UNIT-III

MODULATION and DEMODULATION

* Introduction

In radio transmission, it is necessary to send audio signal (e.g. music, speech) from a broadcasting station over great distances to a receiver This communication of audio signal does not employ any wire and is called wireless. The audio signal cannot be sent directly over the air for appreciable distance, Even if the audio signal is converted into electrical signal, latter cannot be sent very far without employing large amount of power. The energy of a wave is directly proportional to its frequency. At audio frequencies (20 Hz to 20 kHz) the signal power is quite small and radiation is not practicable.

The radiation of electrical energy is practicable only at high frequencies e.g. above 20 kHz. The high frequency signals can be sent thousands of miles, even with comparatively small power. Therefore, if audio signal is to be transmitted properly, some means must be devised which will permit transmission to occur at high frequencies while it simultaneously allow the carrying of audio signal. This is achieved by superimposing electrical audio signal on high frequency carrier. The resultant waves are known as modulated waves or radio waves and the process is called Modulation.

* Modulation

A high frequency carrier wave is used to carry the audio signal. The question arrises how the audio signal should be "added" to the carrier wave. The solution lies in changing some characteristics of carrier wave in accordance with the signal. Under such conditions, the audio signal will be contained in the resultant wave. This process is called modulation and may be defined as under:

"The process of changing some characteristic (e.g. amplitude, frequency or phase) of a carrier wave in accordance with the intensity of the signal is known as modulation".

Modulation means to "change". In modulation, some characteristics of carrier wave is changed in accordance with the intensity (i.e amplitude) of the signal. The resultant wave is called modulated wave or radio wave and contains the audio signal. Therefore, modulation permits the transmission to occur at high frequency while it simultaneously allows the carrying of the audio signal

Need For Modulation

Modulation is extremely necessary in communication system due to the following reasons:

⟨I⟩ Practical antenna length

In order to transmit a wave effectively, the length of the transmitting antenna should be approximately equal to the wavelength of the wave.

Now, $\text{wavelength} = \frac{\text{velocity}}{\text{frequency}} = \frac{3\times10^8 \text{ meters}}{\text{frequency (Hz)}}$

As the audio frequencies range from 20 Hz to 20 kHz, therefore, if they are transmitted directly into space, the length of the transmitting antenna would be extremely large. To radiate a frequency of 20 kHz directly into space, we would need an antenna of length $3\times10^8/20\times10^3 = 15000$ meters. This is too long antenna to be constructed practically. For this reason, it is impracticable to radiate audio signal directly into space. On the other hand, if a carrier wave say of 1000 kHz is used to carry the signal, we need an antenna of length 300 meters, this size can be easily constructed.

⟨II⟩ Operating range

The energy of a wave depends upon its frequency. The greater the frequency of the wave, the greater the energy possessed by it. As the audio signal frequencies are small, therefore these cannot be transmitted over large distances, if radiated directly into space. The only practical solution is to modulate a high frequency carrier wave with audio signal and permit the transmission to occur at this high frequency.

(III) Wireless communication

The desirable feature of radio transmission is that it should be carried without wires i.e radiated into space. At audio frequencies, radiation is not practicable because the efficiency of radiation is poor. However, efficient radiation of electrical energy is possible at high frequencies (> 20 kHz). For this reason, modulation is always done in communication system.

* Types of Modulation

Modulation is the process of changing amplitude or frequency or phase of a carrier wave in accordance with the intensity of the signal. Accordingly, there are three basic types of modulation, namely:

<I> Amplitude Modulation (AM)
<II> Frequency Modulation (FM)
<III> Phase Modulation (PM)

In India, amplitude modulation is used in radio broadcasting. However, in television transmission, frequency modulation is used for sound signal and amplitude modulation is for picture signal.

* Amplitude Modulation (AM)

When the amplitude of high frequency carrier wave is changed in accordance with the intensity of the signal, it is called amplitude modulation.

In amplitude modulation, only the amplitude of the carrier wave is changed in accordance with the intensity of the signal, However, the frequency of the modulated wave remains the same i.e carrier frequency. The below Fig. 1 shows the principle of amplitude modulation. Fig. 1.1 shows the audio electrical signal, where-as Fig 1.2 shows a carrier wave of constant amplitude. Fig 1.3 shows the amplitude modulated (AM) wave.

