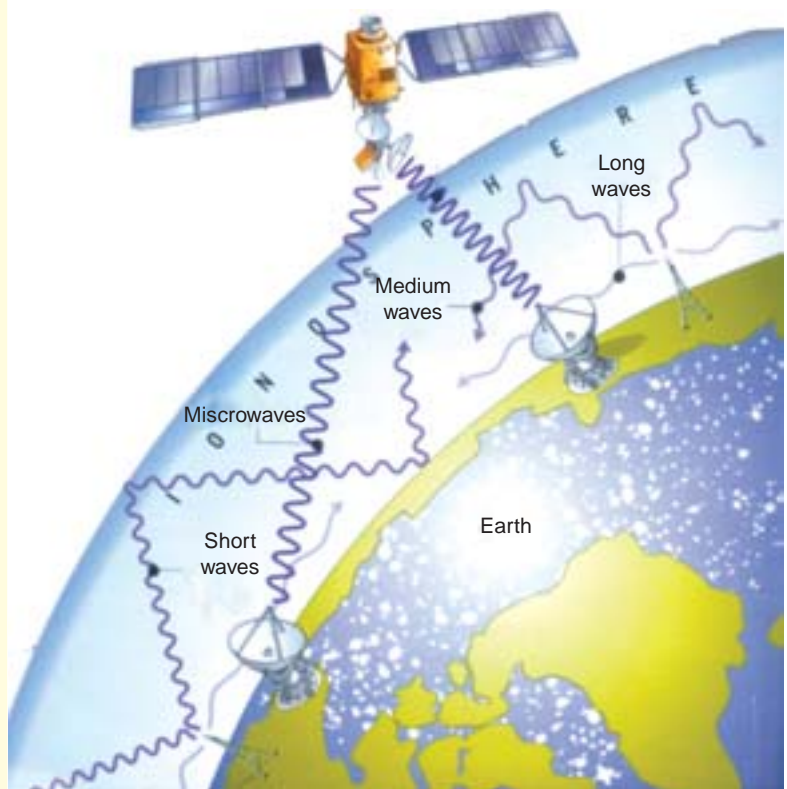


CHAPTER 66

Learning Objectives

- What is a Carrier Wave?
- Radio Frequency Spectrum
- Sound
- Need for Modulation
- Radio Broadcasting
- Modulation
- Methods of Modulation
- Amplitude Modulation
- Percent Modulation
- Upper and Lower Sidebands
- Mathematical Analysis of a Modulated Carrier Wave
- Power Relation in an AM Wave
- Forms of Amplitude Modulation
- Generation of SSB
- Methods of Amplitude Modulation
- Modulating Amplifier Circuit
- Frequency Modulation
- Modulation Index
- Deviation Ratio
- Percent Modulation
- FM Sidebands
- Modulation Index and Number of Sidebands
- Demodulation or Detection
- Essentials of AM Detection
- Transistor Detectors for AM Signals
- Quadrature Detector
- Frequency Conversion
- Standard Superhet AM Receiver
- FM Receiver
- Comparison between AM and FM
- The Four Fields of FM

MODULATION AND DEMODULATION



The radio waves travel through the air, bounce off a layer of the atmosphere called the ionosphere, or are relayed by satellite

66.1. Introduction

For successful transmission and reception of intelligence (code, voice, music etc.) by the use of radio waves, two processes are essential :

- (i) modulation and (ii) demodulation.

Speech and music etc. are sent thousands of kilometres away by a radio transmitter. The scene in front of a television camera is also sent many kilometres away to viewers. Similarly, a Moon probe or Venus probe checking its environments, sends the information it gathers millions of kilometres through space to receivers on earth. In all these cases, the carrier is the high-frequency radio wave. The intelligence i.e. sight, sound or other data collected by the probe is impressed on the radio wave and is carried along with it to the destination.

Modulation is the process of **combining the low-frequency signal with a very high-frequency radio wave called carrier wave (CW)**. The resultant wave is called **modulated carrier wave**. This job is done at the transmitting station.

Demodulation is the process of separating or **recovering the signal from the modulated carrier wave**. It is just the opposite of modulation and is performed at the receiving end.

66.2. What is a Carrier Wave?

It is a high-frequency undamped radio wave produced by radio-frequency oscillators (Chapter 65). As seen from Fig. 66.1, the output of these oscillators is first amplified and then passed on to an antenna. This antenna radiates out these high-frequency (electromagnetic) waves into space. These waves have constant amplitude and travel with the velocity of light. They are inaudible *i.e.* by themselves they cannot produce any sound in the loudspeaker of a receiver. As their name shows, their job is to **carry the signal** (audio or video) from transmitting station to the receiving station. The resultant wave is called **modulated carrier wave**.

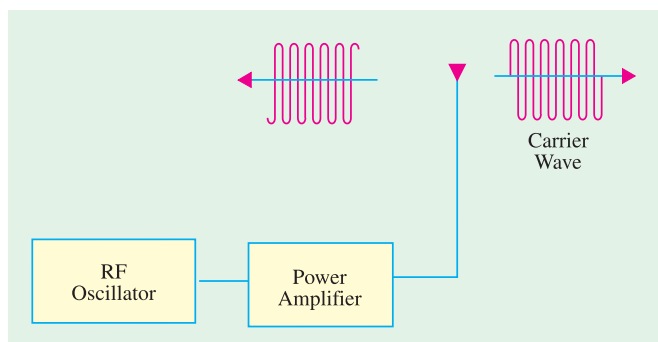


Fig. 66.1

66.3. Radio Frequency Spectrum

Radio frequencies used by different communication systems extend from very low frequencies to extra high frequencies as tabulated below along with their acronym abbreviations.

Table No. 66.1			
Frequency	Designation	Abbreviation	Uses
3-30 kHz	very low frequency	VLF	long distance telegraphy broadcasting
30-300 kHz	low frequency	LF	long distance point-to-point service, navigational aids, sound broadcasting and line carrier systems.
300 kHz-3MHz	medium frequency	MF	sound broadcasting, ship-shore services and line carrier systems
3-30 MHz	high frequency	HF	medium and long-distance point-to-point services, sound broadcasting, linear carrier systems.



30-300 MHz	very high frequency	VHF	short-distance communication, TV and sound broadcasting, radar
300 MHz-3GHz	ultra high frequency	UHF	outer-space radio communication,
3-30 GHz	super high frequency	SHF	point-to-point microwave communication systems and radar.
30-300 GHz	extra high frequency	EHF	

Generally, none of the frequencies above 300 GHz is classified as radio waves.

66.4. Sound

It is a sort of disturbance which requires some physical medium for its propagation. Human voice consists of a series of compressions and rarefactions which travel through air with a velocity of about 345 m/s. The frequency range of human voice is from 20-4000 Hz which lies within the audible range of 20 to 20,000 Hz. Variations in human voice can be converted into corresponding variations in electric current with the help of a microphone as shown in Fig.66.2.

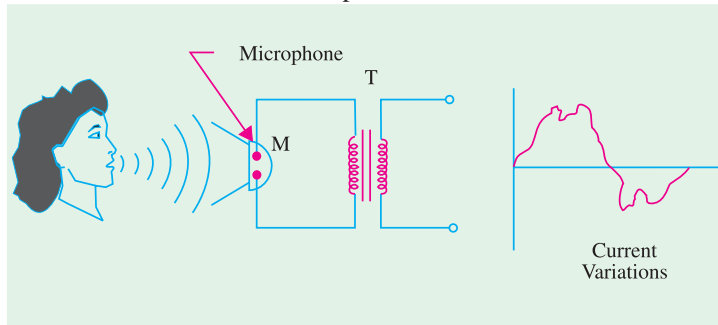


Fig. 66.2

When a sound wave strikes the microphone, it produces AF sound current. The positive half-cycles of sound current are produced by the compressions and negative half cycles by rarefactions.

As seen, human voice does not produce pure sinusoidal current because it does not consist of one frequency alone. It is quite complex and can be analysed to consist of a fundamental (or lowest frequency) and its integral multiple frequencies called **overtones** or **harmonics**.

We are interested in two main characteristics of sound :

- (i) **Intensity**—It is the energy content of the wave. It depends on its amplitude. In fact, intensity of a wave is directly proportional to the square of its amplitude *i.e.* $I \propto a^2$. Sensation of loudness felt by a listener depends directly on the intensity of the wave falling on his ears.
- (ii) **Frequency**—It produces the sensation called pitch. Audible sounds have a frequency range from 20 Hz to 20,000 Hz.

Though every sound has complex frequency structure, we will consider only single-frequency sound whose current wave is a pure sine wave as shown in Fig. 66.3. It will be used as the modulating signal when discussing the process of modulation.

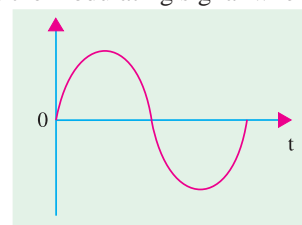


Fig. 66.3

66.5. Need for Modulation

Sometimes, beginners question the necessity of modulation *i.e.* using a carrier wave to carry the low-frequency signal from one place to another. Why not transmit the signals directly and save lot of both-eration? Unfortunately, there are three main hurdles in the process of such direct transmission of audio-frequency signals :

1. They have relatively short range,
2. If everybody started transmitting these low-frequency signals directly, mutual interference will render all of them ineffective
3. Size of antennas required for their efficient radiation would be large i.e. about 75 km as explained below.

For efficient radiation of a signal, the minimum length of an antenna is one quarter wavelength ($\lambda/4$). The antenna length L is connected with the frequency of the signal wave by the relation $L = 75 \times 10^6/f$ metres. For transmitting an audio signal of $f = 1000$ Hz, $L = 75 \times 10^6/10^3 = 75,000$ m = 75 km ! In view of this immense size of antenna length, it is impractical to radiate audio-frequency signals directly into space.

Hence, the solution lies in modulation which enables a low-frequency signal to travel very large distances through space with the help of a high-frequency carrier wave. These carrier waves need reasonably-sized antennas and produce no interference with other transmitters operating in the same area.

66.6. Radio Broadcasting

Let us see how radio broadcasting stations broadcast speech or music etc. from their broadcasting studios.

First, the speech or music which consists of a series of compressions and rarefactions is translated into a tiny varying electric current with the help of a crystal microphone. The frequency of variations of this current lies in the audio-range, hence it is known as audio frequency signal.

The audio-frequency signal cannot be radiated out from the antenna directly because transmission at audio-frequencies is not practical. For this purpose, oscillations of very high frequency or radio-frequency are produced with the help of any one of the oscillators discussed in Chapter 15. The electromagnetic waves so produced are of constant amplitude but of extremely high frequency. These waves, which are neither seen nor heard, travel through space with the velocity of light i.e. 3×10^8 m/s (approx). The audio-frequency signal which is to be broadcast, is then superimposed on the RF waves, which are known as carrier waves (because they carry A.F. signal through space to distant places). In a way, the carrier waves can be likened to a horse and the audio-frequency signal to a rider. The process by which AF signal or information is impressed on the carrier wave is known as modulation. The horse and rider travel through space. At the receiving end, they strike the receiving aerial and enter the receiver which separates the horse from the rider. The horse i.e. carrier wave is returned and the rider i.e. audio-frequency signal is converted back into sound. This process by which the R.F. waves and A.F. waves are separated is known as **detection** or **demodulation** (because it is the reverse of modulation).

66.7. Modulation

It is the process of combining *an audio-frequency (AF) signal with a radio frequency (RF) carrier wave*. The AF signal is also called a *modulating wave* and the resultant wave produced is called *modulated wave*.

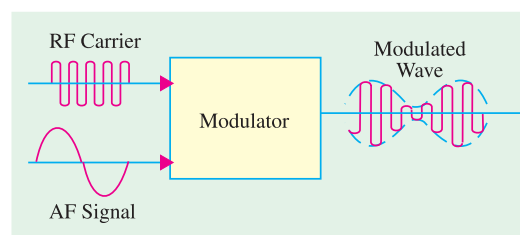


Fig. 66.4

During modulation, some characteristic of the carrier wave is varied in time with the modulating signal and is accomplished by combining the two.

66.8. Methods of Modulation

The mathematical expression for a sinusoidal carrier wave is

$$e = E_C \sin (\omega_c t + \phi) = E_C \sin (2 \pi f_c t + \phi)$$

Obviously, the waveform can be varied by any of its following three factors or parameters :

1. E_C — the amplitude,
2. f_c — the frequency,
3. ϕ — the phase.

Accordingly, there are three types of sine-wave modulations known as :

1. Amplitude Modulation (AM)

Here, the information or *AF* signal changes the amplitude of the carrier wave without changing its frequency or phase.

2. Frequency Modulation (FM)

In this case, the information signal changes the frequency of the carrier wave without changing its amplitude or phase.

3. Phase Modulation (PM)

Here, the information signal changes the phase of the carrier wave without changing its other two parameters.

66.9. Amplitude Modulation

In this case, the **amplitude** of the carrier wave is varied in proportion to the **instantaneous amplitude** of the information signal or *AF* signal. Obviously, the amplitude (and hence the intensity) of the carrier wave is changed **but not its frequency**. Greater the amplitude of the *AF* signal, greater the fluctuations in the amplitude of the carrier wave.

