are Radio broadcasting and Television broadcasting.

7.5. What is a transducer? What is its role in a communication system?

A transducer is a device that converts any physical parameter such as temperature, pressure, flow-rate etc into an electrical signal like voltage or current or vice-versa.

In an electronic communication system, the input signal must be an electrical signal. If the information to be transmitted is a physical parameter, then an input transducer is required to convert the physical parameter into an electrical signal. At the receiving end, the electrical signal is converted into the original physical parameter by another transducer called the output transducer. These are illustrated in Fig. 7.1.

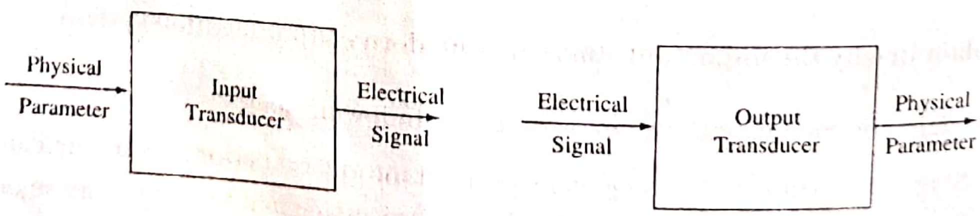

Fig. 7.1 Signal conversion transducers

7.6. Draw the block diagram of a communication system and explain the function of each stage.

A communication system is an integration of various equipment needed for the process of communication. Fig. 7.2 shows the block diagram of a general communication system. The function of each block is explained below.

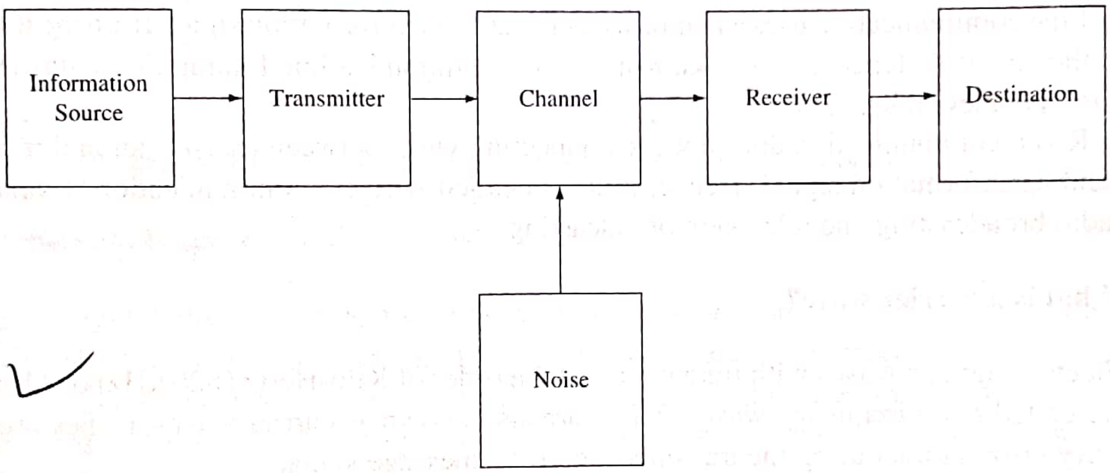

Fig. 7.2 Block diagram of a communication system.

Information source: The main aim of a communication system is to convey a message called information. This message originates from an information source.
Transmitter: It processes the input message signal to make it suitable for sending it over the channel. This operation termed as modulation is a process that changes or modulates the characteristics of a high frequency signal called the carrier in accordance with the message signal.
Channel: It is the physical medium or path that connects the transmitter and receiver. This may be a pair of wires such as telephone wires or free space. The term *channel* is often used to refer to the frequency range allocated to a particular service or transmission such as a television channel.
Noise: Noise is an unwanted energy that gets added to the message signal during transmission over the channel. It is random in nature and has its greatest effect when the message signal is weakest.
Receiver: The receiver processes the signal and makes an estimate of the actual message that is transmitted. It performs a process called demodulation, which is the reverse of modulation and extracts the information superimposed on the carrier wave. The receiver, in addition to demodulation also performs amplification and filtering.

from the channel parameters using the following expression.

$$C = [B \log_2(1 + S/N)] \tag{7.1}$$

where,

B = frequency bandwidth of the channel
S/N = Signal to noise ratio of the channel.

Typically, $C = 30$ k bits/sec for a telephone link with $B = 3$ kHz and $S/N = 10^3$. However, in practice a telephone line uses $C = 9.6$ k bits/sec (kbps).

7.12. Define modulation and list its types.

In a communication system, the transmitter modifies the message signal into a form suitable for transmission over the channel, by using a process known as modulation.
Modulation is defined as the process by which some characteristic or property of a high frequency sine wave called the carrier is varied in accordance with the instantaneous amplitude of the message signal called the modulating signal.

The characteristic of the carrier wave that is modified may be amplitude, frequency or phase angle. Accordingly, we have three types of modulation, namely,

1. Amplitude modulation
2. Frequency modulation
3. Phase modulation.

7.13. Discuss the classification of communication systems based on the modulation scheme and input signal.

Based on the modulation scheme and input signal, communication systems may be classified as follows:

1. *Analog communication system:* This transmits analog input signals using analog modulation schemes.
2. *Digital communication system:* This transmits digital information using digital modulation schemes.
3. *Hybrid communication system:* This converts analog input signal into digital format and transmits it using digital modulation techniques.

7.14. Briefly explain the process of modulation.

A sine wave carrier which is a high frequency signal, may be represented by the equation.

$$v_c = V_c \sin(\omega_c t + \phi) \tag{7.2}$$

where

v_c = the instantaneous value of the sine wave called the carrier
V_c = the peak or maximum amplitude of the carrier
ω_c = the angular frequency of the carrier
ϕ_c = the phase angle of the carrier with respect to some reference

In modulation, one of the last three parameters of the carrier namely V_c, ω_c or ϕ is varied according to the instantaneous amplitude of the message or modulating signal resulting in amplitude, frequency or phase modulation respectively.