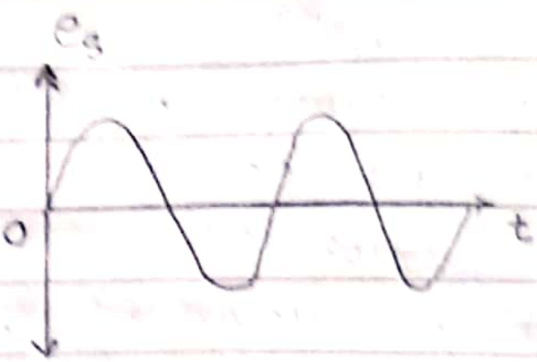

Fig. 1.1 Signal wave

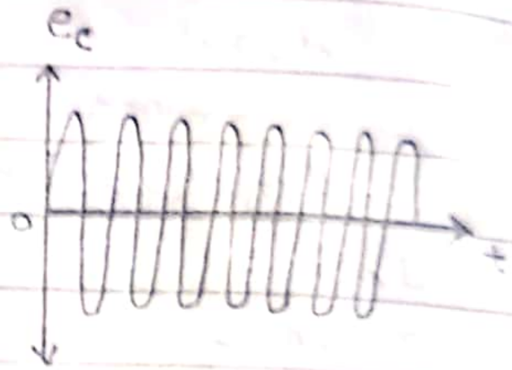

Fig 1.2 Carrier wave

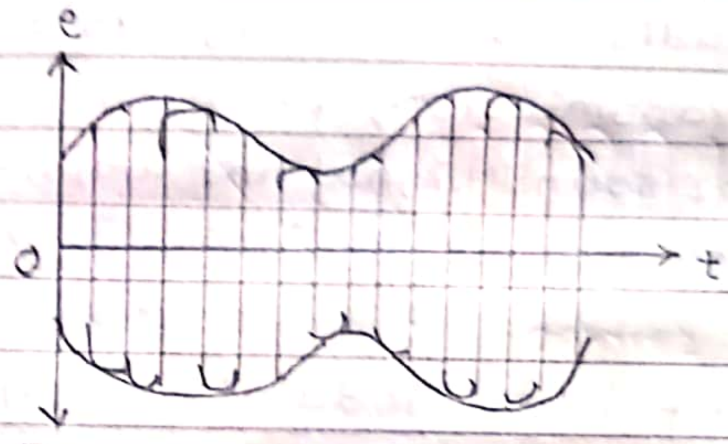

Fig. 1.3 AM wave

Fig 1

The amplitudes of both positive and negative half-cycles of carrier wave are changed in accordance with the signal. Amplitude modulation is done by an electronic circuit called modulator

The following points are to be noted in an amplitude modulation

(i) The amplitude of the carrier wave changes according to the intensity of the signal.

(ii) The amplitude variations of the carrier wave is at the signal frequency f_s.

(iii) The frequency of the amplitude modulated wave remains the same i.e. carrier frequency f_c.

Modulation Factor

An important consideration in amplitude modulation is to describe the depth of modulation i.e the extent to which the amplitude of carrier wave is changed by the signal. This is described by a factor called modulation factor which may be defined as

"The ratio of change of amplitude of carrier wave to the amplitude of normal carrier wave is called the modulation factor m" i.e

Modulation factor,

$$m = \frac{\text{Amplitude change of carrier wave}}{\text{Normal carrier amplitude (unmodulated)}}$$

The value of modulation factor depends upon the amplitudes of carrier and signal.

The modulation factor is very important since it determines the strength and quality of the transmitted signal. When the carrier is modulated to small degree then transmitted signal is not very strong. If $m > 1$, distortion will occur during reception. The AM waveform is clipped the envelope is discontinuous. Therefore, degree of modulation should never exceed 100%.