The process of amplitude modulation is shown graphically in Fig. 66.5. For the sake of simplicity, the *AF* signal has been assumed sinusoidal [Fig. 66.5 (a)]. The carrier wave by which it is desired to transmit the *AF* signal is shown in Fig. 66.5 (b). The resultant wave called modulated wave is shown in Fig. 66.5 (c).

The function of the modulator is to mix these two waves in such a way that (a) is transmitted along with (b). All stations broadcasting on the standard broadcast band (550-1550 kHz) use *AM* modulation.

If you observe the envelope of the modulated carrier wave, you will realize that it is an exact replica of the *AF* signal wave.

In summary

(i) **fluctuations** in the amplitude of the carrier wave depend on the **signal amplitude**,

(ii) **rate** at which these fluctuations take place depends on the **frequency** of the audio signal.

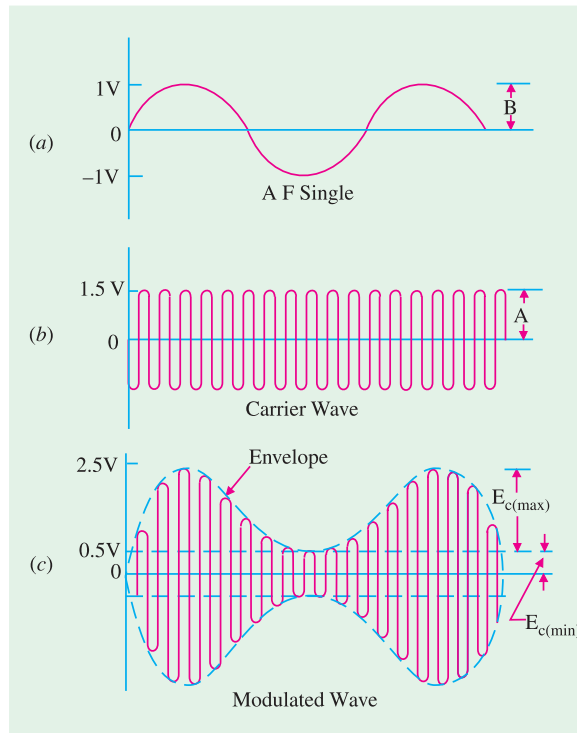


Fig. 66.5

66.10. Percent Modulation

It indicates the degree to which the AF signal modulates the carrier wave

$$m = \frac{\text{maximum value of signal wave}}{\text{maximum value of carrier wave}} \times 100 = \frac{\text{signal amplitude}}{\text{carrier amplitude}} \times 100$$

$$= \frac{B}{A} \times 100 \text{ —Fig. 66.5}$$

The ratio B/A expressed as a fraction is called **modulation index (MI)**

$$m = M.I. \times 100$$

From Fig. 66.5, it is seen that $B = 1$ V and $A = 1.5$ V

$$\therefore m = \frac{1}{1.5} \times 100 = 66.7\%$$

Modulation may also be defined in terms of the values referred to the modulated carrier wave.

$$m = \frac{E_{c(max)} - E_{c(min)}}{E_{c(max)} + E_{c(min)}} \times 100$$

where $E_{c(max)}$ and $E_{c(min)}$ are the maximum and minimum values of the amplitude of the **modulated carrier wave**.

Again, from Fig. 66.5 we see that

$$m = \frac{2.5 - 0.5}{2.5 + 0.5} \times 100$$

$$= \frac{2}{3} \times 100 = 66.7\%$$

Fig. 66.6 shows a modulated wave with different degrees of modulation. As before, both the signal and carrier waves are assumed to be sine waves. Smallest value of $m = 0$ i.e. when amplitude of the modulating signal is zero. It means that $m = 0$ for an unmodulated carrier wave. Maximum value of $m = 1$ when $B = A$. Value of m can vary anywhere from 0 to 100% without introducing distortion. Maximum undistorted power of a radio transmitter is obtained when $m = 100\%$. If m is less than 100 per cent, power output is reduced though the power content of the carrier is not. Modulation in excess of 100 per cent produces severe distortion and interference (called splatter) in the transmitter output.

Example 66.1 A modulated carrier wave has maximum and minimum amplitudes of 750 mV and 250 mV. Calculate the value of percentage modulation.

Solution. The modulated wave is shown in Fig. 66.7.

Here, $E_{c(max)} = 750$ mV and $E_{c(min)} = 250$ mV

$$\therefore m = \frac{E_{c(max)} - E_{c(min)}}{E_{c(max)} + E_{c(min)}} \times 100$$

$$= \frac{750 - 250}{750 + 250} \times 100 = 50\%$$

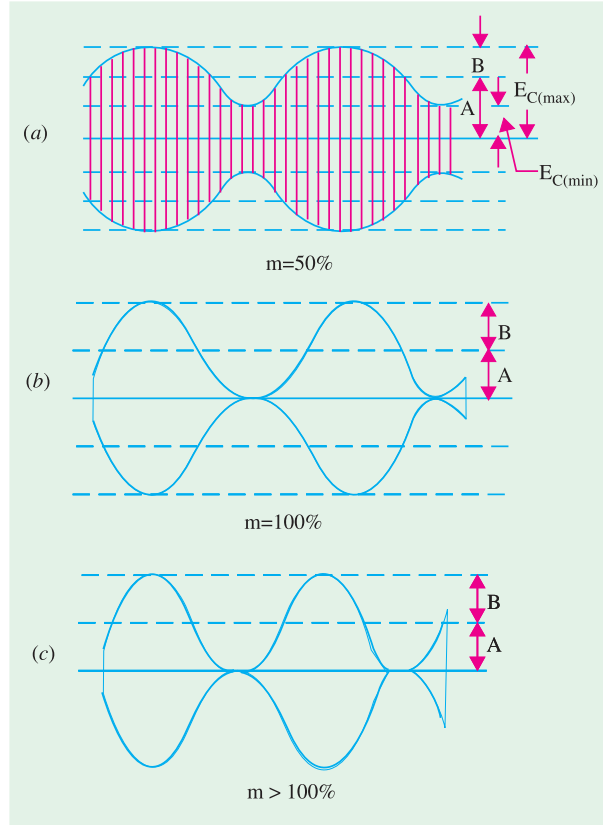


Fig. 66.6

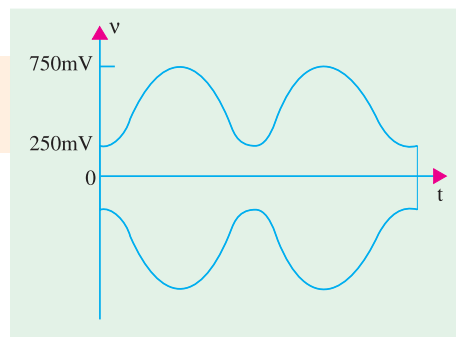


Fig. 66.7

66.11. Upper and Lower Side Frequencies

An unmodulated carrier wave consists of only one single-frequency component of frequency f_c . When it is combined with a modulating signal of frequency f_m , heterodyning action takes place.

As a result, two additional frequencies called **side frequencies** are produced. The AM wave is found to consist of three frequency components :

1. The original carrier frequency component, f_c .
2. A higher frequency component ($f_c + f_m$). It is called the sum component.
3. A lower frequency component ($f_c - f_m$). It is called the difference component.

The two new frequencies are called the **upper-side frequency (USF)** and **lower-side frequency (LSF)** respectively and are symmetrically located around the carrier frequency. The modulating frequency remains unchanged but does not appear in the amplifier output because the amplifier's load presents practically zero impedance to this low frequency.

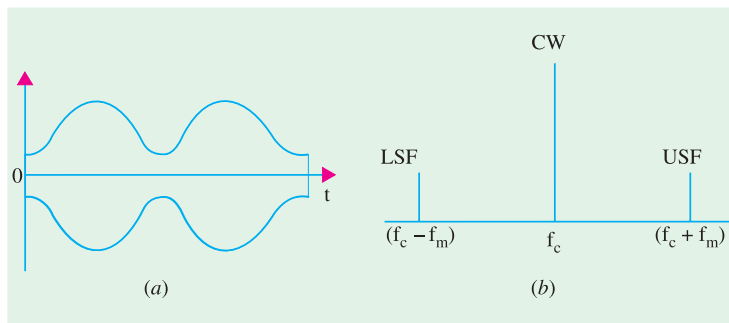


Fig. 66.8

These are shown in time domain in Fig. 66.8 (a) and in frequency domain in Fig. 66.8 (b). The amplitude of the side frequencies depends on the value of m . The amplitude of each side frequency = $mA/2$ where A is the amplitude of unmodulated carrier wave.

Example 66.2. A 10-MHz sinusoidal carrier wave of amplitude 10 mV is modulated by a 5 kHz sinusoidal audio signal wave of amplitude 6 mV. Find the frequency components of the resultant modulated wave and their amplitudes.

(Electronics & Comm. Engg.; Madras Univ. 1991)

Solution. Here, $f_c = 10$ MHz and $f_m = 5$ kHz = 0.005 MHz. The modulated carrier contains the following frequencies :

1. original carrier wave of frequency
 $f_c = 10$ MHz
2. USF of frequency
 $= 10 + 0.005 = 10.005$ MHz
3. LSF of frequency
 $= 10 - 0.005 = 9.995$ MHz

The frequency spectrum is shown in Fig. 66.9

$$\text{Here, } m = \frac{B}{A} = \frac{6}{10} = 0.6 = 0.6$$

Amplitude of LSF = USF = $mA/2 = 0.6 \times 10/2 = 3$ mV as shown.

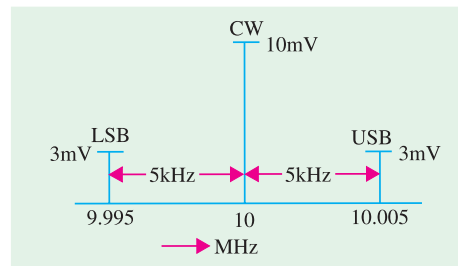


Fig. 66.9

66.12. Upper and Lower Sidebands

In Art 66.11, it was assumed that the modulating signal was composed of one frequency component only. However, in a broadcasting station, the modulating signal is the human voice (or music) which contains waves with a frequency range of 20-4000 Hz. Each of these waves has its own LSF and USF. When combined together, they give rise to an upper-side **band (USB)** and a lower-side **band (LSB)** as shown in Fig. 66.10. The USB, in fact, contains all sum components of the signal and carrier frequency whereas LSB contains their difference components.

The channel width (or bandwidth) is given by the difference between extreme frequencies i.e. between maximum frequency of *USB* and minimum frequency of *LSB*. As seen,

Channel width = $2 \times$ maximum frequency of modulating signal = $2 \times f_{m(max)}$

Example 66.3. An audio signal given by $15 \sin 2\pi(2000 t)$ amplitude-modulates a sinusoidal carrier wave $60 \sin 2\pi(100,000) t$.

Determine :

- (a) modulation index, (b) percent modulation, (c) frequencies of signal and carrier,
- (d) frequency spectrum of the modulated wave.

(Electronics & Telecom Engg., Jadavpur Univ. 1991)

Solution. Here, $B = 15$ and $A = 60$

(a) $M.I. = \frac{B}{A} = \frac{15}{60} = 0.25$

(b) $m = M.I. \times 100 = 0.25 \times 100 = 25\%$

(c) $f_m = 2000 \text{ Hz}$ — by inspection of the given equation

$f_c = 100,000 \text{ Hz}$ — by inspection of the given equation

(d) The three frequencies present in the modulated CW are

(i) $100,000 \text{ Hz} = 100 \text{ kHz}$

(ii) $100,000 + 2000 = 102,000 \text{ Hz} = 102 \text{ kHz}$

(iii) $100,000 - 2000 = 98,000 \text{ Hz} = 98 \text{ kHz}$

Example 66.4. A bandwidth of 15 MHz is available for AM transmission. If the maximum audio signal frequency used for modulating the carrier is not to exceed 15 kHz, how many stations can broadcast within this band simultaneously without interfering with each other?

(Electronics & Telecom Engg.; Pune Univ. 1991)

Solution. BW required by each station

$$= 2f_{m(max)} = 2 \times 15 = 30 \text{ kHz}$$

Hence, the number of station which can broadcast within this frequency band without interfering with one another is

$$= \frac{15 \text{ MHz}}{30 \text{ kHz}} = 500$$

Example 66.5. In a broadcasting studio, a 1000 kHz carrier is modulated by an audio signal of frequency range, 100-5000 Hz. Find (i) width or frequency range of sidebands (ii) maximum and minimum frequencies of USB (iii) maximum and minimum frequencies of LSB and (iv) width of the channel.