7.15. Explain the need for modulation in communication systems.

Modulation is needed for the following reasons:

1. Most of the message signals are low audio frequency signals lying within the range of 20Hz to 20kHz. Direct transmission without modulation, of such low frequency signals over long distances would require enormous power. With modulation the frequency of the signal to be transmitted is increased and consequently signals can be transmitted over long distances with considerably lower in power.
2. Transmission of signals in the form of electromagnetic waves cannot be done without the use of antennas. For efficient transmission and reception the heights of the transmitting and receiving antennas should be comparable to quarter-wavelength of the frequency of the signal used. This is 75 meters at 1 MHz, but increases to 5000 meters or 16000 feet at 15 kHz A vertical antenna of this height is unimaginable. Since modulation uses a high frequency carrier for transmission the height of antennas is considerably reduced to practical values.
3. When a number of stations transmit sound or audio signals directly, the signals get mixed up as all of them fall within the range from 20Hz to 20kHz. Consequently, proper reception of the signals at the receiver would be very difficult. With modulation, each station is allotted a different carrier frequency and the signal from a station can be properly received by tuning the receiver to that particular carrier frequency.

7.16. Define and explain amplitude modulation.

Amplitude modulation or AM is defined as a process in which the amplitude of the high frequency sinusoidal carrier wave is made to vary in accordance with the instantaneous amplitude of the low frequency message signal called modulating signal.

The frequency and phase angle of the carrier are unaffected in amplitude modulation.

Let v_c and v_m represent the instantaneous values of the carrier voltage and modulating voltage given respectively by

$$v_c = V_c \sin \omega_c t \tag{7.3}$$

and

$$v_m = V_m \sin \omega_m t \tag{7.4}$$

Where, V_c = Peak amplitude of the unmodulated carrier wave

V_m = peak amplitude of modulating signal

In the above expressions, the phase angle has been omitted as it is unaffected by amplitude modulation.

After amplitude modulation, the peak amplitude of the carrier wave is proportional to v_m and is given by

$$A(t) = V_c + Kv_m \tag{7.5}$$

where, K is the proportionality constant, known as the amplitude sensitivity of modulation, which is usually made equal to unity

$$\therefore \quad A(t) = V_c + v_m \tag{7.6}$$

7.17. Explain the principle of amplitude modulation with suitable waveforms.

The magnitude of the carrier wave is varied in accordance with amplitude of the modulating signal in case of amplitude modulation. The principle of amplitude modulation is illustrated in Fig. 7.3, which shows a single frequency sinsoidal voltage modulating a high frequency carrier signal.

Fig. 7.3(c) shows amplitude modulated wave for one cycle of the modulating sine wave. When there is no modulation, the amplitude of the carrier is equal to its unmodulated value V_c. When modulation is present the amplitude of the carrier is varied by the instantaneous value of the modulating sine wave and is given by

$$A(t) = V_c + v_m = V_c + V_m \sin \omega_m t \tag{7.7}$$

as depicted in Fig. 7.4

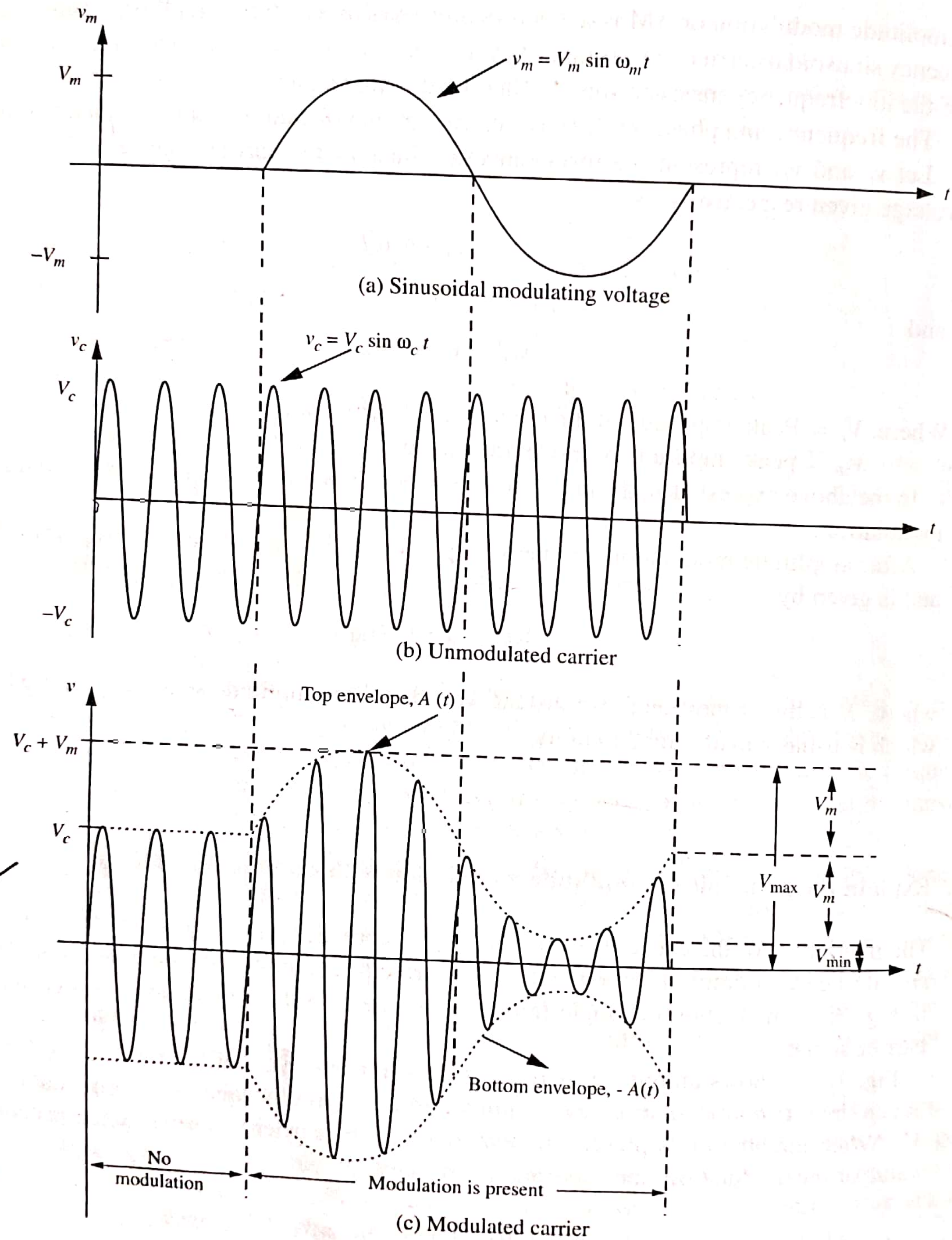

Fig. 7.3 Amplitude modulation.

