Communication Systems

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COMMUNICATION SYSTEM

A communication system is the set-up used in the transmission of information from one place to another. The present day communication system are electrical, electronic or optical in nature.

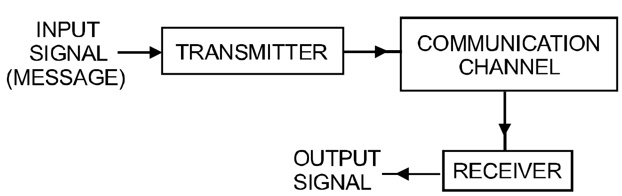
In principle, a communication system consists of the following three parts :

(i) Transmitter

(ii) Communication Channel

(iii) Receiver

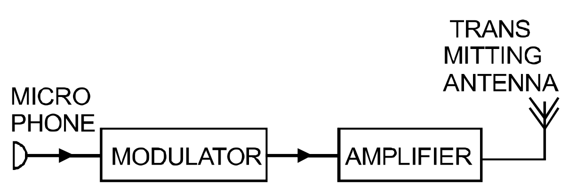
A schematic model of an electrical communication system is shown in Figure.



(i) **A transmitter :** transmits the information after modifying it to a form suitable for transmission. The key to communication system is to obtain an electrical signal (voltage or current), which contains the information. For example, a *microphone* converts speech signals into electrical signals. Similarly, *piezoelectric sensors* convert pressure variations into electrical signals. Light signals are converted into electrical signals by *photo detectors*. The devices like microphone, piezoelectric sensors and photo detectors, which convert a physical quantity (called information, here) into electrical signal are known as **Transducers**. Such an electrical signal contains the information to be transmitted.

We define a **signal** as a single valued function of time (that conveys the information). This function has a unique value at every instant of time.

Most of the speech or information signals cannot be transmitted directly over long distances. These signals have to be loaded or superimposed on a high frequency wave, which acts as the *carrier wave*. This process is known as *modulation*. The signal so obtained is called modulated signal/wave. The power of the signal is boosted signal using a *suitable amplifire*. The modulated signal is then radiated into space with the help of an antenna called *transmitting antenna*. The arrangement is shown in Fig



(ii) Communication Channel : The communication channel carries the modulated wave from the transmitter to the receiver. In ordinary conversation, the air through which sound travels from the speaker to the listener serves as the communication channel. In case of telephony and telegraphy, communication channel is the *transmission lines*, which connect the transmitter and the receiver. In radio communication (or wireless communication), the *free space* through which the modulated signal travels serves as the communication channel.

(iii) The receiver ; In the radio communication or wireless communication, the receiver consists of :

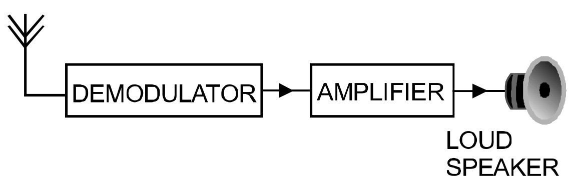
(a) a pick up antenna to pick the signal,

(b) a demodulator, to separate the low frequency audio signal from the modulated signal,

(c) an amplifier, to boost up suitably the audio signal, and

(d) the transducer, like loud speaker to convert the audio signal (in the form of electrical pulses) into sound waves.

The receiver part of the communication system is shown schematically in Fig.



ANTENNA

An antenna plays a vital role in a communication system. It is used in both, the transmission and reception of radio frequency signals.

Infact, an antenna is a structure that is capable of radiating electromagnetic waves or receiving them, as the case may be. Basically, an antenna is generally a metallic object, often a wire or collection of wires, used to convert high frequency current into electromagnetic waves and vice-versa. Thus, a transmitting antenna converts electrical energy into electromagnetic waves, whereas a receiving antenna converts electromagnetic waves into electrical energy. Apart from their different function, transmitting and receiving antennas behave idenically i.e. their behaviour is reciprocal.