(Electronics & Comm. Engg. IERE, London)

Solution. (i) Width of sideband = $5000 - 100 = 4900 \text{ Hz}$

(ii) Max. frequency of USB = $1000 + 5 = 1005 \text{ kHz}$

Min. frequency of USB = $1000 + 0.1 = 1000.1 \text{ kHz}$

(iii) Max. frequency of LSB = $1000 - 0.1 = 999.9 \text{ kHz}$

Min. frequency of LSB = $1000 - 5 = 995 \text{ kHz}$

(iv) Width of channel = $1005 - 995 = 10 \text{ kHz}$

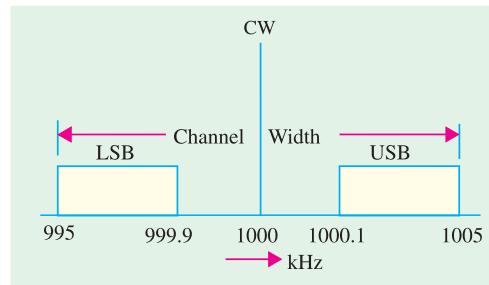


Fig. 66.10

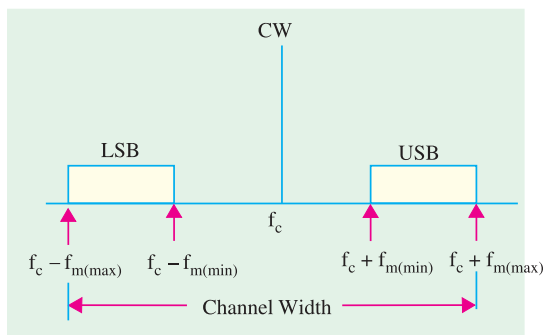


Fig. 66.11

66.13. Mathematical Analysis of a Modulated Carrier Wave

The equation of an unmodulated carrier wave is

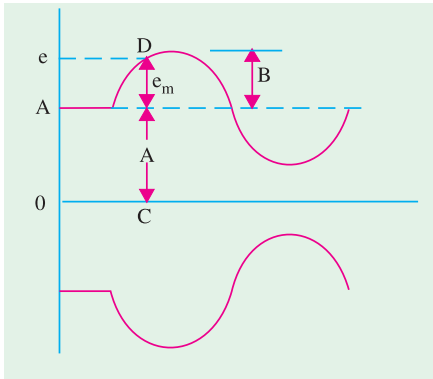


Fig. 66.12

$e_c = E_c \sin 2\pi f_c t = A \sin 2\pi f_c t = A \sin \omega t$
 where A is the constant amplitude of the carrier wave and $\omega = 2\pi f_c$.

Let the equation of the single-frequency sinusoidal modulating signal be

$$e_m = E_m \sin 2\pi f_m t = B \sin 2\pi f_m t = B \sin \pi t \quad \text{— where } p = 2\pi f_m$$

As seen from Fig. 66.12, the amplitude of the modulated carrier wave at any instant is

$$= A + e_m \quad (\because A \text{ is constant}) \\ = (A + B \sin \pi t)$$

Hence, its *instantaneous* value is given by

$$e = (A + B \sin pt) \sin \omega t = A \sin \omega t + B \sin \omega t \cdot \sin pt$$

$$= A \sin \omega t + \frac{B}{2} \cdot 2 \sin \omega t \cdot \sin pt = A \sin \omega t + \frac{B}{2} [\cos(\omega - p)t - \cos(\omega + p)t] *$$

$$= A \sin \omega t + \frac{B}{2} \cos(\omega - p)t - \cos(\omega + p)t$$

$$= A \sin 2\pi f_c t + \cos 2\pi (f_c - f_m)t - \cos 2\pi (f_c + f_m)t$$

As seen from Art. 66.10, $m = B/A$ or $B = mA$

$$\therefore e = A \sin 2\pi f_c t + \cos 2\pi (f_c - f_m)t - \cos 2\pi (f_c + f_m)t$$

It is seen that the modulated wave contains three components :

- (i) $A \sin 2\pi f_c t$ — the original carrier wave
- (ii) $\frac{mA}{2} \cos 2\pi (f_c + f_m)t$ — upper side frequency
- (iii) $\frac{mA}{2} \cos 2\pi (f_c - f_m)t$ — lower side frequency

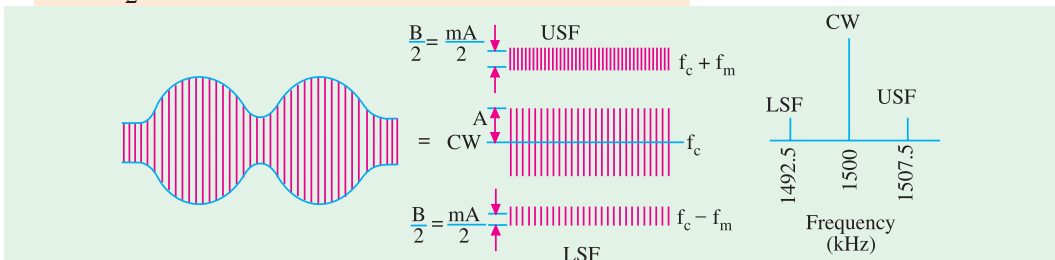


Fig. 66.13

These three frequencies are not a mathematical fiction but they actually exist. In fact, with the help of a narrow band filter, we can separate side frequencies from the carrier wave.

Example 66.6. The tuned circuit of the oscillator in an AM transmitter uses a 40 mH coil and a 1 nF capacitor. If the carrier wave produced by the oscillator is modulated by audio frequencies upto 10 kHz, calculate the frequency band occupied by the side bands and channel width.

(Electronics & Telecom. Engg., Calcutta Univ. 1990)

Solution. The resonant frequency is given by

$$f_c = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{40 \times 10^{-6} \times 1 \times 10^{-9}}} = 796 \text{ kHz}$$

* $2 \sin A \cdot \sin B = \cos(A - B) - \cos(A + B)$

The frequency range occupied by the sidebands is from **786 kHz to 806 kHz**. The channel width

$$= 2 \times 10 = \mathbf{20 \text{ kHz}}$$

66.14. Power Relations in an AM Wave

As discussed in Art. 66.13, a modulated carrier wave consists of the following three components :

1. original carrier wave of amplitude A
2. *USF* wave of amplitude $(mA/2)$
3. *LSF* wave of amplitude $(mA/2)$

Now, power radiated out by a wave through an antenna is proportional to (amplitude)².

$$\text{Carrier power, } P_C \propto A^2 = KA^2$$

$$\text{USB power, } P_{USB} \propto \left(\frac{B}{2}\right)^2 = \frac{KB^2}{4}; \text{ LSB power, } P_{LSB} \propto \left(\frac{B}{2}\right)^2 = \frac{KB^2}{4}$$

$$\text{Total sideband power } P_{SB} = 2 \times \frac{KB^2}{4} = \frac{KB^2}{2}$$

$$\text{Total power radiated out from the antenna is } P_T = P_C + P_{SB} = KA^2 + \frac{KB^2}{2}$$

$$\text{Substituting } B = mA, \text{ we get } P_T = KA^2 + \frac{KB^2}{2}(mA)^2 = KA^2 \left(1 + \frac{m^2}{2}\right)$$

$$\text{Now } P_C = KA^2$$

$$(i) \quad \therefore P_T = P_C \left(1 + \frac{m^2}{2}\right) = P_C \left(\frac{2 + m^2}{2}\right) \quad (ii) \quad P_C = P_T = P_T \left(\frac{2}{2 + m^2}\right)$$

$$(iii) \quad P_{SB} = P_T - P_C = P_C \left(1 + \frac{m^2}{2}\right) - P_C = \frac{m^2}{2} P_C = \left(\frac{m^2}{2 + m^2}\right) P_T$$

$$(iv) \quad P_{USB} = P_{LSB} = \frac{1}{2} P_{SB} = \frac{m^2}{4} P_C = \frac{1}{2} \left(\frac{m^2}{2 + m^2}\right) P_T$$

Let us consider the case when $m = 1$ or 100%

$$(i) \quad P_T = 1.5 P_C = 1.5 \times \text{carrier power} \quad (ii) \quad P_C = \frac{2}{3} P_T = \frac{2}{3} \times \text{total power radiated}$$

$$(iii) \quad P_{USB} = P_{LSB} = \frac{1}{4} P_C = 25\% \text{ of carrier power}$$

$$(iv) \quad P_{SB} = \frac{1}{2} P_C = 50\% \text{ of carrier power} \quad (v) \quad \frac{P_{USB}}{P_T} = \frac{0.25 P_C}{1.5 P_C} = \frac{1}{6}$$

It means that **single side-band contains 1/6th of the total power radiated out by the transmitter**. That is why single-side band (SSB) transmission is more power efficient.

Example 66.7. The total power content of an AM wave is 1500 W. For a 100 percent modulation, determine

- (i) power transmitted by carrier, (ii) power transmitted by each side band.

(Electronics & Comm. Engg., Kerala Univ. 1991)

Solution. $P_T = 1500 \text{ W}, P_C = ? \quad P_{USB} = ? \quad P_{LSB} = ?$

$$(i) \quad P_C = P_T \left(\frac{2}{2 + m^2}\right) = P_T \left(\frac{2}{2 + 1^2}\right) = \frac{2}{3} P_T = \frac{2}{3} \times 1500 = \mathbf{1000 \text{ W}}$$

$$(ii) P_{USB} = P_{LSB} = \frac{m^2}{4} P_C = \frac{1^2}{4} \times 1000 = 250 \text{ W}$$

$$\text{As seen, } P_{USB} = \frac{1}{6} P_T$$

Example 66.8. 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. (Electronics & Comm., Roorkee Univ. 1991)

$$\text{Solution. (i) } P_C = P_T \left(\frac{2}{2+m^2} \right) = 2.64 \times 10^3 \left(\frac{2}{2+0.8^2} \right) = 2000 \text{ W}$$

$$(ii) P_{USB} = P_{LSB} = \frac{m^2}{4} = \frac{0.8^2}{4} \times 2000 = 320 \text{ W}$$

Example 66.9. A transmitter used for radio telephone has an unmodulated carrier power of 10 kW and can be modulated to a maximum of 80 percent by a single-frequency signal before overloading. Find the value to which carrier power can be increased if a 50 percent modulation limit is imposed. (Electronics & Comm. Engg. Andhra Univ.)

$$\text{Solution. } P_T = P_C \left(\frac{2+m^2}{2} \right) = 10 \left(\frac{2+0.8^2}{2} \right) = 13.2 \text{ kW}$$

Now, when $m = 0.5$, P_T is still 13.2 kW. Hence, new value of carrier power is given by

$$13.2 = P_C \left(\frac{2+0.5^2}{2} \right); \quad P_C = 11.73 \text{ kW}$$

It is seen that P_C can be increased from 10 kW to 11.73 kW with a total power limit of 13.2 kW and $m = 0.5$

Example 66.10. A certain transmitter radiates 10 kW of power with the carrier unmodulated and 11.8 kW with the carrier sinusoidally modulated.

- (a) Find the modulation factor,
 (b) If another wave modulated to 40% is also transmitted, calculate the radiated power.

$$\text{Solution. (a) } 11.8 = 10 (1 + m^2/2); \quad m = 0.6 \text{ or } 60\%$$

$$(b) P_T = 10 \left(1 + \frac{0.6^2}{2} + \frac{0.4^2}{2} \right) = 12.6 \text{ kW}$$

66.15. Forms of Amplitude Modulation

As shown in Art. 66.11, **one carrier** and **two sidebands** are produced in AM generation. It is found that it is not necessary to transmit all these signals to enable the receiver to reconstruct the original signal. Accordingly, we may attenuate or altogether remove the carrier or any one of the sidebands without affecting the communication process. The advantages would be

1. less transmitted power and
2. less bandwidth required

The different suppressed component systems are :

(a) DSB-SC

It stands for **double-sideband suppressed carrier** system [Fig. 66.14 (a)]. Here, carrier component is suppressed thereby saving enormous amount of power. As seen from Art. 66.14, carrier signal contains 66.7 per cent of the total transmitted power for $m = 1$, Hence, power saving amounts to 66.7% at 100% modulation.

(b) SSB-TC

As shown in Fig. 66.14 (b), in this case, one sideband is suppressed but the other sideband and carrier are transmitted. It is called **single sideband transmitted carrier** system. For $m = 1$, power saved is 1/6 of the total transmitted power.

(c) SSB-SC

This is the **most dramatic suppression of all** because it suppresses one sideband and the carrier and transmits only the remaining sideband as shown in Fig. 66.14 (c). In the standard or double-sideband full-carrier (DSB-FC) AM, carrier conveys **no information but contains maximum power**. Since the two sidebands are exact images of each other, they carry the same audio information. Hence, **all information is available in one sideband only**. Obviously carrier is **superfluous** and one side band is **redundant**. Hence, one sideband and the carrier can be discarded with no loss of information. The result is SSB signal. The advantage of SSB-SC system are as follows :

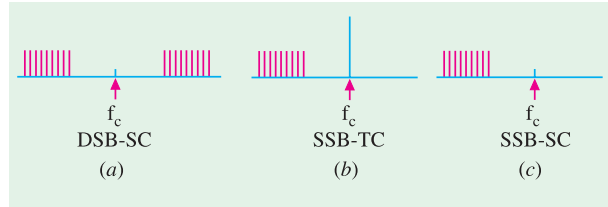


Fig. 66.14

1. Total saving of 83.3% in transmitted power (66.7% due to suppression of carrier wave and 16.6% due to suppression of one sideband). Hence, power is conserved in an SSB transmitter.
2. Bandwidth required is reduced by half *i.e.* 50%. Hence, twice as many channels can be multiplexed in a given frequency range.
3. The size of power supply required is very small. This fact assumes vital importance particularly in a spacecraft.
4. Since the SSB signal has narrower bandwidth, a narrower passband is permissible within the receiver, thereby limiting the noise pick up.