7.18. Define and explain modulation index of amplitude modulation.

Fig. 7.4 shows that distortion will occur if the value of V_m exceeds that of V_c. Hence, the amplitude of modulating voltage, v_m must be less than the amplitude of the carrier, V_c for proper and undistorted amplitude modulation. The relationship between V_m and V_c called modulation index or depth of modulation m_a, is defined as the ratio of the amplitude of the modulating voltage to the amplitude of the carrier wave and is given by

$$m_a = \frac{V_m}{V_c} \tag{7.8}$$

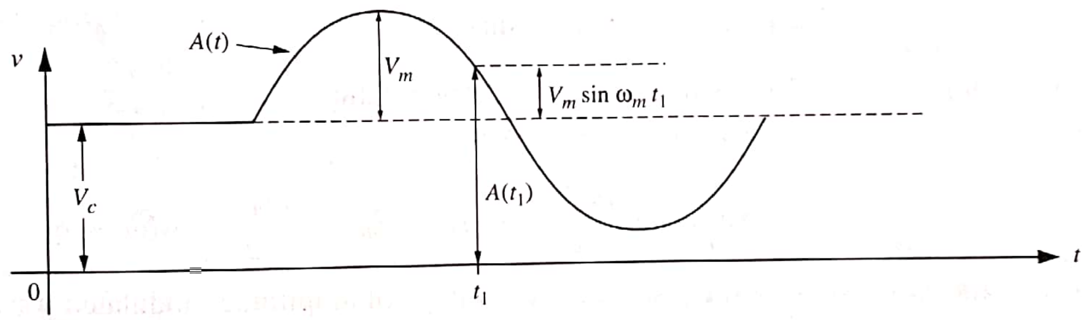

Fig. 7.4 Amplitude of AM wave.

Modulation index is a number that that lies between 0 and 1 for distortion less modulation and is usually expressed as a percentage, called the percentage modulation, given by,

$$\%\ m_a = \frac{V_m}{V_c} \times 100\%$$

7.19. Derive the expression for the instantaneous voltage of amplitude modulated wave.

Consider the amplitude modulation in which the modulating voltage is given by

$$v_m = V_m \sin \omega_m t \tag{7.9}$$

and the carrier voltage is given by

$$v_c = V_c \sin \omega_c t \tag{7.10}$$

Since amplitude modulation varies the amplitude of the carrier in accordance with the instantaneous value of the modulating voltage, v_m, the amplitude of the modulated carrier or AM wave is given by

$$A(t) = V_c + v_m = V_c + V_m \sin \omega_m t \tag{7.11}$$

The instantaneous voltage of the amplitude modulated wave is, therefore

$$v = A(t)\sin\omega_c t$$

$$= (V_c + V_m \sin\omega_m t)\sin\omega_c t$$

$$= V_c\left(1 + \frac{V_m}{V_c}\sin\omega_m t\right)\sin\omega_c t$$

From equation 7.8

$$\frac{V_m}{V_c} = m_a$$

$$\therefore \quad v = V_c(1 + m_a \sin\omega_m t)\sin\omega_c t \qquad (7.12)$$

Expanding equation 7.12 using the trigonometric relation
$\sin A \sin B = \frac{1}{2}[\cos(A - B) - \cos(A + B)]$ we get

$$v = V_c \sin\omega_c t + \frac{m_a V_c}{2}\cos(\omega_c - \omega_m)t - \frac{m_a V_c}{2}\cos(\omega_c + \omega_m)t \qquad (7.13)$$

This is the expression for the instantaneous voltage of amplitude modulated wave.

7.20. Derive the expression for modulation index of amplitude modulation.

An expression for modulation index can be obtained in terms of the maximum and minimum amplitudes, V_{max} and V_{min} of the amplitude modulated wave shown in Fig. 7.3(c).
From Fig. 7.3 (c), we have

$$2V_m + V_{min} = V_{max}$$

$$\therefore \; V_m = \frac{V_{max} - V_{min}}{2} \qquad (7.14)$$

where, V_m = amplitude of modulating voltage, and
From Fig. 7.3(c),

$$V_c = V_m + V_{min} \qquad (7.15)$$

where, V_c = amplitude of unmodulated carrier
Substituting for V_m from equation 7.14 into equation 7.15. We get

$$V_c = \frac{V_{max} - V_{min}}{2} + V_{min}$$

$$\text{or} \quad V_c = \frac{V_{max} + V_{min}}{2} \qquad (7.16)$$

Dividing equation 7.14 by equation 7.16 we get the expression for modulation index m_a as

$$m_a = \frac{V_m}{V_c} = \frac{(V_{\max} - V_{\min})/2}{(V_{\max} + V_{\min})/2}$$

$$= \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} \tag{7.17}$$

Equation 7.17 is the standard procedure to calculate the modulation index of AM wave, by observing on an oscilloscope.

7.21. Discuss the effect of modulation index on amplitude modulation.

The extend to which the amplitude of the carrier is varied in amplitude modulation depends on the value of the modulation index, m_a. Based on the value of modulation index, we have the three cases of modulation:

1. $m_a > 1$: In this case $V_m > V_c$, the carrier is said to be over damped and the AM wave or envelope is distored due to overmodulation.

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2. $m_a < 1$: In this case $V_m < V_c$, and the carrier is said to be under-damped
3. $m_a = 1$: In this case $V_m = V_c$, and the carrier is said to be critically or level-damped.