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* Expression for AM voltage

A carrier wave may be represented by

$$e_c = E_c \cos \omega_c t$$

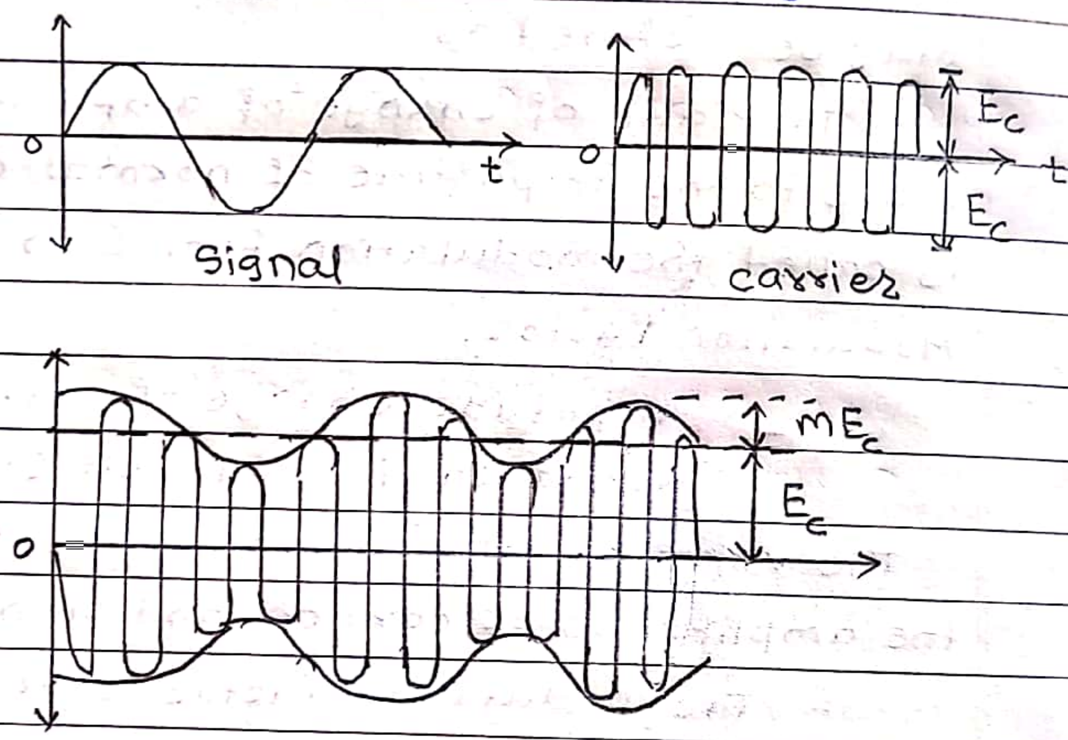
where e_c = instanteneous voltage of carrier

E_c = amplitude of carrier

$\omega_c = 2\pi f_c$

= angular velocity at carrier frequency f_c.

In AM, the amplitude E_c of the carrier wave is varied in accordance with the intensity of the signal as shown in below Fig 1.



AM WAVE

Fig. 1

suppose the modulation factor is m. It means that signal produces a maximum change of mE_c in the carrier amplitude. obviously, the amplitude of signal is mE_c. Therefore, the signal can be represented by:

$$e_s = mE_c \cos \omega_s t$$

where e_s = instanteneous voltage of signal

mE_c = amplitude of signal

$\omega_s = 2\pi f_s$ = angular velocity at signal frequency f_s

The amplitude of the carrier wave varies at signal frequency f_s. Therefore, the amplitude of AM wave is given by

Amplitude of AM wave $= E_c + mE_c \cos \omega_s t$

$= E_c (1 + m \cos \omega_s t)$

The instanteneous voltage of AM wave is:

$$e = \text{Amplitude} \times \cos \omega_c t$$

$$= E_c (1 + m \cos \omega_s t) \cos \omega_c t$$

$$= E_c \cos \omega_c t + mE_c \cos \omega_s t . \cos \omega_c t$$

$$= E_c \cos \omega_c t + \frac{mE_c}{2} (2 \cos \omega_s t . \cos \omega_c t)$$

$$= E_c \cos \omega_c t + \frac{mE_c}{2} [\cos (\omega_c + \omega_s) t + \cos (\omega_c - \omega_s) t]$$

$$= E_c \cos \omega_c t + \frac{mE_c}{2} \cos (\omega_c + \omega_s) t + \frac{mE_c}{2} \cos (\omega_c - \omega_s) t$$

The following points may be noted from the above equation of amplitude modulated wave:

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(i) The AM wave is equivalent to the summation of three sinusoidal waves; one having amplitude E_c and frequency f_c, the second having amplitude $mE_c/2$ and frequency $(f_c + f_s)$ and the third having amplitude $mE_c/2$ and frequency $(f_c - f_s)$

(ii) The AM wave contains three frequencies viz f_c, $f_c + f_s$ and $f_c - f_s$. The first frequency is the carrier frequency. Thus, the process of modulation does not change the original carrier frequency but produces two new frequencies $(f_c + f_s)$ and $(f_c - f_s)$ which are called sideband frequencies.