However, the main reason for wide spread use of DSB-FC (rather than SSB-SC) transmission in broadcasting is the relative simplicity of its modulating equipment.

66.16. Generation of SSB

Three main systems are employed for the generation of SSB.

1. Filter method, 2. Phase cancellation method, 3. The 'third' method.

All these methods use some form of balanced modulator to suppress the carrier.

Example 66.11. In an AM wave, calculate the power saving when the carrier and one sideband are suppressed corresponding to

- (i) $m = 1$ (ii) $m = 0.5$ (Electronics and Comm. Engg., Osmania Univ.)

Solution. (i) When $m = 1$

$$P_T = P_c \left(1 + \frac{m^2}{2} \right) = 1.5 P_c ; \quad P_{LSB} = P_{USB} = \frac{m^2}{4} P_c = 0.25 P_c$$

$$\therefore \text{saving} = P_T - P_{USB} = 1.5 P_c - 0.25 P_c = 1.25 P_c$$

$$\text{saving} = \frac{1.25}{1.5 P_c} \times 100 = 83.3\%$$

(ii) When $m = 0.5$

$$P_T = P_c \left(1 + \frac{m^2}{2} \right) = P_c \left(\frac{1 + 0.5^2}{2} \right) = 1.125 P_c$$

$$P_{USB} = P_{LSB} = \frac{m^2}{4} P_c = \frac{0.5^2}{4} P_c = 0.0625 P_c$$

$$\therefore \text{saving} = \frac{1.125 P_c - 0.0625 P_c}{1.125 P_c} \times 100 = 94.4\%$$

66.17. Methods of Amplitude Modulation

There are two methods of achieving amplitude modulation :

- (i) Amplifier modulation,
- (ii) Oscillator modulation.

Block diagram of Fig. 66.15 illustrates the basic idea of amplifier modulation.

Here, carrier and *AF* signal are fed to an amplifier and the result is an *AM* output . The modulation process takes place in the active device used in the amplifier.

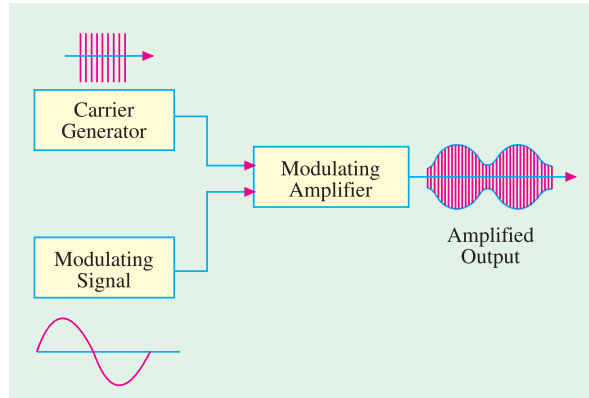


Fig. 66.15

66.18. Block Diagram of an AM Transmitter

Fig. 66.16 shows the block diagram of a typical transmitter. The carrier wave is supplied by a crystal-controlled oscillator at the carrier frequency. It is followed by a tuned buffer amplifier and an *RF* output amplifier.

The source of *AF* signal is a microphone. The audio signal is amplified by a low level audio amplifier and, finally, by a power amplifier. It is then combined with the carrier to produce a modulated carrier wave which is ultimately radiated out in the free space by the transmitter antenna as shown.

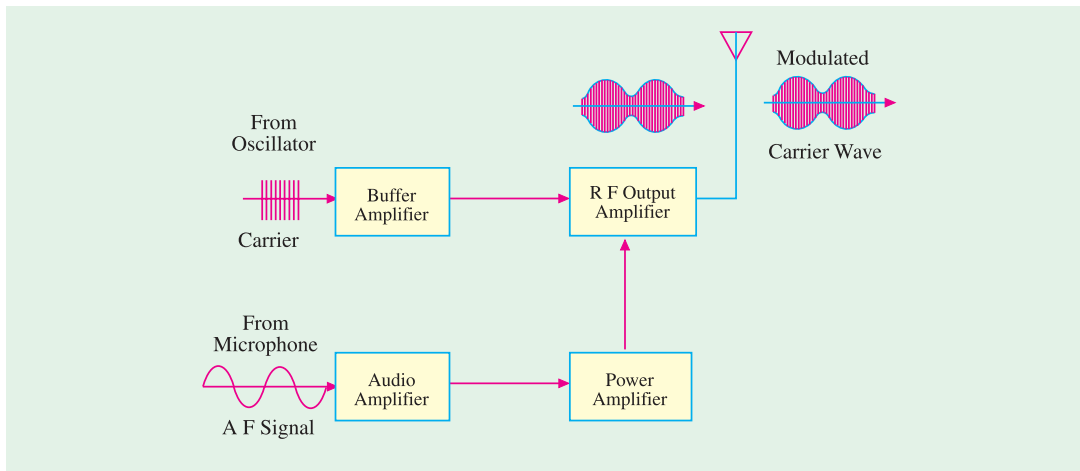


Fig. 66.16

66.19. Modulating Amplifier Circuit

It is shown in Fig. 66.17. The carrier signal from a crystal oscillator is coupled to the base of *Q* through transformer *T₁*. The low-frequency modulating signal is also coupled to the base of *Q* by capacitor *C₁*. The voltage divider *R₁ – R₂*, as usual, provides proper forward bias for the transistor whereas *C₂* and *C₃* are bypass capacitors.

The modulating signal applied across *R₂* causes variations in the base bias in step with its own variations. The amplitude of the transistor *RF* output changes according to the changes in *AF* modulating signal. The *L₁ C₄* circuit is kept tuned to the carrier frequency. The amplitude-modulated

carrier or *RF* current in L_1 induces similar current in L_2 which is connected to an antenna. Finally, the *AM* carrier wave is radiated out in space by the transmitting antenna.

66.20. Frequency Modulation OR CAD Simulation Diagram.

As the name shows, in this modulation, it is only the **frequency of the carrier which is changed and not its amplitude.**

The **amount of change** in frequency is determined by the **amplitude** of the modulating signal whereas **rate of change** is determined by the **frequency** of the modulating signal. As shown in Fig. 16.18, in an *FM* carrier, information (or intelligence) is carried as variations in its frequency. As seen, frequency of the modulated carrier increases

as the signal amplitude increases but decreases as the signal amplitude decreases. It is at its highest frequency (point *H*) when the signal amplitude is at its maximum positive value and is at its lowest frequency (point *L*) when signal amplitude has maximum negative value. When signal amplitude is zero, the carrier frequency is at its normal frequency f_0 (also called **resting or centre** frequency.)

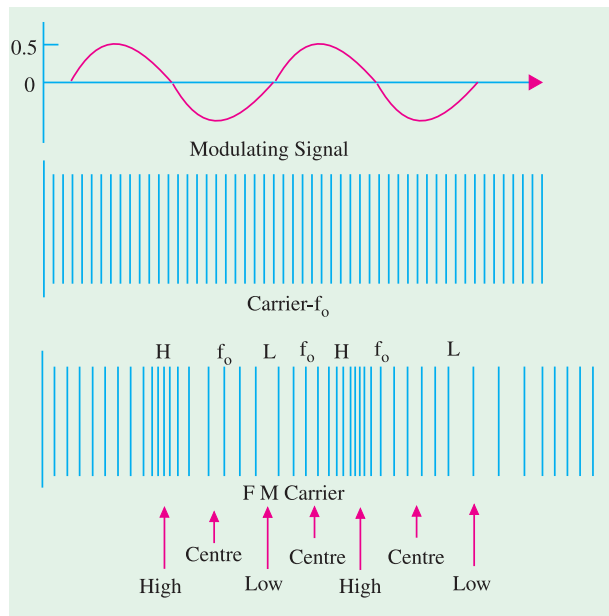


Fig. 66.18

swing between its maximum frequency and lowest frequency 1000 times per second. If $f_m = 2$ kHz, the rate of frequency swing would be twice as fast :

- In short, we have established two important points about the nature of frequency modulation:
- (i) The **amount** of frequency deviation (or shift or variation) depends on the **amplitude** (loudness) of the audio signal. **Louder the sound, greater the frequency deviation and vice-versa.**

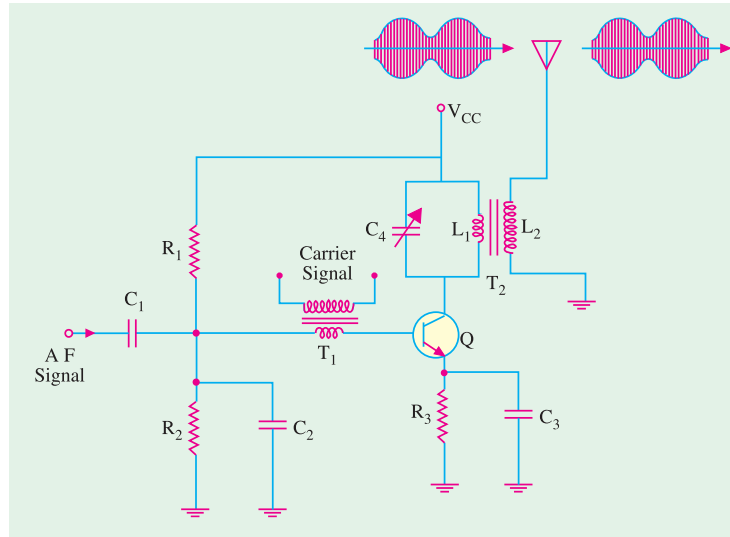


Fig. 66.17

The fact that amount of change in frequency depends on signal amplitude is illustrated in Fig. 66.19 where *R* stands for resting frequency. Here, signal amplitude is almost double of that in Fig. 66.18 **though its frequency is the same.** This **louder** signal causes **greater** frequency change in modulated carrier as indicated by **increased bunching and spreading** of the waves as compared with relatively weaker signal of Fig. 66.18.

The **rate** at which frequency shift takes place depends on the signal frequency as shown in Fig. 66.20. For example, if the modulating signal is 1 kHz, then the modulated carrier will

swing between its maximum frequency and lowest frequency 1000 times per second. If $f_m = 2$ kHz, the rate of frequency swing would be twice as fast :

However, for the purposes of *FM* broadcasts, it has been internationally agreed to restrict maximum deviation to **75 kHz** on each side of the centre frequency for sounds of maximum loudness. Sounds of lesser loudness are permitted *proportionately less frequency deviation*.

- (ii) The **rate** of frequency deviation depends on the **signal frequency**.

66.21. Frequency Deviation and Carrier Swing

The frequency of an *FM* transmitter without signal input is called the **resting frequency** or **centre frequency** (f_0) and is the allotted frequency of the transmitter. In simple words, it is the carrier frequency on which a station is allowed to broadcast. When the signal is applied, the carrier frequency deviates up and down from its resting value f_0 .

This change or shift either above or below the resting frequency is called frequency deviation (Δ_f)

The total variation in frequency from the lowest to the highest is called carrier swing (CS). Obviously,

$$\text{carrier swing} = 2 \times \text{frequency deviation of CS} = 2 \times \Delta_f$$

A maximum frequency deviation of 75 kHz is allowed for commercial *FM* broadcast stations in the 88 to 168 MHz *VHF* band. Hence, *FM* channel width is $275 = 150$ kHz. Allowing a 25 kHz guard band on either side, the channel width becomes $= 2(75 + 25) = 200$ kHz (Fig. 66.21). This guard band is meant to prevent interference between adjacent channels. However, a maximum frequency deviation of 25 kHz is allowed in the sound portion of the TV broadcast.