These three cases are illustrated in Fig. 7.5

7.22. What is the significance of modulation index?

In an AM wave the signal or information is contained in the variation of the carrier amplitude. The degree of modulation or modulation index is an indication of the strength of the message signal i.e., the greater the modulation index, m_a, the stronger and clearer will be the message signal. Thus, for $m_a = 1$ or 100%, the message signal being transmitted will be the strongest. However, when the carrier is overmodulated i.e., for $m_a > 1$ or 100% the AM wave will be clipped off and a large distortion will occur during reception. Hence modulation index should never exceed 1 or 100%.

7.23. What is frequency spectrum? Explain the frequency spectrum of AM wave.

Frequency spectrum is a plot of amplitude versus frequency of a wave.

Equation 7.13 shows that the AM wave contains three terms. The first term with frequency ω_c or $f_c = \frac{\omega_c}{2\pi}$ represents the unmodulated carrier. The two additional terms produced by AM are called the side bands.

The frequency of the lower sideband is

$$f_{\text{LSB}} = f_c - f_m \tag{7.18}$$

and that of the upper sideband is

$$f_{USB} = f_c + f_m \tag{7.19}$$

where, $f_m = \frac{\omega_m}{2\pi}$, is the frequency of the modulating signal in Hz.

The amplitude of the two sidebands are the same and equal to $\frac{m_a V_c}{2}$. Fig. 7.6 shows the plot of the frequency spectrum of the amplitude modulated wave

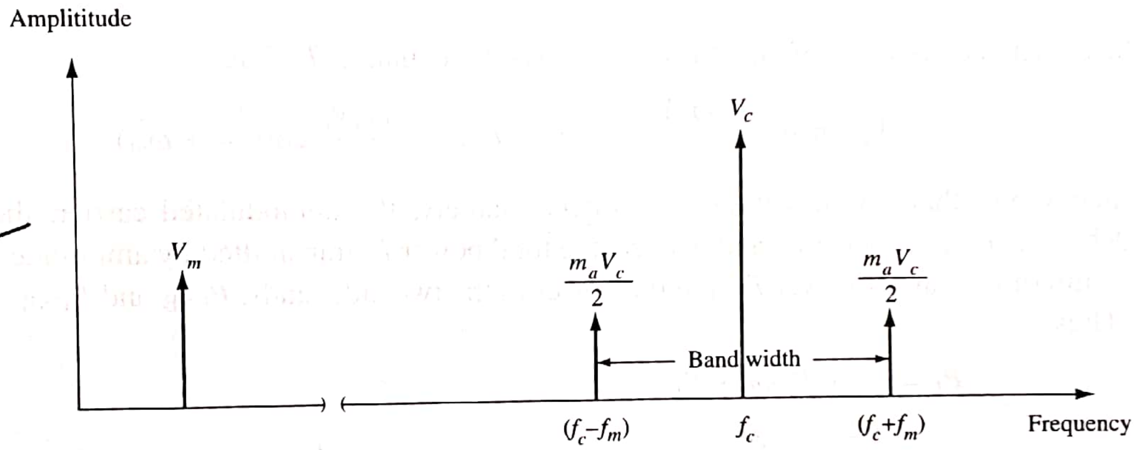

Fig. 7.6 Frequency spectrum of AM wave.

In practice, the carrier frequency f_c is very much greater than the modulating frequency f_m and hence the sideband frequencies are very close to the carrier frequency. In practice, the AM wave is a voltage or a current wave.

7.24. What is the bandwidth of an AM wave?

In case of AM wave the bandwidth is the difference between the sideband frequencies.

$$BW = f_{USB} - f_{LSB} = (f_c + f_m) - (f_c - f_m) = 2f_m \tag{7.20}$$

Thus, the bandwidth of amplitude modulation is twice the signal or modulating frequency.

7.25. An audio signal of 1 kHz is used to amplitude modulate a carrier of 600 kHz. Determine (a) side band frequencies and (b) bandwidth required.

Given $f_c = 600$ kHz and $f_m = 1$ kHz

From equations 7.18 and 7.19 the sideband frequencies are

$$f_{LSB} = f_c - f_m = 600 - 1 = 599 \text{ kHz}$$

and

$$f_{USB} = f_c + f_m = 600 + 1 = 601 \text{ kHz}$$

From equation 7.20 the bandwidth required is

$$B_w = 2f_m = 2 \times 1 = 2 \text{ kHz}$$

7.26. Obtain an expression for the total average power of a sinusoidal AM wave.

The instantaneous value of an AM wave is given by equation 7.13 as

$$v = V_c \sin \omega_c t + \frac{m_a V_c}{2} \cos(\omega_c - \omega_m)t - \frac{m_a V_c}{2} \cos(\omega_c + \omega_m)t$$

which shows that AM has three components namely, the unmodulated carrier, the lower sideband and the upper sideband. Hence, the total power P_t transmitted by amplitude wave is the sum of the carrier power P_c and the power in the two sidebands, P_{LSB} and P_{USB}.

Thus,

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

$$= \frac{V_{carr}^2}{R} + \frac{V_{LSB}^2}{R} + \frac{V_{USB}^2}{R} \tag{7.21}$$

Where,

P_t = total average power delivered
V_{carr} = rms value of the unmodulated carrier
V_{LSB} = rms value of the lower sideband
V_{USB} = rms value of the upper sideband
R = resistance of the transmitting antenna in which power is dissipated

Since, the carrier and sidebands are sinusoidal voltages

$$V_{carr} = \frac{V_c}{\sqrt{2}} \tag{7.22}$$

and

$$V_{LSB} = V_{USB} = \frac{(m_a V_c/2)}{\sqrt{2}} \tag{7.23}$$

We know that power is given by

$$\text{Power} = \frac{(\text{Voltage})^2}{\text{resistance}}$$

Using equation 7.22, the power in the unmodulated carrier is given by

$$P_c = \frac{(V_c/\sqrt{2})^2}{R} = \frac{V_c^2}{2R} \tag{7.24}$$

Using equation 7.23, the power in the sidebands is given by

$$P_{\text{LSB}} = P_{\text{USB}} = \frac{1}{R}\left(\frac{m_a V_c/2}{\sqrt{2}}\right)^2 = \frac{m_a^2}{4}\frac{V_c^2}{2R} = \frac{m_a^2}{4}P_c \tag{7.25}$$

Thus the total power in the amplitude modulated wave is

$$P_t = \frac{V_c^2}{2R} + \frac{m_a^2}{4}\frac{V_c^2}{2R} + \frac{m_a^2}{4}\frac{V_c^2}{2R} \tag{7.26}$$

since $\frac{V_c^2}{2R} = P_c$, the above equation can be written as

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

or

$$\boxed{P_t = P_c\left(1 + \frac{m_a^2}{2}\right)} \tag{7.27}$$

Equation 7.24 show that the total power in the amplitude modulated wave is
(i) more than that the carrier had prior to modulation
(ii) dependent on the modulation index m_a.