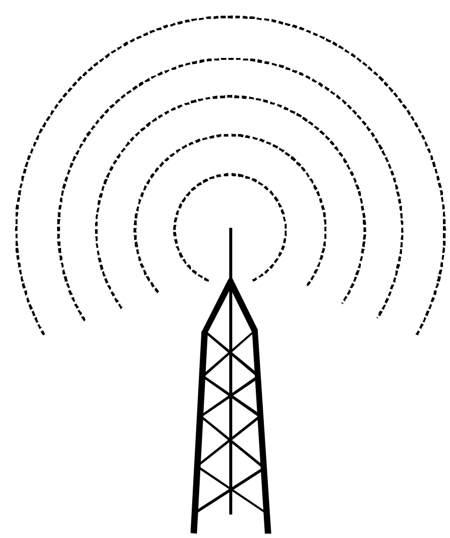
When a transmitting antenna is held vertically, the electromagnetic waves produced are polarized vertically.

A **Hertz** antenna is a straight conductor of length equal to half the wavelength of radio signals to be transmitted or received i.e. $l = \lambda/2$.

A **Marconi** antenna is a straight conductor of length equal to a quarter of the wavelength of radio signals to be transmitted or received i.e. $l = \lambda/4$. It is held vertically with its lower end touching the ground. The ground provides a reflection of the voltage and current distributions set up in the antenna. The electromagnetic waves emitted from (Marconi) antenna ground system are the same as those emitted from Hertz antenna, which is not grounded.

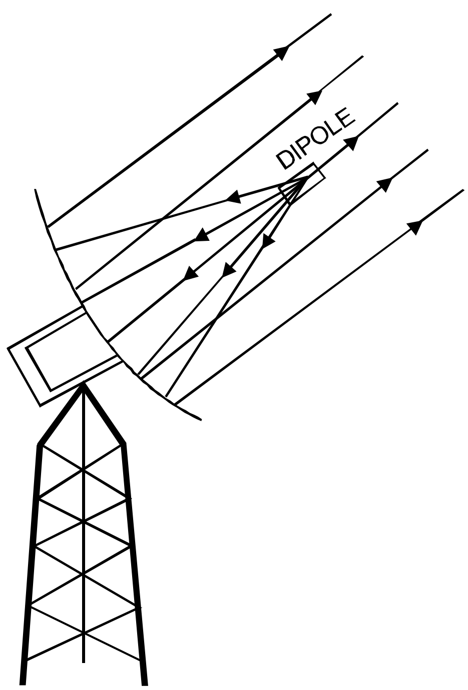
The design of an antenna depends on frequency of carrier wave and directivity of the beam etc. Two common types of antenna are :

(i) Dipole antenna, shown in Fig. is used in transmission of radio waves. It is *omni directional*.



(ii) **Dish type antenna,** shown in Fig.5 is a directional antenna.

Such an antenna has a parabolic reflector with an active element, called the **dipole** or **horn feed** at focus of the reflector. The dish type antenna can transmit waves in a particular direction. Also, it can receive only those waves which are directed towards it. For transmission, the signal is fed to the active element, which directs it on to the reflector. The signal is then transmitted in the form of a parallel beam as shown in Fig. For reception, the waves directed towards the dish are reflected on to the active element, which converts them into electrical signals. The dish type antennas are commonly used in radar and satellite communication.



MESSAGE SIGNALS

Message signals are electrical signals generated from the original information to be transmitted, using an appropriate transducer. *A message signal is a single valued function of time that conveys the information*. This function has a unique value at every instant of time. These signals are of two type :

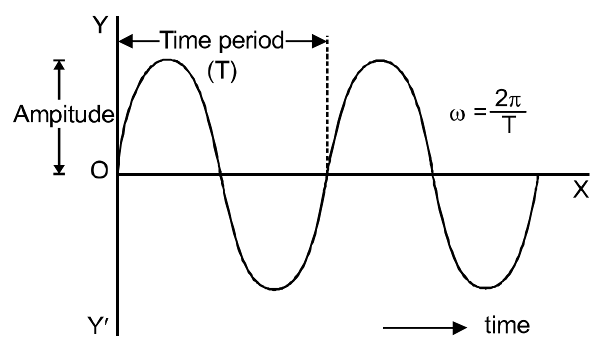
(i) Analog signals (ii) Digital signals

(i) **Analog signals.** An analog signal is that in which current or voltage value varies continuously with time.