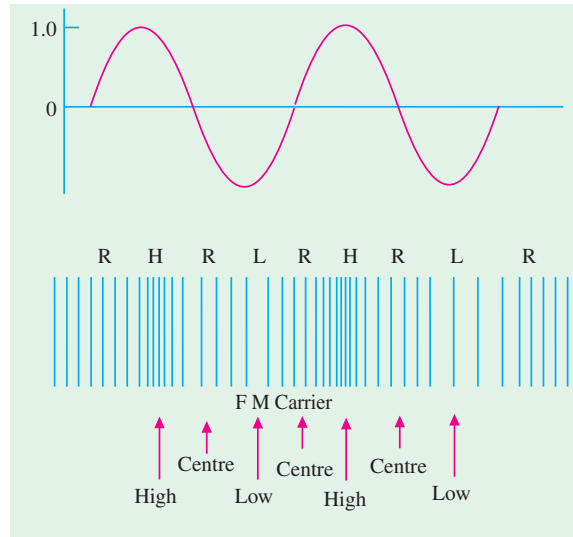


Fig. 66.19

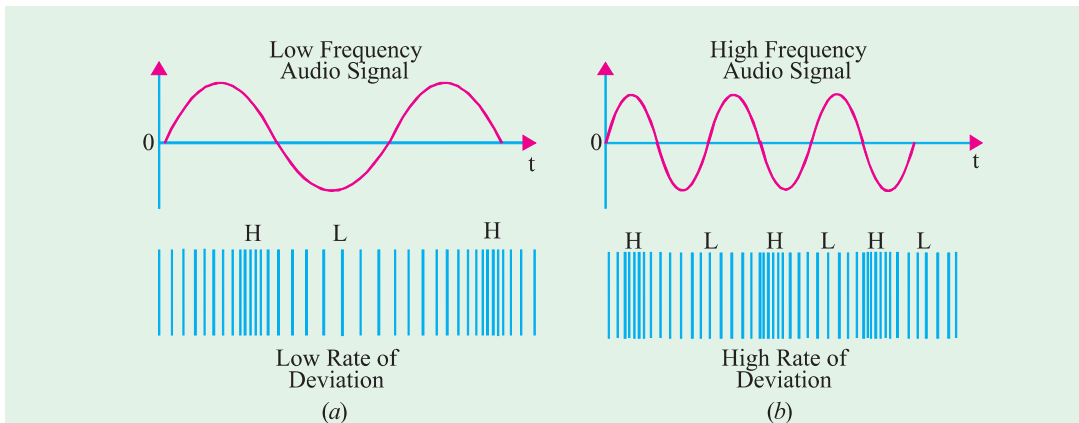


Fig. 66.20

In *FM*, the highest audio frequency transmitted is 15 kHz.

Consider an *FM* carrier of resting frequency 100 MHz. Since $(\Delta f)_{max} = 75$ kHz, the carrier frequency can swing from the lowest value of 99.925 MHz to the highest value of 100.075 MHz. Of course, deviations lesser than 75 kHz corresponding to relatively softer sounds are always permissible.

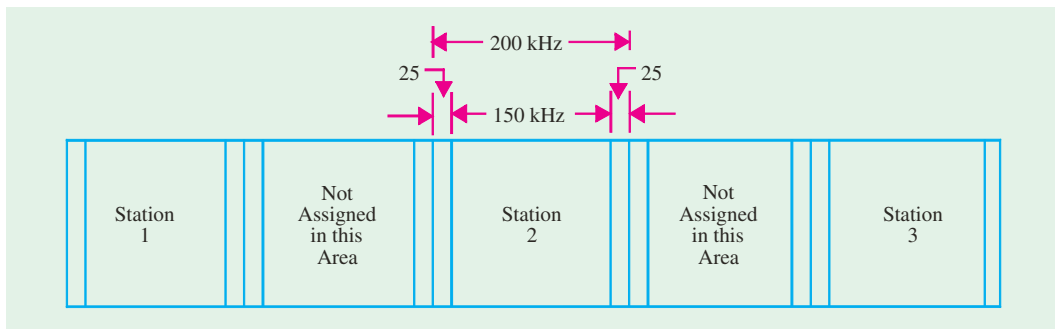


Fig. 66.21

66.22. Modulation Index

It is given by the ratio $m_f = \frac{\text{frequency deviation}}{\text{modulation frequency}} = \frac{\Delta f}{f_m}$

Unlike amplitude modulation, this **modulation index can be greater than unity**. By knowing the value of m_f , we can calculate the number of significant sidebands and the bandwidth of the *FM* signal.

66.23. Deviation Ratio

It is the worst-case modulation index in which maximum permitted frequency deviation and maximum permitted audio frequency are used.

$$\therefore \text{deviation ratio} = \frac{(\Delta f)}{f_{m(\max)}}$$

Now, for *FM* broadcast stations, $(\Delta f)_{\max} = 75 \text{ kHz}$ and maximum permitted frequency of modulating audio signal is 15 kHz.

$$\therefore \text{deviation ratio} = \frac{75 \text{ kHz}}{15 \text{ kHz}} = 5$$

$$\text{For sound portion of commercial TV deviation ratio} = \frac{25 \text{ kHz}}{15 \text{ kHz}} = 1.67$$

66.24. Percent Modulation

When applied to *FM*, this term has slightly different meaning than when applied to *AM*. In *FM*, it is given by the ratio of actual frequency deviation to the maximum allowed frequency deviation.

$$m = \frac{(\Delta f)_{\text{actual}}}{(\Delta f)_{\max}}$$

Obviously, 100% modulation corresponds to the case when actual deviation equals the maximum allowable frequency deviation. If, in some case, actual deviation is 50 kHz, then

$$m = \frac{50}{75} = \frac{2}{3} = 0.667 = \mathbf{66.7\%}$$

Value of $m = 0$ corresponds to zero deviation *i.e.* unmodulated carrier wave. It is seen from the above equation that $m \propto (\Delta f)_{\text{actual}}$. It means that when **frequency deviation (*i.e.* signal loudness) is doubled, modulation is doubled**.

Example 66.12. What is the modulation index of an *FM* carrier having a carrier swing of 100 kHz and a modulating signal of 5 kHz ?

Solution. $CS = 2 \times \Delta f$
 $\therefore \Delta f = \frac{CS}{2} = \frac{100}{2} = 50 \text{ kHz} \therefore m_f = \frac{\Delta f}{f_m} = \frac{50}{5} = 10$

Example. 66.13. An FM transmission has a frequency deviation of 18.75 kHz. Calculate percent modulation if it is broadcast
 (i) in the 88-108 MHz band (ii) as a portion of a TV broadcast.
 (Elect. and Comm. Engg., Madurai Kamaraj Univ. 1990)

Solution. (i) For this transmission band,
 $(\Delta f)_{max} = 75 \text{ kHz} \therefore m = \frac{18.75}{75} \times 100 = 25\%$
 (ii) In this case, $(\Delta f)_{max} = 25 \text{ kHz} \therefore m = \frac{18.75}{25} \times 100 = 75\%$

Example 66.14. An FM signal has a resting frequency of 105 MHz and highest frequency of 105.03 MHz when modulated by a signal of frequency 5 kHz. Determine
 (i) frequency deviation, (ii) carrier swing, (iii) modulation index,
 (iv) percent modulation, (v) lowest frequency reached by the FM wave.
 (Electronics and Comm. Engg., Osmania Univ. 1992)

Solution. (i) $\Delta f = 105.03 - 105 = 0.03 \text{ MHz} = 30 \text{ kHz}$
 (ii) $CS = 2 \times \Delta f = 2 \times 30 = 60 \text{ kHz}$ (iii) $m_f = \frac{30}{5} = 6$
 (iv) $m = \frac{30}{5} \times 100 = 40\%$ (v) **lowest frequency** = $105 - 0.03 = 104.97 \text{ kHz}$

66.25. FM Sidebands

In FM, when a carrier is modulated, a number of sidebands are formed.* Though theoretically their number is infinite, their strength becomes negligible after a few sidebands. They lie on both sides of the centre frequency spaced f_m apart as shown in Fig.66.22. Sidebands at equal distances from f_0 have equal amplitudes. If f_0 is the centre frequency and f_m the frequency of the modulating signal, then FM carrier contains the following frequencies :

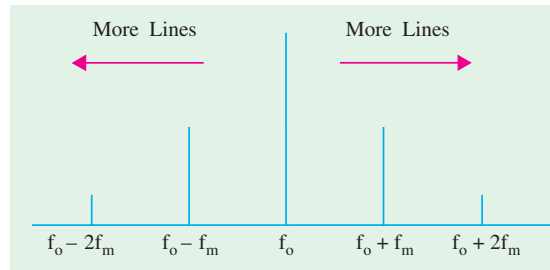


Fig. 66.22

- (i) f_0 (ii) $f_0 \pm f_m$ (iii) $f_0 \pm 2f_m$ (iv) $f_0 \pm 3f_m$ and so on

The bandwidth occupied by the spectrum is $BW = 2nf_m$ where n is the highest order of the significant sideband.

Another approximate expression for spectrum bandwidth is $BW = 2(1 + m_f)f_m$

Now, $m_f = \frac{\Delta f}{f_m}$, hence $BW = 2(\Delta f + f_m)$

This expression is based on the assumption that sidebands having amplitudes less than 5% of the unmodulated carrier wave are negligible or when m_f is at least 6.

66.26. Modulation Index and Number of Sidebands

It is found that the number of sidebands

1. depends **directly** on the amplitude of the modulating signal,
2. depends **inversely** on the frequency of the modulating signal.

* An AM signal has only two side frequencies for each modulating frequency (Art. 16.11)

Since frequency deviation is directly related to the amplitude of the modulating signal, the above two factors can be combined in one factor called **modulation index**.

Hence, number of sidebands depends on $m_f = \Delta f / f_m$

Obviously, the number of pairs of sidebands

(i) **increases** as frequency deviation (or amplitude of modulating signal) **increases**.

(ii) **increases** as the modulating signal frequency **decreases**.

Table No. 66.2

m_f	0.5	1	2	3	4	5	6	7
n	2	3	4	6	7	8	9	11
$BW = 2nf_m$	$4f_m$	$6f_m$	$8f_m$	$12f_m$	$14f_m$	$16f_m$	$18f_m$	$22f_m$
m_f	8	9	10	11	12	13	14	15
n	12	13	14	15	16	17	18	19
$BW = 2nf_m$	$24f_m$	$26f_m$	$28f_m$	$30f_m$	$32f_m$	$34f_m$	$36f_m$	$38f_m$

Table 66.2 summarizes the relation between the number (n) of sidebands on either side of the carrier and the corresponding bandwidth of the spectrum.

Example 66.15. A 5 kHz audio signal is used to frequency-modulate a 100 MHz carrier causing a frequency deviation of 20 kHz. Determine

- (i) modulation index (ii) bandwidth of the FM signal.

Solution. (i) $m_f = \frac{\Delta f}{f_m} = \frac{20}{5} = 4$

As seen from Table 66.2 $BW = 14f_m = 14 \times 5 = 70 \text{ kHz}$

Note. We cannot use the alternate expression for BW given in Art. 66.25 above because $m_f < 6$

Example 66.16. In an FM circuit, the modulation index is 10 and the highest modulation frequency is 20 kHz. What is the approximate bandwidth of the resultant FM signal ?

(Applied Electronics, Bombay Univ. 1990)

Solution. Since the value of m_f is more than 6, we will use the expression

$$BW = 2(\Delta_f + f_m)$$

Now, $m_f = \frac{\Delta f}{f_m}$ or $10 = \frac{\Delta f}{20} \quad \therefore \quad \Delta_f = 200 \text{ kHz}$

$\therefore BW = 2(200 + 20) = 440 \text{ kHz}$

66.27. Mathematical Expression for FM Wave

The unmodulated carrier is given by $e_c = A \sin 2\pi f_0 t$

The modulating signal frequency is given by $e_m = B \sin 2\pi f_m t$

The modulated carrier frequency f swings around the resting frequency f_0 thus

$$f = f_0 + \Delta_f \cdot \sin 2\pi f_m t$$

Hence, equation for the frequency-modulated wave becomes

$$\begin{aligned}
 e &= A \sin 2\pi f t = A \sin [2\pi(f_0 + \Delta_f \cdot \sin 2\pi f_m t)t] \\
 &= A \sin (2\pi f_0 t + \frac{\Delta f}{f_m} + \cos 2\pi f_m t) = A \sin (2\pi f_0 t + m_f \cos 2\pi f_m t)
 \end{aligned}$$

66.28. Demodulation or Detection

When the RF modulated waves, radiated out from the transmitter antenna, after travelling through space, strike the receiving aerials, they induce very weak RF currents and voltages in them. If these high-frequency currents are passed through headphones or loudspeakers, they produce no effect on them because all such sound-producing devices are unable to respond to such high frequencies due to large inertia of their vibrating discs etc. Neither will such RF currents produce any effect on human ear because their frequencies are much beyond the audible frequencies (20 to 20,000 Hz approximately). Hence, it is necessary to demodulate them first in order that the sound-producing devices may be actuated by audio-frequency current similar to that used for modulating the carrier wave at the broadcasting station.

This process of **recovering AF signal from the modulated carrier wave is known as demodulation or detection.**

The demodulation of an AM wave involves two operations :

- (i) rectification of the modulated wave and
- (ii) elimination of the RF component of the modulated wave.

However, demodulation of an FM wave involves three operations (i) conversion of frequency changes produced by modulating signal into corresponding amplitude changes, (ii) rectification of the modulating signal and (iii) elimination of RF component of the modulated wave.

66.29. Essentials of AM Detection

For recovering the AF waveform from modulated wave (a mixture of AF wave and RF carrier), it is essential to find some way of reducing (or better, eliminating) one half of the modulated wave. The result of this elimination (or rectification) would be that the average value of the wave would not be zero because, now, the impulse would be all in one direction as shown in Fig. 66.23. If this new wave is now passed through a headphone shunted by a suitable capacitor, then AF wave will pass through the headphone whereas the RF wave will be by-passed by the capacitor (because the high inductance of magnet coils of the headphones will offer tremendous impedance to RF currents). Hence, two will become separated.