(iii) The sum of carrier frequency and signal frequency i.e. $(f_c + f_s)$ is called upper sideband frequency. The lower sideband frequency is $f_c - f_s$ i.e the difference between carrier and signal frequencies

* Frequency Spectrum of AM wave

(Sideband Frequencies in AM waves)

The below Fig. 1 shows the frequency spectrum of an amplitude modulated wave.

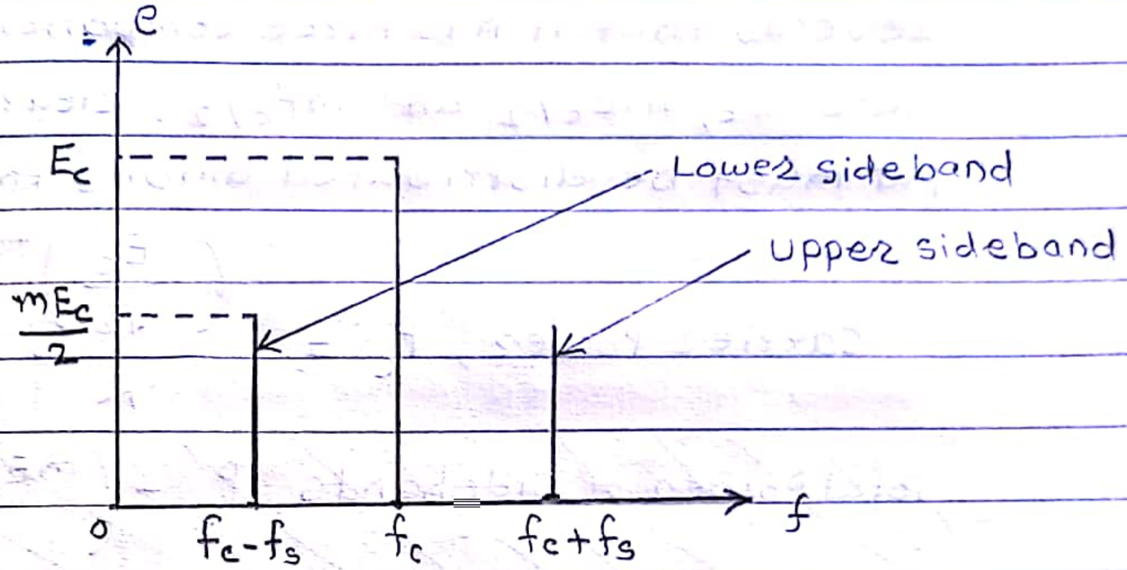

Fig. 1

The frequency components in the AM wave are shown by verticle lines. The height of each verticle line is equal to the amplitude of the components present. In radio transmission carrier frequency f_c is many times greater than signal frequency f_s. Hence the sideband frequencies are generally close to the carrier frequency. It may be seen that a carrier ~~frequency~~ modulated by a single frequency is equivalent to three simultaneous signals, the carrier itself and two other steady frequencies i.e. $f_c + f_s$ and $f_c - f_s$.

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* Power in AM wave

The power dissipated in any circuit is a function of the square of voltage and the effective resistance of the circuit. Equation of AM wave reveals that it has three components of amplitude E_c, $mE_c/2$ and $mE_c/2$. Clearly, power output must be distributed among these components.

$$\text{Carrier Power, } P_c = \frac{\left(\frac{E_c}{\sqrt{2}}\right)^2}{R} = \frac{E_c^2}{2R}$$