In the simplest form of an analog signal, amplitude of the signal varies sinusoidally with time. It is represented by the equation

$$E = E_0 \sin(\omega t + \phi)$$

where E_0 is max. value of voltage, called the amplitude, T is time period and $\omega = \frac{2\pi}{T}$ is angular frequency of the signal. In fig, ϕ represents the phase angle. Such signals can have all sorts of values at different instants, but these values shall remain within the range of a maximum value ($+E_0$) and a minimum value ($-E_0$).



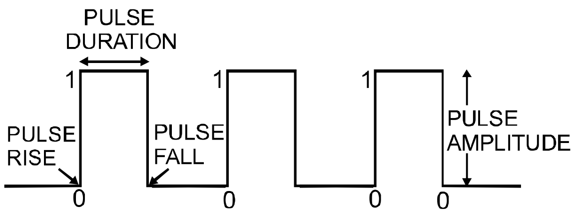
Examples of analog signals are speech, music, sound produced by a vibrating tuning fork, variations in light intensity etc. These are converted into current/voltage variations using suitable transducers. The information bearing signals are called **base band signals.**

(ii) **Digital signals.** A digital signal is a discontinuous function of time, in contrast to an analog signal, wherein current or voltage value varies continuously with time.

Such a signal is usually in the form of *pulses*. Each pulse has two levels of current or voltage, represented by 0 and 1. Zero (0) of a digital signal refers to open circuit and (1) of a digital signal refers to closed circuit. Zero (0) is also referred to as 'No' or space and (1) is referred to as 'Yes' or mark. Both 0 and 1 are called bits.

A typical digital signal is shown in Fig.

The significant characteristics of a digital signal are : Pulse amplitude ; Pulse Duration or Pulse Width and Pulse Position, representing the time of rise and time of fall of the pulse amplitude, as shown in Fig.



Examples of digital messages are :

(i) letters printed in this book

(ii) listing of any data,

(iii) output of a digital computer,

(iv) Electronic transmission of a document at a distant place via telephone line i.e. FAX etc.

An analog signal can be converted suitably into a digital signal and vice-versa.

Note. As stated above, a digital signal is represented by binary digits 0 and 1 called bits.

A group of bits is called a binary word or a byte. A byte made of 2 bits can give four code combinations : 00, 01, 10 ; 11.

TYPES OF COMMUNICATIONS SYSTEMS

There is no unique way of classifying communication systems. However, for the sake of convenience, we can classify them broadly on the basis of -

(i) nature of information source,

(ii) mode of transmission,

(iii) type of transmission channel used,

(iv) type of modulation employed, as detailed below:

(a) Based on nature of information source

(i) Speech transmission as in radio

(ii) Picture as well as speech transmission as in television

(iii) Facsimile transmission, as in FAX

(iv) Data transmission as in computers

(b) Based on mode of transmission

(i) Analog communication, where the modulating signal is analog. The carrier wave may be sinusoidal or in the form of pulses. For example, in telegraphy, telephony, radio network, radar, television network, teleprinting, telex etc.

(ii) Digital communicatoin, where the modulating signal is digital in nature. For example, Fax, mobile phone network, e-mail, teleconferencing, telemetry, communication satellites and global positioning system are all digital communication systems.

(c) Based on transmission channel

(i) Line communication

1. Two wire transmission line

2. Co-axial cable transmission

3. Optical fibre cable communication

(ii) Space communication

(d) Based on the type of modulation

(i) For sinusoidal continuous carrier waves, the types of modulation are :

1. Amplitude Modulation (AM)

2. Frequency Modulation (FM)

3. Phase Modulation

(ii) For pulsed carrier waves, the modes of modulation are :

1. Pulse Amplitude Modulation (PAM)

2. Pulse Time Modulation (PTM).

It includes

– Pulse Position Modulation (PPM),

– Pulse Width modulation (PWM),

– Pulse Duration Modulation (PDM)

3. Pulse Code Modulation (PCM)

AN IMPORTANT STEP IN COMMUNICATIONS MODULATION AND ITS NEED

Suppose we wish to transmit an electrical signal in the audio frequency (AF) range (20 Hz to 20 kHz) over a long distance. We cannot do it, as such because of the following reasons :

1. Size of the antenna or aerial. An antenna or aerial is needed both for transmission and reception. Each antenna should have a size comparable to the wavelength of the signal, (atleast $\lambda/4$ in size), so that time variation of the signal is properly sensed by the antenna.