7.27. A 400W carrier is modulated to a depth of 75%. Calcuate the total power in the modulated wave.

✓

Given $P_c = 400\,\text{W}$, $m_a = 75\% = 0.75$.
From equation 7.27 the total power is

$$P_t = 400\left(1 + \frac{0.75^2}{2}\right) = 512.5W$$

7.28. A local AM transmitter broadcasts a carrier power of 50 kW. Determine the radiated power at a modulation index of 0.6.

✓

Given $P_c = 50\,\text{kW}$, $m_a = 0.6$
From equation 7.27

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right) = 50\left(1 + \frac{0.6^2}{2}\right) = 59\ \text{kW}$$

7.29. What is the maximum power in an AM wave?

From equation 7.27 the total power in the AM wave is

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

It is easy to see that P_t is maximum when m_a is maximum.
The maximum value of $m_a = 1$, at which

$$P_t = P_c\left(1 + \frac{1}{2}\right) = 1.5P_c \tag{7.28}$$

Thus the maximum power in the AM wave is $1.5P_c$ or 150% of the carrier power P_c.

7.30. Why is AM not efficient?

In amplitude modulation most of the power is in the carrier. The power in the sidebands, $P_{SB} = P_{LSB} + P_{USB}$, which contains the information or signal is much less. For example, consider the amplitude modulation in which the depth of modulation is 1 or 100%. The total power in the AM wave for this case is maximum and is

$$P_t = \left(1 + \frac{m_a^2}{2}\right)P_c = \left(1 + \frac{1}{2}\right)P_c = 1.5P_c$$

However, the net power in the sidebands which contain the useful information is

$$P_{SB} = P_t - P_c = 1.5P_c - P_c = 0.5P_c$$

Therefore, the maximum percentage of useful power in the AM wave is

$$\frac{P_{SB}}{P_t} \times 100 = \frac{0.5P_c}{1.5P_c} \times 100 = 33.3\%$$

which shows that AM is not very efficient.

7.31. Define the transmission efficiency of AM wave and obtain an expression for it.

The transmission efficiency of AM wave is defined as

$$\text{Transmission efficiency, } \eta = \frac{\text{transmitted power that contains information}}{\text{total transmitted power, } P_t}$$

Since, the transmitted power that contains the information is the sideband power, $P_{SB} = P_{LSB} + P_{USB}$, we have

$$\eta = \frac{P_{LSB} + P_{USB}}{P_t} \tag{7.29}$$

From equation 7.25,

$$P_{\text{LSB}} = P_{\text{USB}} = \frac{m_a^2}{4}\frac{V_c^2}{2R} = \frac{m_a^2}{4}P_c \tag{7.30}$$

Substituting equations 7.27 and 7.30 into equation 7.29 we get

$$\eta = \frac{\frac{m_a^2}{4}P_c + \frac{m_a^2}{4}P_c}{P_c\left(1+\frac{m_a^2}{2}\right)} = \frac{\frac{m_a^2}{2}}{1+\frac{m_a^2}{2}}$$

or

$$\eta = \frac{m_a^2}{2+m_a^2} \tag{7.31}$$

The percentage transmission efficiency is

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

$$\text{or} \quad \%\,\eta = \frac{m_a^2}{m_a^2\left(1+\frac{2}{m_a^2}\right)} = \frac{1}{1+\frac{2}{m_a^2}} \tag{7.32}$$

This shows that the transmission efficiency increases with modulation index. This happens as the sideband power P_{SB}, which corresponds to the information power, increases with increase in modulation index.

When $m_a = 1$ or 100%

$$\%\eta = \frac{1^2}{2+1^2} \times 100\% = 33.3\%$$

Hence the maximum transmission efficiency of the AM wave is 33.3%.

Where $m_a = 0.8$ or 80%.

$$\%\,\eta = \frac{0.8^2}{2+0.8^2} \times 100 = 24.24\%$$

Thus higher the modulation index, higher is the transmission efficiency.

7.32. Express modulation index in terms of carrier power and total power of the AM wave.

From equation 7.27 the total power in the AM wave is

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

$$\therefore \quad \frac{P_t}{P_c} = 1 + \frac{m_a^2}{2}$$

or

$$\frac{m_a^2}{2} = \frac{P_t}{P_c} - 1$$

i.e.,

$$m_a^2 = 2\left(\frac{P_t}{P_c} - 1\right)$$

$$\therefore \quad m_a = \sqrt{2\left(\frac{P_t}{P_c} - 1\right)} \tag{7.33}$$

This is the equation for modulation index m_a in terms of the total power, P_t and carrier power, P_c.

7.33. How do you determine the total modulation index and total power when a carrier is amplitude modulated by several sine waves?

In practice, modulation of a carrier by several sine waves is very common. If V_1, V_2, V_3 etc., are the amplitudes of simultaneous sinusoidal modulating voltages, then the total modulating voltage V_t is given by

$$V_t = \sqrt{V_1^2 + V_2^2 + V_3^2 + \cdots} \tag{7.34}$$

Dividing both sides of equation 7.34 by V_c, the amplitude of the carrier, we get

$$\frac{V_t}{V_c} = \frac{\sqrt{V_1^2 + V_2^2 + V_3^2 + \ldots}}{V_c}$$

$$= \sqrt{\left(\frac{V_1}{V_c}\right)^2 + \left(\frac{V_2}{V_c}\right)^2 + \left(\frac{V_3}{V_c}\right)^2 + \cdots}$$

But $\dfrac{V_t}{V_c}$ = the total modulation index, m_{at}

$$\therefore \quad m_{at} = \sqrt{m_{a1}^2 + m_{a2}^2 + m_{a3}^2 + \cdots}$$

where

$$m_{a1} = \frac{V_1}{V_c}, \quad m_{a2} = \frac{V_2}{V_c}, \quad m_{a3} = \frac{V_3}{V_c}, \text{ etc.,}$$

are the individual modulation indices.