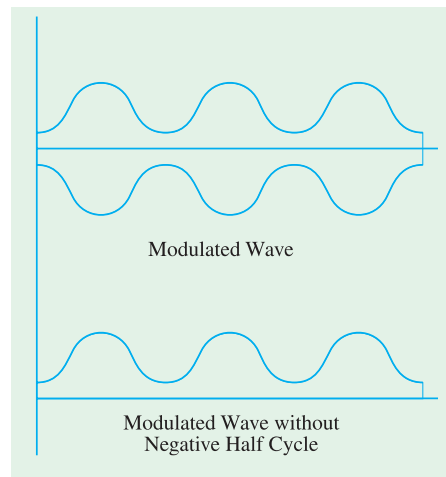


Fig. 66.23

66.30. Diode Detector for AM Signals

Diode detection is also known as **envelope-detection** or **linear detection**. In appearance, it looks like an ordinary half-wave rectifier circuit with capacitor input as shown in Fig. 66.24. It is called **envelope detection** because it recovers the AF signal envelope from the composite signal. Similarly, diode detector is called **linear detector** because its output **is proportional to the voltage of the input signal***.

Circuit Action

Of the various RF voltages induced in the receiver aerial, only those having the **same** frequency as the resonant frequency of LC circuit are tuned in due to electromagnetic induction between coils L_1 and L . By varying C , the resonant frequency of the LC circuit can be varied and hence RF signal of any desired frequency can be tuned in. This input signal is rectified by the diode and passed on to the low-pass filter RC_1 .

* A detector circuit in which the rectified output is proportional to the square of the input signal voltage is called square-law or non-linear detector.

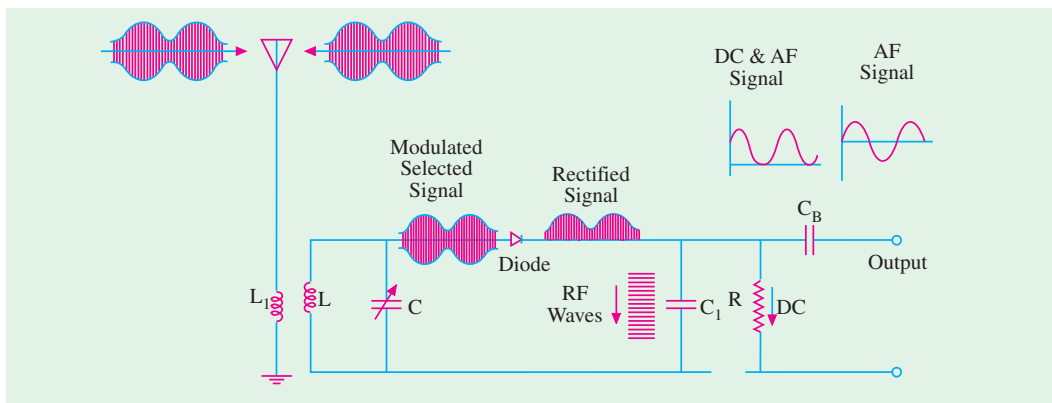


Fig. 66.24

The *RF* carrier wave is filtered out by low-reactance capacitor C_1 which is called *RF* filter capacitor or *RF* by-pass capacitor. The dc component of the remaining signal is shunted out through R because it cannot pass through blocking capacitor C_B . But the low, frequency *AF* signal can easily get through C_B and becomes available across the output. When passed through a suitable device, say, a headphone, the original sound can be heard.

Advantages

Diode detectors are extensively used in AM broadcast receivers because they have the following advantages :

1. They can handle comparatively large input signals;
2. They can be operated as linear or power detectors;
3. They rectify with negligible distortion and, hence, have good linearity;
4. They are well-adapted for use in simple automatic-gain control circuits.

Disadvantages

However, the disadvantages are that

1. they do not have the ability to amplify the rectified signal by themselves as is done by a transistor detector (Art. 66.31). However, it is not a very serious drawback since signal amplification can be affected both before and after rectification;
2. while conducting, the diode consumes some power which reduces the Q of its tuned circuit as well as its gain and selectivity.

66.31. Transistor Detectors for AM Signals

Transistors can be used as detector amplifiers *i.e.* both for rectification and amplification. As shown in Fig. 66.25, the *RF* signal is applied at the base-emitter junction where rectification takes place. The amplification of the recovered signal takes place in the emitter-collector circuit.

It should be noted that when used as a detector, the transistor has to be biased at cut-off or operated as class-B. As is usual, C_2 ac grounds R_3

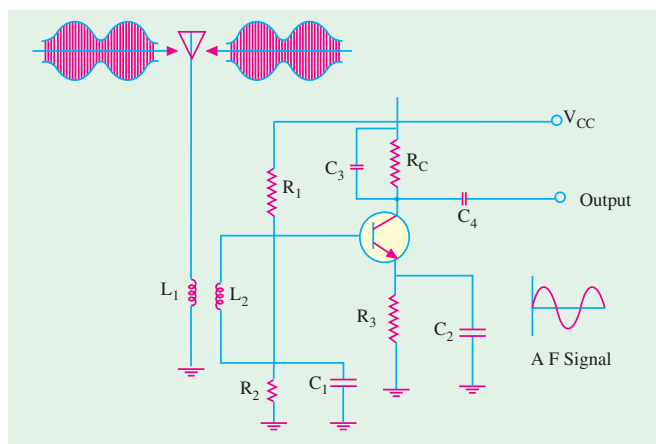


Fig. 66.25

whereas voltage divider $R_1 - R_2$ establishes proper bias which holds the transistor just at cut-off.

Obviously, only positive half-cycles of the modulated RF input signal will drive the transistor into conduction, whereas negative half-cycles would be cut-off. Thus, rectification of the input signal takes place in the base-emitter circuit. The small variations in base current produced by the positive half-cycle of the input signal produce large (β times) variations in the collector current. Hence, an amplified version of the rectified signal appears across $R_C - C_3$ combination. C_3 eliminates RF component so that only AF signal voltage drops across RC . The capacitor C_4 permits AF signal to pass through but blocks its dc component.

66.32. FM Detection

As discussed earlier, an FM carrier signal contains information (or intelligence we wish to convey) in the form of frequency variations above and below the centre frequency of the carrier. For recovering the information, we must first convert the FM signal in such a way that it appears as a modulated RF voltage across the diode. A simple method of converting frequency variations into voltage variations is to make use of the principle that reactance (of coil or capacitor) varies with frequency. When an FM signal is applied to an inductor, the current flowing through it varies in amplitude according to the changes in frequency of the applied signal. Now, changes in frequency of the FM signal depend on the amplitude of the modulating AF signal. Hence, the current in the inductor varies as per the amplitude of the original modulating signal. In this way, frequency changes in FM signal are converted into amplitude changes in current. These changes in current when passed through a resistor produce corresponding changes in voltage.

Hence, we find that, ultimately, frequency variations in FM signal are converted into voltage changes. Also, there exists a linear relation between the two – something essential for distortion-less demodulation.

FM demodulation may be carried out with the help of (i) ratio detector and (ii) quadrature detector.

66.33. Quadrature Detector

This detector depends on the frequency/phase relationship of a tuned circuit. It uses only one tuned circuit and is becoming increasingly popular in the integrated FM strips.

Theory

Let us first consider the general principle. A sinusoidal current is given by the equation

$$i = I_m \sin \theta = I_m \sin \omega t$$

Suppose, it flows through a circuit shown in Fig. 66.27 (a). The voltage V_L across the inductor (assumed pure) leads the current I by 90°

$$\therefore V_L = V_L \cos \omega t$$

The voltage V_z across the parallel tuned circuit will be in phase with I at resonance. However, at frequencies slightly different ($\pm 1\%$) from the resonant frequency, the phase angle ϕ will be given by

$$\tan \phi = \frac{yQR}{R} = yQ \quad \text{assuming } f_0/f \cong 1. \quad \text{— Fig.66.26}$$

Here
$$\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega} = \frac{f}{f_0} - \frac{f_0}{f} \cong \frac{2\Delta f}{f_0}$$

where $\Delta f = f - f_0$

f_0 = resonant frequency

f = slightly off-resonance frequency

Hence, equation for V_z is given by $V_z = V_z \sin(\omega t - \phi)$

When the two voltages V_L and V_z are applied as inputs to a multiplier, the output voltage V_0 is found to be proportional to their product as shown in Fig. 66.27(b).

$$\begin{aligned} V_0 &\propto V_L \cdot V_z \propto \cos \omega t \cdot \sin(\omega t - \phi) \\ &\propto \sin(2\omega t + \phi) + \sin \phi \end{aligned}$$

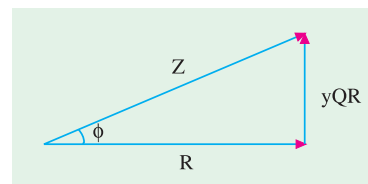


Fig. 66.26

A low-pass filter is used to reject the double frequency component $\sin(2\omega t + \phi)$ and select only the low-frequency $\sin \phi$ component.

$$\begin{aligned} \therefore V_0 &\propto \sin \phi \propto \tan \phi && \text{— since } \phi \text{ is very small} \\ &\propto y\phi \propto y \propto 2 \cdot \frac{\Delta f}{f_0} && \text{— where } V_m \text{ is the modulating AF voltage.} \end{aligned}$$

Now, $\Delta_f = f - f_0 \propto k V_m$
 $\therefore V_0 \propto V_m$

It shows that output voltage v_0 is proportional to the original modulating signal voltage.

66.34. Frequency Conversion

Let us first consider its necessity for radio broadcasting purposes and the basic principle of heterodyning action.

1. Need

It is very difficult to design amplifiers which give uniformly high gain over a wide range of radio

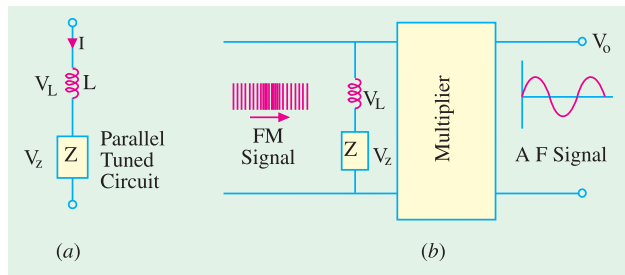


Fig. 66.27

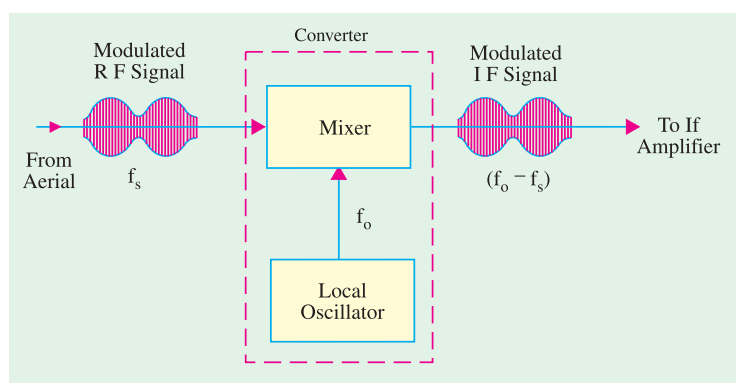


Fig. 66.28

This IF signal is then amplified by narrow-band IF amplifiers and passed on to the AM detectors.

2. Basic Principle

The frequency conversion can be achieved by utilizing the heterodyne principle. For this purpose, the modulated RF signal is mixed (in a mixer) with an unmodulated RF signal produced by local oscillator as shown in Fig. 66.28.

The oscillator and the mixer may be either two separate devices or may be combined into one device called converter. The process of combining two ac signals of different frequencies in order to obtain a signal of new frequency is called heterodyning action.

3. Heterodyning Action

Suppose the carrier signal of frequency f_s is heterodyned with another signal of frequency f_0 , then two additional signals are produced whose frequencies are :

- (i) $f_0 + f_s$ — the sum component
- (ii) $f_0 - f_s$ — the difference component

Usually, the sum frequency is removed by bandpass filtering. The difference frequency (also called **beat frequency**) is retained and forms the IF frequency in AM receivers.

frequencies used in commercial broadcast stations. However, it is possible to design amplifiers which can provide high-gain uniform amplification over a narrow band of comparatively lower frequencies called intermediate frequencies (IF). Hence, it is necessary to convert the modulated RF carrier into modulated IF carrier by using a frequency converter.