~~Total Power of sidebands, $P_s = \frac{(mE_c/2\sqrt{2})^2}{R} + \frac{\left(\frac{mE_c}{2\sqrt{2}}\right)^2}{R}$~~

$$\text{Total Power in sidebands, } P_s = \frac{\left(\frac{mE_c}{2\sqrt{2}}\right)^2}{R} + \frac{\left(\frac{mE_c}{2\sqrt{2}}\right)^2}{R}$$

$$= \frac{m^2E_c^2/8}{R} + \frac{m^2E_c^2/8}{R}$$

$$P_s = \frac{m^2E_c^2}{8R} + \frac{m^2E_c^2}{8R}$$

$$\therefore P_s = \frac{m^2E_c^2}{4R}$$

Total Power of AM wave,

$$P_T = P_c + P_s$$

$$= \frac{E_c^2}{2R} + \frac{m^2E_c^2}{4R}$$

$$= \frac{E_c^2}{2R}\left[1 + \frac{m^2}{2}\right]$$

$$P_T = \frac{E_c^2}{2R}\left[\frac{2+m^2}{2}\right]$$

Fraction of total power carried by sideband is

$$\frac{P_S}{P_T} = \frac{m^2 E_c^2 / 4R}{\frac{E_c^2}{2R}\left[\frac{2+m^2}{2}\right]}$$

$$= \frac{m^2}{2\left[\frac{2+m^2}{2}\right]}$$

$$\therefore \frac{P_S}{P_T} = \frac{m^2}{2+m^2}$$

We know that

$$P_c = \frac{E_c^2}{2R} \text{ and } P_S = \frac{m^2 E_c^2}{4R}$$

$$\therefore \frac{P_S}{P_c} = \frac{m^2 E_c^2 / 4R}{E_c^2 / 2R}$$

$$\therefore \frac{P_S}{P_c} = \frac{1}{2} m^2$$

or

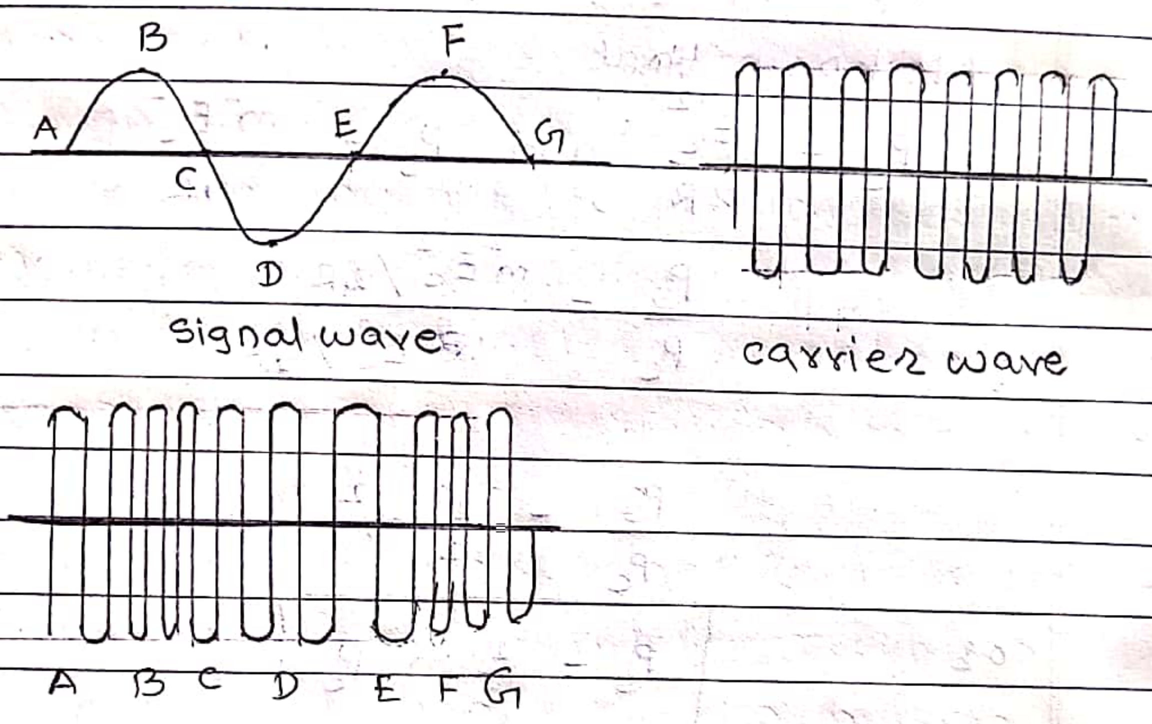
$$\boxed{P_S = \frac{1}{2} m^2 P_c}$$

The above equation gives the relation between total sideband power (P_S) and carrier power (P_c).

* Frequency Modulation (FM)

When the frequency of carrier wave is changed in accordance with the intensity of the signal is called as frequency modulation (FM).