Hence, the total modulation index in modulation by several sine waves is the square root of the sum of the squares of the individual modulation indices. This total modulation index should not exceed 1.

The total power in the AM wave of the above case is given by

$$P_t = P_c\left(1 + \frac{m_{at}^2}{2}\right) \tag{7.35}$$

7.34. A radio transmitter radiates 10 kW when the modulation percentage is 60. How much of this is carrier power?

Given

$$P_t = 10\,\text{kW}, \quad m_a = 60\% = 0.6$$

From equation 7.27

$$P_c = \frac{P_t}{1 + \frac{m_a^2}{2}} = \frac{10}{1 + \frac{0.6^2}{2}} = 8.47\,\text{kW}$$

7.35. The total power content of an AM wave is 2.64 kW at a modulation factor of 80% Determine the power content of (i) carrier (ii) each sideband.

Given

$$P_t = 2.64\,\text{kW}, \quad m_a = 80\% = 0.8$$

(i) From equation 7.27, the carrier power is

$$P_c = \frac{P_t}{1 + \frac{m_a^2}{2}} = \frac{2.64}{1 + \frac{0.8^2}{2}} = 2\,\text{kW}$$

(ii) From equation 7.25, the power in each sideband is

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

$$= \frac{0.8^2}{4} \times 2 = 0.32\text{ W}$$

Alternatively,

$$P_{\text{LSB}} = P_{\text{USB}} = \frac{P_t - P_c}{2} = \frac{2.64 - 2}{2} = 0.32\text{ W}$$

7.36. A carrier of 2 MHz has 1 kW of its power amplitude modulated with a sinusoidal signal of 2 kHz. The depth of modulation is 60%. Calculate the sideband frequencies, the signal bandwidth, the power in the sidebands and the total power in the modulated wave.

Given,

$$P_c = 1\text{ kW}, \quad f_c = 2\text{ MHz}, \quad f_m = 2\text{ kHz} \text{ and } m_a = 60\% = 0.6$$

From equation 7.18 and 7.19 the sideband frequencies are

$$f_{\text{LSB}} = f_c - f_m = 2\text{ MHz} - 2\text{ kHz}$$

$$= 2000\text{ kHz} - 2\text{ kHz}$$

$$= 1998\text{ kHz or } 1.998\text{ MHz}$$

$$f_{\text{USB}} = f_c + f_m = 2\text{ MHz} + 2\text{ kHz} = 2000\text{ kHz} + 2\text{ kHz}$$

$$= 2002\text{ kHz or } 2.002\text{ MHz}$$

From equation 7.20 the bandwidth is

$$BW = 2f_m = 2 \times 2\text{ kHz} = 4\text{ kHz}$$

From equation 7.25 the power in each sideband is

$$P_{\text{LSB}} = P_{\text{USB}} = \frac{m_a^2}{4} P_c = \frac{0.6^2}{4} \times 1\text{ kW} = 0.09\text{ kW or } 90\text{ W}$$

From equation 7.27, the total power in the AM is

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right) = 1\text{ kW}\left(1 + \frac{0.6^2}{2}\right) = 1.18\text{kW}$$

Observe that when the depth of modulation is 60%, out of the total power of 1180 W, only 90 W is related in useful information as confined with sidebands.

7.37. The rms value of a carrier voltage is 100 V. After amplitude modulation by a sinusoidal audio voltage, the rms value becomes 110 V. Calculate the modulation index.

From equation 7.27 we have

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

i.e.,

$$\frac{V_t^2/R}{V_{carr}^2/R} = 1 + \frac{m_a^2}{2}$$

Where

V_t = rms value of modulated voltage

V_{carr} = rms value of unmodulated carrier voltage

$$\therefore \left(\frac{V_t}{V_{carr}}\right)^2 = 1 + \frac{m_a^2}{2} \qquad (7.36)$$

i.e,

$$m_a = \sqrt{2\left[\left(\frac{V_t}{V_{carr}}\right)^2 - 1\right]} \qquad (7.37)$$

substituting $V_t = 110\text{V}$ and $V_{carr} = 100\text{V}$, we have

$$m_a = \sqrt{2\left[\left(\frac{110}{100}\right)^2 - 1\right]} = 0.65 \text{ or } 65\%$$

7.38. The antenna current of an AM transmitter is 8A when only the carrier is sent, and increases to 8.93 A when the carrier is modulated by a single sine wave. Find the percentage modulation. Determine the antenna current when the depth of modulation changes to 0.8.

Let I_t and I_{carr} be respectively the rms values of the unmoduled current and the total or modulated current. If R is the resistance in which these currents flow, then from equation 7.27 we can write.

$$\frac{P_t}{P_c} = \frac{I_t^2 R}{I_{carr}^2 R} = \left(\frac{I_t}{I_{carr}}\right)^2 = 1 + \frac{m_a^2}{2} \qquad (7.38)$$

or

$$m_a = \sqrt{2\left[\left(\frac{I_t}{I_{carr}}\right)^2 - 1\right]} \tag{7.39}$$

Substituting $I_t = 8.93A$ and $I_{carr} = 8A$ in the above equation we get

$$m_a = \sqrt{2\left[\left(\frac{8.93}{8}\right)^2 - 1\right]} = 0.701 \text{ or } 70.1\%$$

From equation 7.38

$$I_t = I_{carr}\sqrt{1 + \frac{m_a^2}{2}}$$

Substituting $m_a = 0.8$ and $I_{carr} = 8A$ we get

$$I_t = 8\sqrt{1 + \frac{0.8^2}{2}} = 9.19 \text{ A}$$

7.39. An AM broadcasting station broadcasts with an average transmitted power of 20kW at a modulation index of 0.7. Find the transmission power efficiency and the average power in the carrier component.