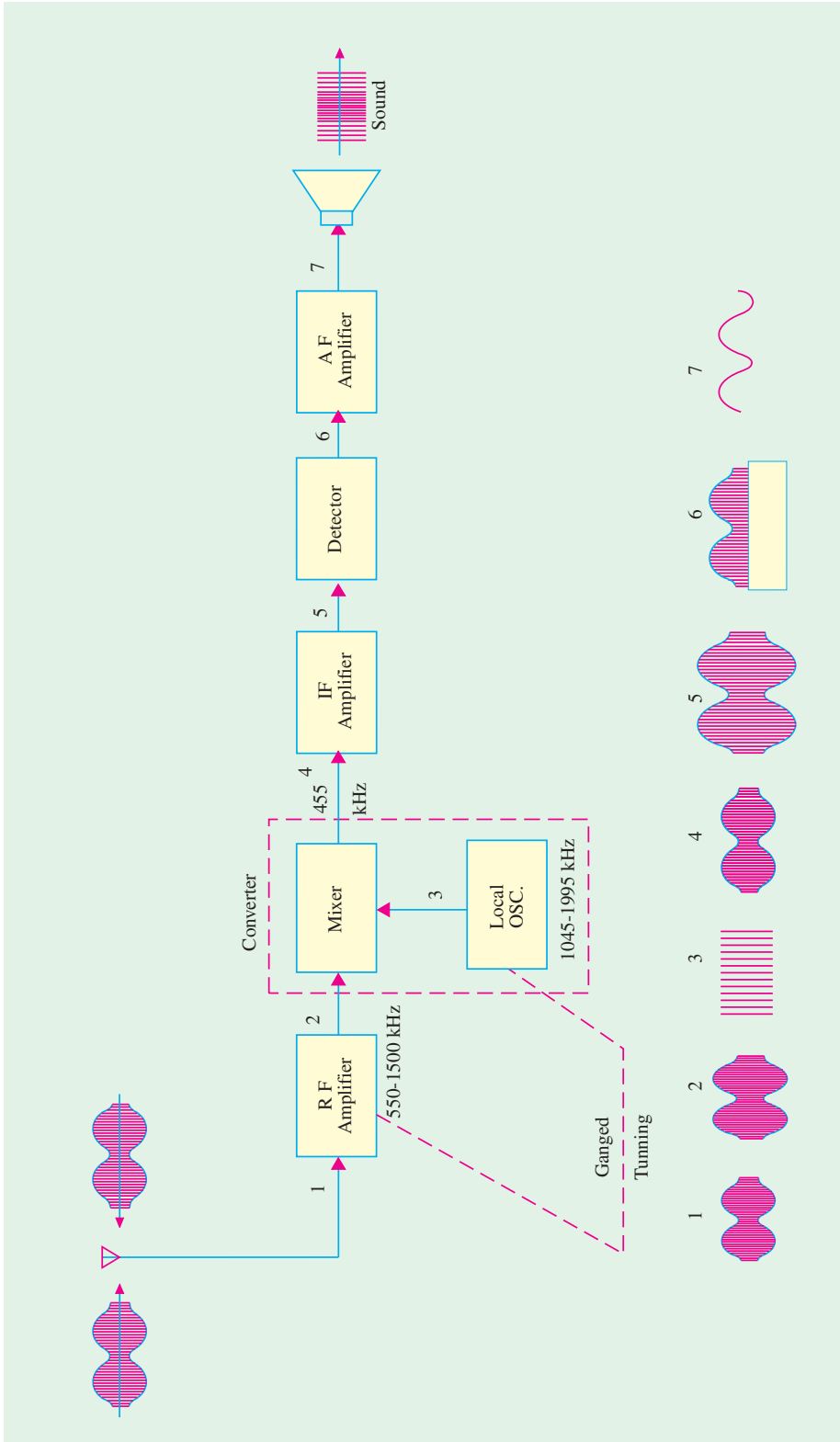


Fig. 66.29

Suppose, an AM carrier signal of frequency 1500 kHz is mixed with an unmodulated carrier (produced by local oscillator) of frequency 1955 kHz. Then, following two frequencies are produced

- (i) 3455 kHz and (ii) 455 kHz

The **higher frequency** is generally filtered out leaving behind the difference frequency of 455 kHz which forms the *IF* frequency.

66.35. Superhetrodyne AM Receiver

It is also referred to as superhet and is extensively used in modern AM receivers. Its block diagram with signals is shown in Fig. 66.29. The operation of this receiver is as under :

- (i) Let us assume that the incoming signal frequency is 1500 kHz. It is first amplified by the *R.F.* amplifier.
- (ii) Next, it enters a mixer circuit which is so designed that it can conveniently combine two radio frequencies—one fed into it by the *R.F.* amplifier and the other by a local oscillator.
- (iii) The local oscillator is an *RF* oscillator whose frequency of oscillation can be controlled by varying the capacitance of its capacitor. In fact, the tuning capacitor of the oscillator is ganged with the capacitor of the input circuit so that the difference in the frequency of the selected signal and oscillator frequency is always constant. Usually, the difference is maintained at 455 kHz. If signal frequency is 1,500 kHz, then oscillator frequency can be either 1,955 or 1,045 kHz. Let us suppose that it is 1,955 kHz. In fact, local oscillator frequency is always higher than the frequency of the incoming signal.
- (iv) When two alternating currents of these two different frequencies are combined in the mixer transistors, then phenomenon of beats is produced. In the present case, the beat frequency is $1955 - 1500 = 455$ kHz. Since this frequency is lower than the signal frequency but still above the range of audio frequencies, it is called **intermediate frequency (IF)**.
- (v) The 455 kHz output of the mixer is then passed on to the *IF* amplifier which is **fixed-tuned** to 455 kHz frequency. In practice, one or more stages of *IF* amplification may be used.
- (vi) The output of *IF* amplifier is demodulated by a detector which provides the audio signal.
- (vii) This audio signal is amplified by the audio-frequency (*AF*) amplifier whose output is fed to a loud-speaker which reproduces the original sound.

66.36. Standard Superhet AM Receiver

Fig. 66.30 shows the block diagram of a standard superhet AM receiver along with its seven-transistor circuit diagram. Usually, transistor radios are all-wave radios having two or more bands. With the help of a band switch, the coils and trimmers of any one band can be connected to the circuit at will. For the sake of simplicity, the coils and trimmers of one band only have been shown in Fig. 66.30. The operation of various stages and the functions of various radio components used in the radio circuit of Fig. 66.30 are described below.

1. Frequency Changer or Converter

It is the first stage* in a transistor radio and has two sections—oscillator and mixer. A single silicon transistor Q_1 performs both the above functions. L_4 is the oscillator coil whereas L_2 is the signal input coil. Resistors R_1 and R_2 form a voltage divider for giving base bias to Q_1

The signals intercepted by the aerial are picked up by coil L_1 which is tuned to the transmission frequency of the desired station with the help of ganged capacitor C_1 and its fine-tuning trimmer C_2 . This signal is then induced into the secondary winding L_2 which passes it on to the base of Q_1 via C_3 . The local oscillations produced by L_4 and ganged capacitor C_7 are given to the emitter of Q_1 via C_4 .

As seen, Q_1 has been used in *CE* configuration for producing oscillations. The positive feedback required for producing oscillations is given from the collector of Q_1 to its emitter through L_3 , L_4 and C_4 .

* Sometimes, there is an RF stage before it (Fig. 66.29)

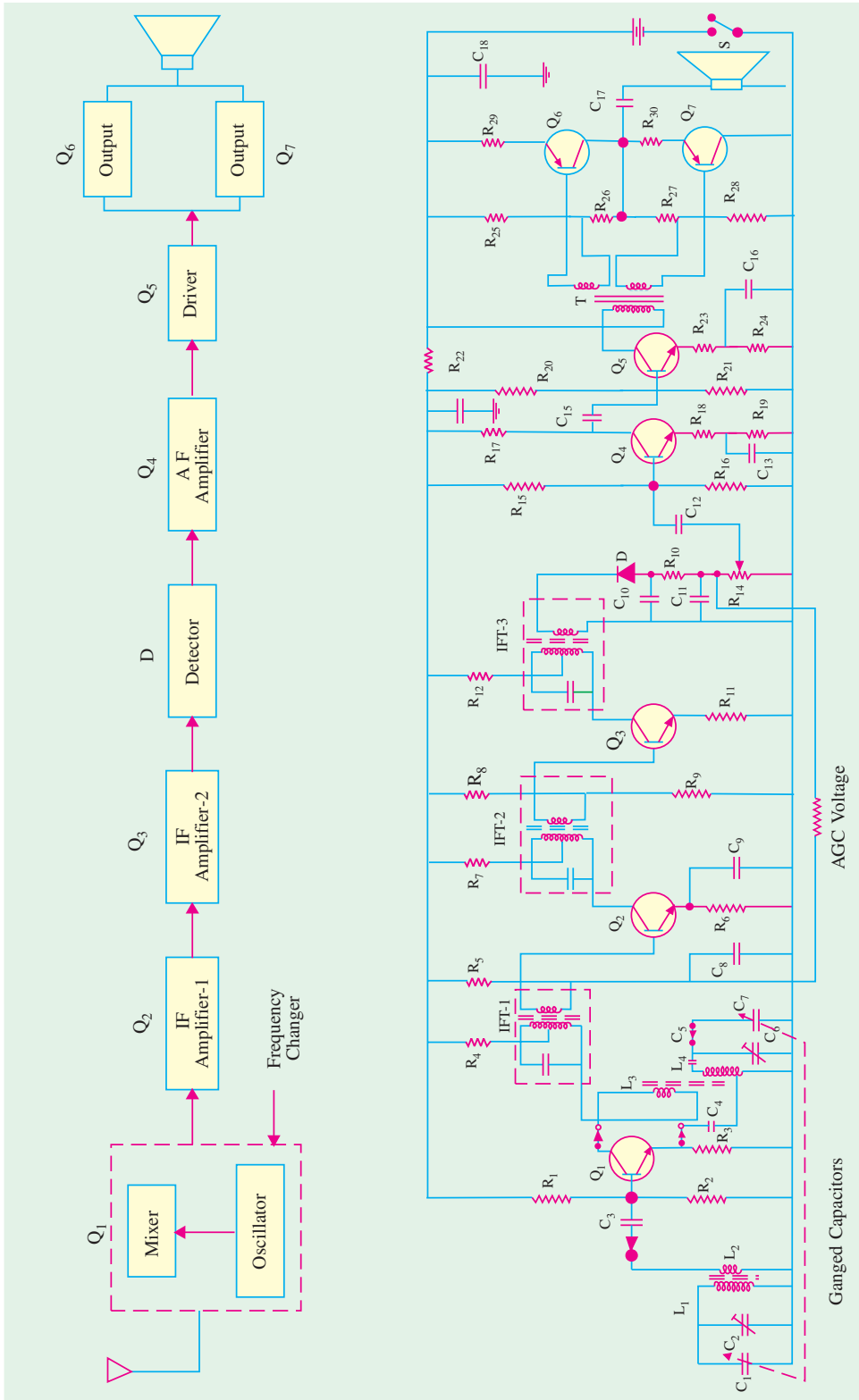


Fig. 66.30

The transistor Q_1 mixes the incoming signal frequency f_s and oscillation frequency f_0 thereby producing the sum and difference frequencies of $(f_0 + f_s)$ and $(f_0 - f_s)$ respectively. The difference frequency called *IF* frequency is then passed on to the *IF* transformer IFT-1 connected in the collector of Q_1 .

2. IF Amplifier

As the name indicates, its function is to amplify the *IF* signal obtained from the frequency changer. Usually, two stages are used to obtain sufficient gain. The gain of the first stage is controlled by the automatic gain control circuit (*AGC*) with the help of dc voltage drop across R_{10} . This dc voltage is obtained from the detector diode. Three fixed-tuned *IF* transformers are used—one at the collector of the frequency changer and the other two for the two *IF* amplifier stages. These transformers are also used as collector load as well as for inter-stage-coupling.

Resistor R_5 gives base bias to Q_2 whereas capacitor C_8 decouples the *AGC* voltage. As usual, R_8 and R_9 form the voltage divider circuit for giving base bias to Q_3 .

The amplified *IF* signal obtained from *IFT-2* is further amplified by *IFT-3* of the second *IF* amplifier stage before it is passed on to the detector diode.

3. Detector Circuit

It consists of a diode* which rectifies the *IF* signal. Resistor R_{13} , capacitors C_{10} and C_{11} together filter out *RF*. The audio signal is given to the following audio section through potentiometer R_{14} which is also used as a volume control. Capacitor C_{12} blocks the dc component in the rectified signal. This dc voltage is used for *AGC* via R_{10} . The main purpose of using *AGC* is to minimize the variations in sound due to changes in signal strength (because of fading) and to prevent overloading of second *IF* stage because of a very strong signal from a close-by transmitter.

4. Audio Frequency (AF) Amplifier

The audio section consists of three stages *i.e.* audio amplifier, driver and output which feeds a loud speaker. The audio-amplifiers amplify the audio signal given to Q_4 through volume control and C_{12} , R_{15} and R_{16} are biasing resistors whereas R_{19} is the emitter resistor with a by-pass capacitor C_{13} . The amplified signal is developed over collector load resistor R_{17} . This amplified signal is capacitively-coupled to the driver stage through C_{14} .

5. Driver

The driver stage further amplifies the audio signal obtained from the previous *AF* amplifier till it is large enough to drive the output stage. Transformer T (having two secondary windings) is used for coupling to the output stage. The emitter resistor of Q_5 is split into two parts (R_{23} and R_{24}) with only R_{24} being by-passed by C_{16} . This provides some negative feedback and reduces distortion.

6. Output Stage

The function of this stage is to amplify the audio signal received from the driver stage and hence provide sufficient power to drive the loudspeaker. Class-B push-pull amplifier employing transistors Q_6 and Q_7 is used for economizing battery consumption. Resistors R_{25} and R_{26} provide base bias to Q_6 and R_{27} and R_{28} to Q_7 whereas R_{29} and R_{30} are the emitter resistors of the two respective transistors. The audio signal is given via C_{17} to the loudspeaker which converts it into sound similar to the one transmitted by the broadcasting transmitter.