In frequency modulation, only the frequency of the carrier wave is changed in accordance with the signal. However, the amplitude of the modulated wave remains the same i.e carrier wave amplitude. The frequency variations of carrier wave depend upon the instanteneous amplitude of the signal as shown in below Fig 1.



Signal wave

carrier wave

FM wave

Fig 1

When the signal voltage is zero as at A, C, E and G, the carrier frequency is unchanged. When the signal approaches its positive peaks as at B and F, the carrier frequency is increased to maximum as shown by the closely spaced cycles. However, during the negative peaks of signal as at D, the carrier frequency is reduced to minimum as shown by the widely spaced cycles.

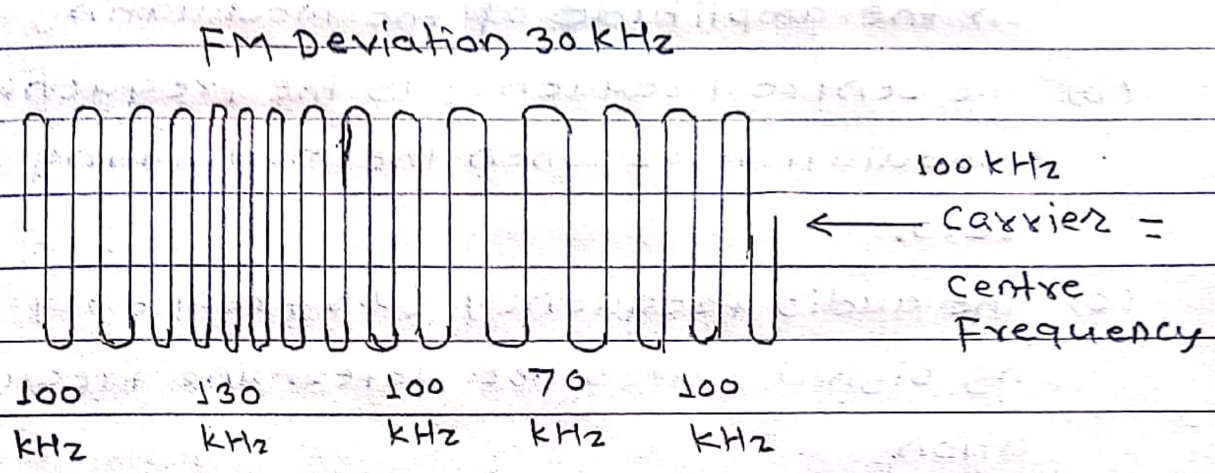


Fig.2 FM Signal

Fig. 2 shows the FM signal having carrier frequency f_c = 100 kHz. FM signal has constant amplitude but varying frequencies above and below the carrier frequency of 100 kHz (f_c). For this reason f_c is called centre frequency. The ~~amount of~~ changes in the carrier frequency are produced by the audio modulating signal. The amount of change in frequency from f_c (= 100 kHz) or frequency deviation depends upon the amplitude of the audio-modulating signal. The frequency deviation increases with the increase in the modulating signal and vice versa. Thus the peak audio voltage will produce maximum frequency deviation. From

Fig. 1, the centre frequency is 100 kHz and the maximum frequency deviation is 30 kHz. The following points about frequency modulation (FM) may be noted

(a) The frequency deviation of FM signal depends on the amplitude of the modulating signal.

(b) The centre frequency is the frequency without modulation or when the modulating voltage is zero.

(c) The audio frequency (i.e frequency of modulating signal) does not determine frequency deviation.

Advantages:

The following are the advantages of FM over AM:

(i) It gives noiseless reception. Noise is a form of amplitude variations and a FM receiver will reject such signals.

(ii) The operating range is quite large

(iii) It gives high-fidelity reception.

(iv) The efficiency of transmission is very high.

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* Expression For Frequency Modulated Voltage

In frequency modulation, the carrier frequency is varied sinusoidally at signal frequency. The instanteneous deviation in frequency from the carrier is proportional to the instanteneous amplitude of the modulating signal. Thus the instanteneous angular frequency of FM is given by:-

$$\omega_i = \omega_c + \Delta\omega_c \cos \omega_s t$$

Total phase angle $\theta = \omega t$ so that if ω is variable, then

$$\theta = \int_0^t \omega_i \, dt$$

$$= \int_0^t (\omega_c + \Delta\omega_c \cos \omega_s t) \, dt$$

$$\therefore \quad \theta = \omega_c t + \frac{\Delta\omega_c}{\omega_s} \sin \omega_s t$$

The term $\frac{\Delta\omega_c}{\omega_s}$ is called modulation index m_f.

$$\therefore \quad \theta = \omega_c t + m_f \sin \omega_s t$$

The instanteneous value of FM voltage wave is given by

$$e = E_c \cos \theta$$

or

$$e = E_c \cos (\omega_c t + m_f \sin \omega_s t)$$

The above equation is the general voltage eq^n.

of a FM wave.