Given $P_t = 20$ kW, $m_a = 0.7$
From equation 7.27

$$P_c = \frac{P_t}{1 + \frac{m_a^2}{2}} = \frac{20}{1 + \frac{0.7^2}{2}} \times 100\% = 16.06W$$

From equation 7.32 the transmission power efficiency is

$$\%\,\eta = \frac{m_a^2}{2 + m_a^2} \times 100\% = \frac{0.7^2}{2 + 0.7^2} \times 100\,\% = 19.7\%$$

Alternatively,

$$\%\,\eta = \frac{P_t - P_c}{P_t} \times 100\% = \frac{20 - 16.06}{20} \times 100\% = 19.7\%$$

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7.40. Maximum and minimum amplitudes of an AM wave are 600 mV and 200 mV respectively. Find the modulation index.

Given $V_{\max} = 600$ mV, $V_{\min} = 200$ mV
From equation 7.17, the modulation index is

$$m_a = \frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}} = \frac{600 - 200}{600 + 200} = 0.5 \text{ or } 50\%$$

7.41. A carrier wave with amplitude 10V and frequency 10 MHz is amplitue modulated by an audio signal of frequency 1 kHz. Write the equation for this AM wave and sketch its frequency spectrum. Assume $m_a = 0.5$.

Given

$$V_c = 10\text{V}, f_c = 10\,\text{MHz} = 10 \times 10^6 \text{ Hz}$$
$$f_m = 1\text{kHz},\ m_a = 0.5$$

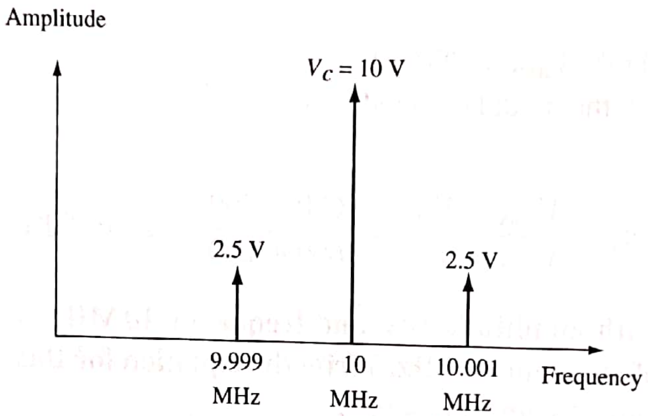
From equation 7.12

$$v = V_c(1 + m_a \sin \omega_m t) \sin \omega_c t$$
$$\omega_c = 2\pi f_c = 2\pi \times 10 \times 10^6 = 62.8 \times 10^6 \text{ rad/s}$$
$$\omega_m = 2\pi f_m = 2\pi \times 1 \times 10^3 = 6280 \text{ rad/s}$$
$$\therefore\ v = 10(1 + 0.5 \sin 6280t) \sin(62.8 \times 10^6 t)$$

From equation 7.13 the amplitude of each sideband is $= \dfrac{m_a V_c}{2} = \dfrac{0.5 \times 10}{2} = 2.5\,\text{V}$
From equations 7.18 and 7.19

$$f_{\text{LSB}} = f_c - f_m = 10 \times 10^6 - 1 \times 10^3 = 9.999 \times 10^6 \text{ Hz}$$
$$f_{\text{USB}} = f_c + f_m = 10 \times 10^6 + 1 \times 10^3 = 10.001 \times 10^6 \text{ Hz}$$

The frequency spectrum is shown below



7.42. **An AM broadcasting station broadcasts with an average transmitted power of 20kW. Modulation index is set at 0.8. Find the saving in power if the power contained in the LSB alone is used.**

Given

$$P_t = 20\,\text{kW},\ m_a = 0.8$$

From equation 7.27, the carrier power is

$$P_c = \frac{P_t}{1+\frac{m_a^2}{2}} = \frac{20}{1+\frac{0.8^2}{2}} = 15.15\ \text{kW}$$

The power in the sidebands is

$$P_t - P_c = 20 - 15.15 = 4.85\ \text{kW}$$

The power in the LSB is

$$P_{\text{LSB}} = \frac{4.85}{2} = 2.425W$$

saving in power is $P_t – P_{\text{LSB}} = 15.15 - 2.425 = 12.725$ kW

$$\%\ \text{Saving in Power} = \frac{P_t - P_{\text{LSB}}}{P_t} \times 100\% = \frac{12.725}{15.15} \times 100\% = 84\%$$

Table 7.1

Amplitude Modulation	Frequency Modulation
In AM, amplitude of the carrier varies while its frequency remains constant	In FM, the frequency of the carrier changes while its amplitude remains constant
Modulation index (m_a) can have values from 0 to 1 only	Modulation index (m_f) is much greater than 1
AM has only two sidebands	FM has infinite number of sidebands
The bandwidth is twice the highest modulating frequency $BW = 2f_m$	Bandwidth is much larger than AM $BW = \cancel{2(m_f + f_m)}$ $2f_m(1+m_f)$
Carrier frequency is in the lower RF-500 kHz to 3 MHz	Carrier frequency is very high – VHF and UHF (88 to 108 MHz)
Susceptible to noise	More immune to noise
Propagation is by ground waves and sky waves	Propagation is by space waves
AM transmission covers long distances	FM transmission covers smaller distances only (line of sight)
Requires less complex and less expensive equipment	Requires more complex and expensive equipment

7.62. With the help of block diagrams explain a radio telegraphy system.

Fig. 7.8 shows the block diagrams of the transmitter and receiver sections of a radio telegraphy system.

Radio telegraphy can be used to transmit only written message using a special type of code called Morse code. In this code each letter of the message is represented as a combination of dots and dashes. Dots are interruptions of short duration – 2 cycles of the carrier and dashes are interruptions of long duration – 5.5 cycles of the carrier wave.

The oscillator of the transmitter section as shown in Fig 7.8(a), generates the RF carrier waves of required frequency. These waves are interrupted according to the Morse code and the coded carrier is amplified and then radiated into space by the transmitting antenna. The carrier waves are interrupted by cutting off the power supply for the oscillator with a Morse key.