   For an audio frequency signal of frequency $\nu = 15$ kHz, the wavelength, $\lambda = \frac{c}{\nu} = \frac{3\times10^8}{15\times10^3} =$ 20000 m. The length of the antenna $= \frac{\lambda}{4} = \frac{20000}{4} = 5000$ metre. To set up an antenna of vertical height 5000 metre is practically impossible. Therefore, we need to use high frequencies for transmission.

2. Effective Power radiated by antenna. Theoretical studies reveal that power P radiated from a linear antenna of length l is

   $$P \propto \frac{1}{l^2}$$

   As high powers are needed for good transmission, l should be small i.e. antenna length should be small, for which wavelength λ should be small or frequency ν should be high.

3. Mixing up of signals from different transmitters. Suppose many people are talking at the same time. We just cannot make out who is talking what. Similarly, when many transmitters are transmitting baseband information signals simultaneously, they get mixed up and there is no way to distinguish between them. The possible solution is, communication at high frequencies and allotting a band of frequencies to each user. This is what is being done for different radio and T.V. broadcast stations.

All the three reasons explained above suggest that there is a need for transmissions at high frequencies. This is achieved by a process, called modulation, where in we superimpose the audio frequency baseband message or information signals (called the modulating signals) on a high frequency wave (called, the carrier wave). The resultant wave is called the modulated wave, which is transmitted.

In the process of modulation, some specific haracteristic of the carrier wave is varied in accordance with the information or message signal. The carrier wave may be

(i) Continuous (sinusoidal) wave, or

(ii) Pulse, which is discontinuous

A continuous sinusoidal carrier wave can be expressed as $E = E_0 \sin(\omega t + \phi)$.

Three distinct characteristics of such a wave are : amplitude (E_0), angular frequency (ω) and phase angle (ϕ). Any one of these three characteristics can be varied in accordance with the modulating baseband (AF) signal, giving rise to the respective Amplitude Modulation ; Frequency Modulation and Phase Modulation.

Notes. Phase modulation is not of much practical importance. We shall, therefore, confine ourselves to the study of amplitude and frequency modulations only.

Again, the significant characteristics of a pulse are : Pulse Amplitude, Pulse Duration or Pulse Width and Pulse Position (representing the time of rise or fall of the pulse amplitude). Any one of these characteristics can be varied in accordance with the modulating baseband (AF) signal, giving rise to the respective, Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM) or Pulse Widhth Modulation (PWM) and Pulse Position Modulation (PPM).

Solved Examples

Ex.1 Show that the minimum length of antenna required to transmit a radio signal of frequency 10 MHz is 7.5 m.

Sol. Here, $f = 10 \text{ MHz} = 10^7 \text{ Hz}$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{10^7} = 30 \text{ m}$$

Minimum length of antenna $= \frac{\lambda}{4} = \frac{30}{4} = 7.5 \text{ m}$

AMPLITUDE MODULATION

When a modulating AF wave is superimposed on a high frequency carrier wave in a manner that the frequency of modulated wave is same as that of the carrier wave, but its amplitude is made proportional to the instantaneous amplitude of the audio frequency modulating voltage, the process is called amplitude modulation (AM).

Let the instantaneous carrier voltage (e_c) and modulating voltage (e_m) be represented by

$$e_c = E_c \sin \omega_c t \qquad \text{....(1)}$$

$$e_m = E_m \sin \omega_m t \qquad \text{....(2)}$$

Thus, in amplitude modulation, amplitude A of modulated wave is made proportional to the instantaneous modulating voltage e_m

i.e. $A = E_c + k\, e_m$ ....(3)

where k is a constant of proportionality.