* Sometimes, transistors are used as detectors.

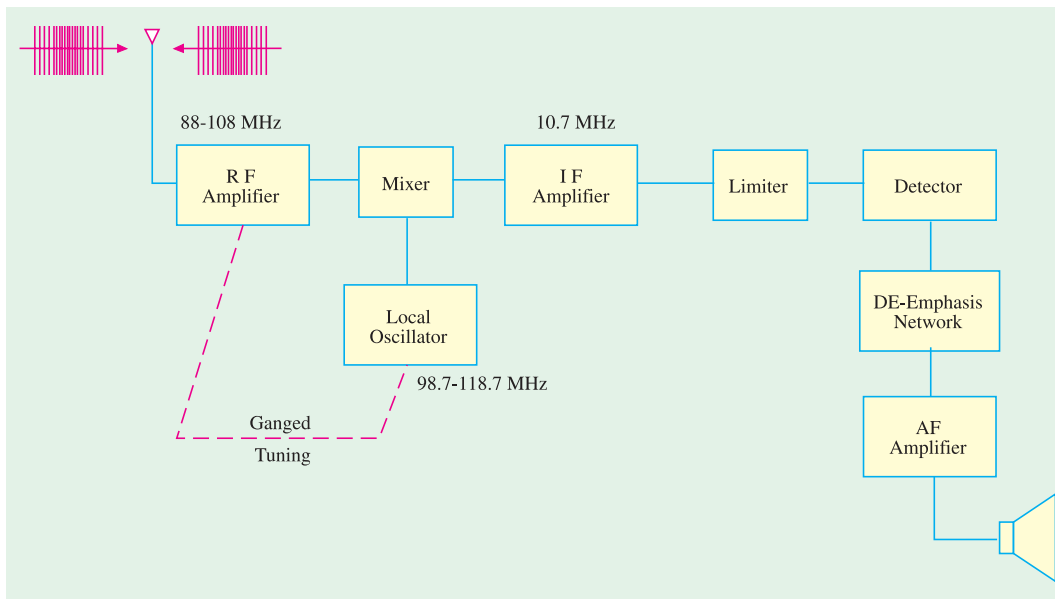


Fig. 66.31

66.37. FM Receiver

The block diagram for such a receiver is shown in Fig. 66.31. These receivers operate in the VHF band of 88-108 MHz and have an IF of 10.7 MHz with a bandpass of $2 \times 75 \text{ kHz} = 150 \text{ kHz}$. Like AM receivers, such receivers also have a frequency converter and IF amplifiers.

The function of the **limiter** is to remove all *amplitude variations* (caused by noise) from IF signal which might have crept into the FM signal. This removal of amplitude variations is necessary for distortionless demodulation. **Limiter is a sort of clipping circuit.**

The de-emphasis network *reduces the amplitude of high frequencies in the audio signal* which was earlier increased by the pre-emphasis network at the transmitting station. It serves to re-establish the **tonal balance** of the speech or music etc. lost in the pre-emphasis. Without it, the sound signal would have a heavy treble effect. It is, in fact, a low-pass filter having a time constant of $75 \mu\text{s}$.

66.38. Comparison Between AM and FM

Frequency modulation (FM) has the following advantages as compared to amplitude modulation (AM) :

1. All transmitted power in FM is useful whereas in AM most of it is in carrier which *serves no useful purpose*.
2. It has high signal-to-noise (S/N) ratio. It is due to two reasons : firstly, there happens to be less noise at VHF band and secondly, FM receivers are fitted with amplitude limiters which remove amplitude variations caused by noise.
3. Due to 'guard-band' there is hardly any adjacent-channel interference.
4. Since only transmitter *frequency* is modulated in FM, only fraction of a watt of audio power is required to produce 100% modulation as compared to high power required in AM.

However, FM has the following disadvantages :

1. It requires **much wider channel** — almost 7 to 15 times as large as needed by AM.
2. It requires complex and expensive transmitting and receiving equipment.
3. Since FM reception is limited to only line of sight, area of reception for FM is much smaller than for AM.

66.39. The Four Fields of FM

There are four major areas of application for *FM* transmission :

1. First use is in **FM** broadcast band 88-108 MHz with 200 kHz channels in which commercial *FM* stations broadcast programmes to their listeners.
2. Second use is in TV. Though video signal is amplitude-modulated, sound is transmitted by a separate transmitter which is frequency-modulated.
3. Third use is in the mobile or emergency services which transmit voice frequencies (20-4000 Hz) only.
4. Fourth use is in the amateur bands where again only voice frequencies are transmitted.

Tutorial Problems No. 66.1

1. A carrier wave has an amplitude of 500 mV. A modulating signal causes its amplitude to vary from 200 mV to 800 mV. What is the percentage modulation? **[60%]**
2. A 100 MHz carrier having an amplitude of 50 V is amplitude-modulated by a 5 kHz audio signal having an amplitude of 20 V. Find
 - (i) modulation index,
 - (ii) percent modulation,
 - (iii) components of modulated wave,
 - (iv) the amplitudes of sidebands.**[(i) 0.4 (ii) 40 (iii) 100 MHz, 100.005 MHz, 99.995 MHz (iv) 10 V]**
3. An audio signal given by $30 \sin(2\pi \times 2500t)$ is used for modulating a carrier wave given by the equation $60 \sin(2\pi \times 200,000t)$. Find
 - (i) percent modulation,
 - (ii) frequencies of the signal and the carrier,
 - (iii) frequency spectrum of the modulated wave.**[(i) 50 (ii) 2500 Hz, 200,000 Hz (iii) 200; 202.5; 197.5 kHz]**
4. How many AM broadcast stations can be accommodated in a 5 MHz bandwidth if each station transmits a signal modulated by an audio signal having a maximum frequency of 5 kHz. **[500]**
5. A 100 kHz bandwidth is to accommodate 5 AM broadcasts simultaneously. What is the maximum modulating frequency permissible for each station? **[5 kHz]**
6. Total power content of an AM signal is 3000 W. For 100 percent modulation, calculate
 - (i) carrier power
 - (ii) power in each sideband**[(i) 2 kW (ii) 0.5 kW]**
7. The total power content of an AM wave is 1320 W. What is the percent modulation if each sideband contains 160 W? **[0.8]**
8. An SSB-SC signal contains 2 kW. Find power contained in
 - (i) carrier
 - (ii) sideband.**[(i) 0 (ii) 2 kW]**
9. As compared to DSB-FC, Calculate the power saving in SSB-SC when percent modulation is (i) 1 (ii) 0.8 (iii) 0.5
 [(i) 83.3% (ii) 87.87% (iii) 94.4%]
10. What is the modulation index of an FM carrier having a carrier swing of 120 kHz and a modulating signal of 10 kHz. **[6]**
11. An FM signal has a resting frequency of 100 MHz and the highest frequency of 100.05 MHz when modulated by an audio signal of 5 kHz. Determine
 - (i) frequency deviation,
 - (ii) carrier swing,
 - (iii) modulation index,
 - (iv) percent modulation.**[(i) 50 kHz (ii) 100 kHz (iii) 10 (iv) 66.7%]**
12. A 10 kHz audio signal is used to frequency-modulate a 100 MHz carrier causing a frequency deviation of 50 kHz. Determine
 - (i) modulation index,
 - (ii) bandwidth of FM signal.**[(i) 5 (ii) 160 kHz]**

13. A carrier of 1MHz with 400 Watt of its power is A amplitude modulated with a sinusoidal signal of 2500 Hz. The depth of modulation is 75%. Calculate the side band frequencies, the band width, the power in the side bands and the total power in the modulated wave.
[(Electronics Engg; Bangalore Univ. 2004)]
14. 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 side band.
[(Electronics Engg. Bangalore Univ. 2002)]
15. A 100MHz carrier wave is frequency modulated by a 10 kHz sinusoidal modulating signal. If the maximum frequency deviation is 50 kHz. Find the modulation index.
[(Electronics Engg. Bangalore Univ., 2002)]
16. A 500 W, 1MHz carrier is amplitude modulated with a sinusoidal signal of 1 kHz. The depth of modulation is 60%. Calculate the band width, power in the side bands and the total power transmitted.
[(Electronics Engg., Bangalore Univ., 2003)]
17. A carrier signal has a peak amplitude of 100V. Modulation index is 40%. Power is developed across a load of $100\ \Omega$. Determine the value of transmitted power.
(Electronics Engg. Bangalore Univ., 2003)

OBJECTIVE TESTS – 66

- The main purpose of modulation is to
 - combine two waves of different frequencies
 - achieve wave-shaping of the carrier wave
 - transmit low-frequency information over long distances efficiently
 - produce sidebands.
- Demodulation
 - is performed at the transmitting station
 - removes side-bands
 - rectifies modulated signal
 - is opposite of modulation.
- In amplitude modulation
 - carrier frequency is changed
 - carrier amplitude is changed
 - three sidebands are produced
 - fidelity is improved.
- 100% modulation is produced in AM when carrier
 - frequency equals signal frequency
 - frequency exceeds signal frequency
 - amplitude equals signal amplitude
 - amplitude exceeds signal amplitude.
- For a given carrier wave, maximum undistorted power is transmitted when value of modulation is
 - 1
 - 0.8
 - 0.5
 - 0.
- In an AM wave with 100 percent modulation, each sideband carries — of the total transmitted power.
 - one-half
 - one-sixth
 - one-third
 - two-third
- Given a carrier frequency of 100 kHz and a modulating frequency of 5 kHz, the bandwidth of AM transmission is ____ kHz.
 - 5
 - 200
 - 10
 - 20
- When modulation of an AM wave is decreased
 - percentage carrier power is decreased
 - percentage carrier power is increased
 - total transmitted power is increased
 - percentage sideband power is unaffected.
- In AM transmission, power content of the carrier is maximum when m equals
 - 0
 - 1
 - 0.8
 - 0.5.
- In AM transmission with $m = 1$, suppression of carrier cuts power dissipation by a factor of
 - 6
 - 2
 - 3
 - 4
- As compared to DSB-FC 100% modulated transmission, power saving in SSB-SC system is _____ per cent.
 - 94.4
 - 50
 - 100
 - 83.3
- In an AM transmission with 100% modulation, 66.7% of power is saved when _____ is/are suppressed.
 - carrier
 - carrier and USB
 - carrier and LSB
 - USB and LSB
- In an AM system, full information can be conveyed by transmitting only
 - the carrier
 - the upper sideband
 - the lower sideband
 - any one sideband.

14. A 10 MHz carrier of peak value 10 V is amplitude modulated by a 10 kHz signal of amplitude 6 V. The amplitude of each side band frequency is
 (a) 3 V (b) 4 V
 (c) 5 V (d) 6 V
15. The block diagram of an AM receiver is shown in Fig. 66.32. The missing block and its location are respectively

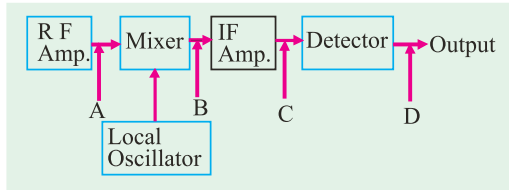


Fig. 66.32

- (a) Band - pass filter at A
 (b) High-pass filter at B
 (c) Band - pass filter at C
 (d) Low-pass filter (audio amplifier) at D.
16. In FM transmission, amplitude of the modulating signal determines
 (a) rate of frequency variations
 (b) amount of frequency shift
 (c) tonal balance of transmission
 (d) distance of broadcast.
17. In FM, when frequency deviation is doubled
 (a) modulation is doubled
 (b) modulation is halved
 (c) carrier swing is halved
 (d) modulation index is decreased.
18. In an FM broadcast in VHF band, channel width is _____
 (a) 75 (b) 25
 (c) 88 (d) 200
19. Modern FM receivers use de-emphasis circuit for
 (a) reducing high frequency noise
 (b) reducing the amplitude of high frequencies in the audio signal
 (c) increasing the amplitude of higher modulating frequencies
 (d) making demodulation easy
20. One of the serious disadvantages of FM transmission is its
 (a) high static noise
 (b) limited line-of-sight range
 (c) expensive equipment
 (d) adjacent channel interference.
21. In India, the maximum frequency deviation is commercial FM broadcasting signals is about,
 (a) 5 kHz (b) 15 kHz
 (c) 7.5 kHz (d) 200 kHz
22. The correct sequence of subsystems in an FM receiver is
 (a) mixer, RF amplifier, limiter, IF amplifier, discriminator, audio amplifier
 (b) RF amplifier, mixer, IF amplifier, limiter, discriminator, audio amplifier
 (c) RF amplifier, mixer, limiter, discriminator, IF amplifier, audio amplifier
 (d) mixer, IF amplifier, limiter, audio amplifier, discriminator.

ANSWERS

1. (c) 2. (d) 3. (b) 4. (c) 5. (a) 6. (b) 7. (c) 8. (b) 9. (a) 10. (c) 11. (d)
 12. (a) 13. (d) 14. (a) 15. (d) 16. (b) 17. (a) 18. (d) 19. (b) 20. (b) 21. (d) 22. (b)