The receiver section receives the continuous wave carrier signals using the receiving antenna and tuning circuit. After suitable amplification these radio waves are converted into AF or audio

The microphone in the transmitter section converts voice into electrical signals which are amplified by the AF amplifier and used to modulate the RF carrier waves generated by the RF oscillator. A modulator is used for this purpose. The modulated carrier wave is amplified by the RF amplifier and transmitted through the antenna.

At the receiver, the desired modulated carrier is selected using a tuning circuit and it is amplified by the RF amplifier. The demodulator extracts the AF signal or modulating signal from the modulated RF carrier. The AF signal is amplified by the AF amplifier and is fed to the loud speaker which converts it back to sound waves.

7.64. What are the salient features of a superheterodyne receiver?

The salient features of a superheterodyne receiver are:

1. Good selectivity
2. Good sensitivity
3. Good stability.

7.65. What is meant by heterodyning?

The process of mixing two frequencies f_1 and f_2 to produce beat frequencies of $f_1 \pm f_2$ i.e., $f_1 - f_2$ and $f_1 + f_2$ is called heterodyning. A superheterodyne receiver is so called because it use the process of heterodyning.

7.66. Explain the principle of operation of a superheterodyne receiver.

In a superheterodyne receiver the incoming or selected radio frequency signal is mixed with a high frequency signal generated by a local oscillator present in the receiver itself. For this purpose a special electronic circuit called a mixer circuit is used.

In the above process beats are produced and the mixer outputs a frequency equal to the difference between the frequency generated by the local oscillator and the selected radio frequency. Thus the radio frequency is converted to a lower frequency called intermediate frequency or IF.

The signal at the IF frequency of 455 kHz contains the same modulation as the original RF carrier. It is now amplified and demodulated to reproduce the original information.

7.67. Draw the block diagram of a superheterodyne receiver and explain the function of each stage.

Fig. 7.10 shows the block diagram of a superheretodyne receiver. It can be seen that the variable capacitors of RF amplifier, mixer and local oscillator are all ganged to a common shaft so that the rotation of the ganged shaft will simultaneously vary the capacitances of tank circuits of all the three stages.

The function of each block in Fig. 7.10 is explained below:

RF amplifier stage: The receiving antenna picks the weak radio signals transmitted by various stations and feeds them to the RF stage. The RF stage selects the desired radio frequency signal using its LC tuning circuit and amplifies it to the desired level.

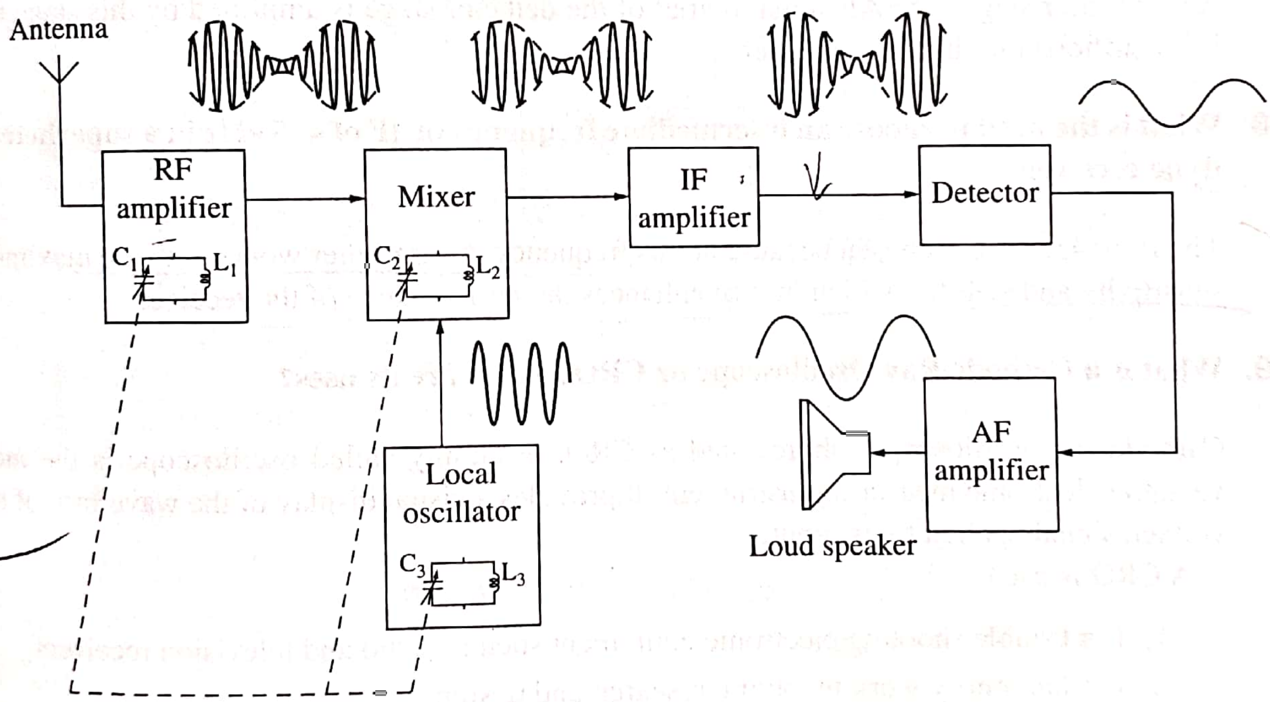


Fig. 7.10 Block diagram of superheterodyne receiver.

Mixer Stage: The output of the RF amplifier stage is fed to the mixer stage where it is mixed with the output of local oscillator. The two frequencies beat together and produce a constant intermediate frequency which is 455 kHz i.e.,

$$f_{IF} = f_{LO} - f_c = 455\text{ kHz}$$

where

f_{IF} = intermediate frequency

f_{LO} = local oscillator frequency

f_c = selected radio frequency

The IF is always 455 kHz independent of the frequency to which the receiver is tuned. For example, if the RF stage is tuned to a frequency of 2 MHz then the local oscillator is tuned to