In amplitude modulation, the proportionality canstant k is made equal to unity. Therefore, max. positive amplitude of AM wave is given by

$$A = E_c + e_m = E_c + E_m \sin \omega_m t \qquad \text{....(4)}$$

It is called top envelope

The maximum negative amplitude of AM wave is given by

$$-A = -E_c - e_m$$

$$= -(E_c + E_m \sin \omega_m t) \qquad \text{....(5)}$$

This is called bottom envelope

The modulated wave extends between these two limiting envelopes, and its frequency is equal to the unmodulated carrier frequency. Fig.(a) shows the variation of voltage of carrier wave with time. Fig.(b) shows one cycle of modulating sine wave and Fig.(c) shows amplitude modulated wave for this cycle.

As is clear from Fig.(c)

$$E_m = \frac{E_{max} - E_{min}}{2}$$

and $E_c = E_{max} - E_m$

$$= E_{max} - \frac{E_{max} - E_{min}}{2}$$

$$E_c = \frac{E_{max} + E_{min}}{2} \qquad \text{....(6)}$$

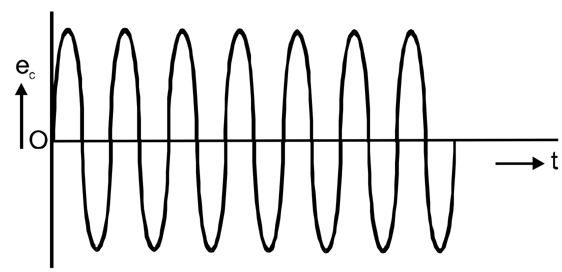


Fig.(a) CARRIER WAVE

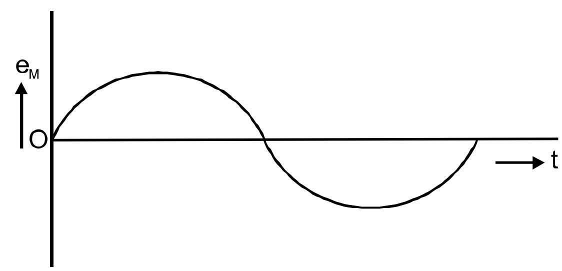


Fig.(b) MODULATING SIGNAL

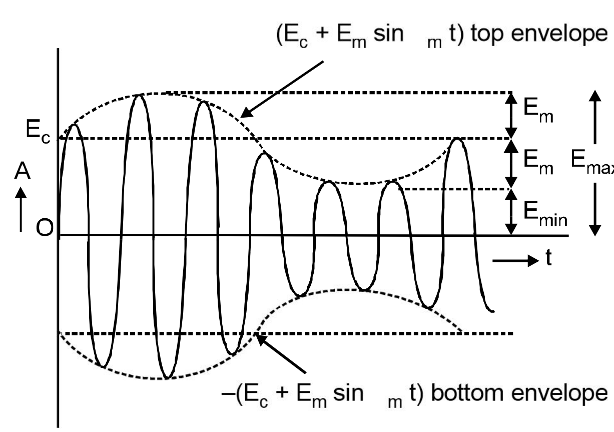


Fig.(c) AMPLITUDE MODULATED WAVE

In amplitude modulation, the degree of modulation is cefined by a term, called modulation index or modulation factor or depth of modulation represented by m_a. It is equal to the ratio of amplitude of modulating signal to the amplitude of carrier wave i.e.

$$m_a = \frac{E_m}{E_c} = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} \quad ....(7)$$

Obviously, modulation index (m_a) is a number lying between 0 and 1. Often, m_a is expressed in percentage and is called the percentage modulatoion. **Importance** of moduation index is that it determines the quality of the transmitted signal. When modulation index is small, veriation in carrier amplitude will be small. Therefore, audio signal being transmitted will be weak. As the modulataion index increases, the audio signal on reception becomes clearer.

Solved Examples

Ex.2 An audio signal of amplitude one half the carrier amplitude is used in amplitude modulation. Calculate the modulation index ?