The following points may be noted carefully

(i) The modulation index m_f is the ratio of maximum frequency deviation (Δf) to the frequency (f_s) of the modulating signal i.e

$$\text{Modulation Index}, \; m_f = \frac{\Delta \omega_c}{\omega_s}$$

$$= \frac{f_{c(max)} - f_c}{f_s} = \frac{\Delta f}{f_s}$$

(ii) The modulation index (m_f) for frequency modulation can be greater than unity.

* Frequency spectrum

If f_c and f_s are the carrier and signal frequencies respectively, then FM spectrum will have the following frequencies

$$f_c, \; f_c \pm f_s, \; f_c \pm 2f_s, \; f_c \pm 3f_s, \; \ldots \text{ so on}$$

Note that $f_c + f_s$ $f_c + 2f_s$, $f_c + 3f_s$, --- are the uppersideband frequencies while $f_c - f_s$, $f_c - 2f_s$ $f_c - 3f_s$ --- are the lower sideband frequencies.

* Limitations of Amplitude Modulation

The amplitude modulation suffers from the following drawbacks:

(i) Noisy reception
(ii) Low efficiency
(iii) small operating range
(iv) Lack of audio quality

* Comparision of AM and FM

Sr. No.	Amplitude Modulation	Frequency Modulation
1.	The amplitude of carrier changes with modulation.	The amplitude of carrier remains constant with modulation.
2.	The carrier frequency remains constant with modulation.	The carrier frequency changes with modulation.
3.	The carrier ~~frequency~~ amplitude changes according to the strength of the modulating signal.	The carrier frequency changes according to the strength of the modulating signal.
4.	The value of modulation factor (m) cannot be more than 1 for distortionless AM signal.	The value of modulation index (m_f) can be more than 1.

* Demodulation

The process of recovering the audio signal from the modulated wave is known as demodulation or detection.

At the broadcasting station, modulation is done to transmit the audio signal over larger distances to receiver. When the modulated wave is picked up by the radio receiver, it is necessary to recover the audio signal from it. This process is accomplished in the radio receiver and is called demodulation.

Necessity of demodulation

The amplitude modulated wave consists of carrier and sideband frequencies. The audio signal is contained in the sideband frequencies which are radio frequencies. If the modulated wave after amplification is directly fed to the speaker as shown in Fig. 1, no sound will be heard.

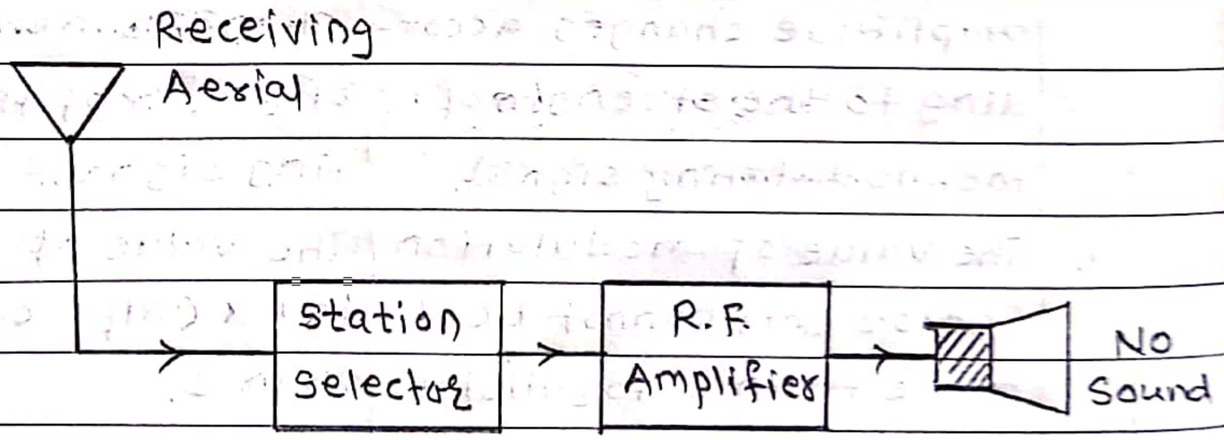

Fig 1

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It is because diaphragm of the speaker is not at all able to respond to such high frequencies. Before the diaphragm is able to move in one direction, the rapid reversal of current tends to move it in the opposite direction i.e diaphragm will not move at all. consequently, no sound will be heard. It is clear that audio signal must be seperated from the carrier at a suitable stage in the receiver. The recovered audio signal is then amplified and fed to the speaker for conversion into sound.

* Linear diode AM detector or Demodulator

The below Fig. 1 shows a simple detector circuit employing vacuum diode and filter circuit.

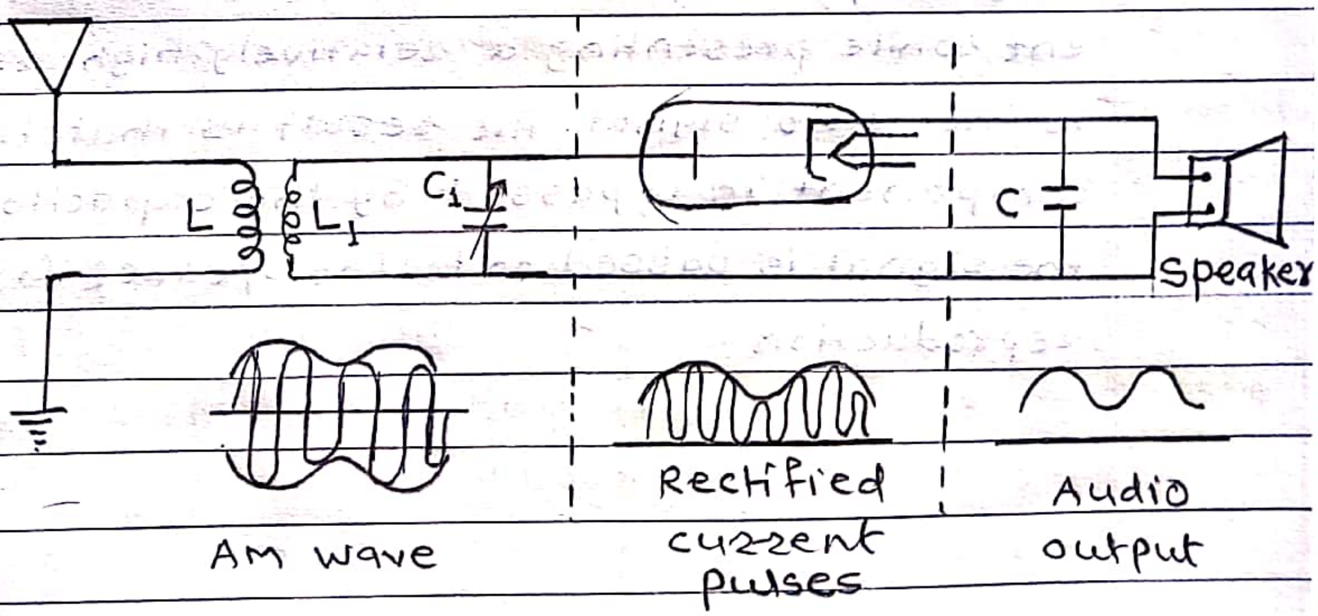

Fig.1 AM diode Detector

The modulated wave of desired frequency is selected by the parallel tuned circuit L_1C_1 and is applied to the vacuum diode. During the positive half-cycles of modulated wave, the diode conducts while during negative half-cycles, it does not. The result of this rectifying action is that output of the diode consists of positive half-cycles of modulated wave as shown.

The rectified modulated wave contains radio frequency and the signal and can not be fed to the speaker for sound reproduction. If done so, no sound will be heard due to the inertia of speaker diaphragm. The r.f. component is filtered by the capacitor C shunted across the speaker. The value of this capacitor is sufficiently large to present low reactance to the r.f. component while presenting a relatively high reactance to the audio signal. The result is that the r.f. component is bypassed by the capacitor C and the signal is passed on to the speaker for sound reproduction.