Sol. Here, $E_m = 0.5\ E_c$

$\therefore\ E_{max} = E_c + E_m = E_c + 0.5\ E_c = 1.5\ E_c$

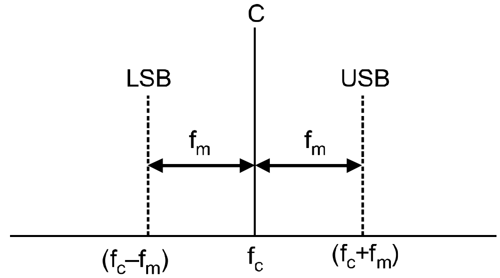
$E_{min} = E_c - E_m = E_c - 0.5\ E_c = 0.5\ E_c$

$$M_a = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

$$= \frac{1.5E_c - 0.5E_c}{1.5E_c + 0.5E_c} = \frac{E_c}{2.0E_c} = 0.5$$

1. Frequency Spectrum of AM wave

A detailed study of amplitude modulation reveals that the amplitude modulated wave consists of three discrete frequencies, as shown in Fig. Of these, the central frequency is the the carrier frequency (f_c), which has the highest amplitude. The other two frequencies are placed symmetrically about it. Both these frequencies have equal amplitudes-which never exceeds half the carrier amplitude. These frequencies are called side band frequencies.



$$f_{SB} = f_c \pm f_m$$

$\therefore$ Frequency of lower side band is

$$f_{LSB} = f_c - f_m \quad ....(8)$$

and frequency of upper side band is

$$f_{USB} = f_c + f_m \quad ....(9)$$

Band width of amplitude modulated wave is

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

$$= (f_c + f_m) - (f_c - f_m) = 2f_m \quad ....(10)$$

Band width = twice the frequency of the modulating signal

2. Power and Current Relations in AM wave

Average power/cycle in the unmodulated carrier wave is

$$P_c = \frac{E_c^2}{2R} \quad ....(11)$$

where R is resistance (of antenna) in which power is dissipated.

It can be shown that total power/cycle in the modulated wave is

$$P_t = P_c\left(1 + \frac{m_a^2}{2}\right) \quad ....(12)$$

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

But $\quad Pt = I_t^2 R$ and $Pc = I_c^2 R$

$$\therefore \quad \frac{I_t^2}{I_c^2} = \left(1 + \frac{m_a^2}{2}\right)$$

or $$\frac{I_t}{I_c} = \sqrt{1 + \frac{m_a^2}{2}} \quad ....(13)$$

FREQUENCY MODULATION

When a modulating AF wave is superimposed on a high frequency carrier wave in such a way that the amplitude of modulated wave is same as that of the carrier wave, but its frequency is varied in accordance with the instantaneous value of the modulating voltage, the process is called frequency modulation (FM).

Let the instantaneous carrier voltage (e_c) and modulating voltage (e_m) be represented by

$$e_c = E_c \sin \omega_c t \qquad ....(15)$$
$$e_m = E_m \sin \omega_m t \qquad ....(16)$$

Fig. (a) represents the variation of carrier voltage with time, and Fig. (b) represents the variation of modulating AF voltage with time.

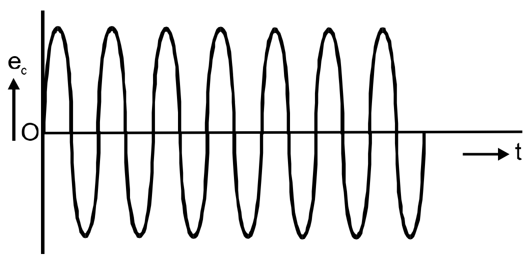


Fig.(a) CARRIER WAVE

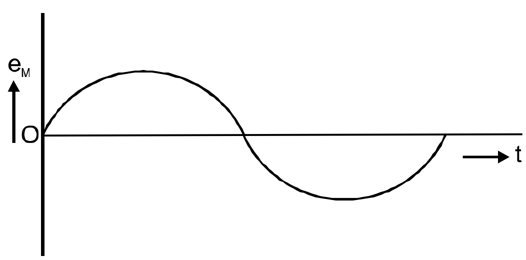


Fig.(b) MODULATING SIGNAL

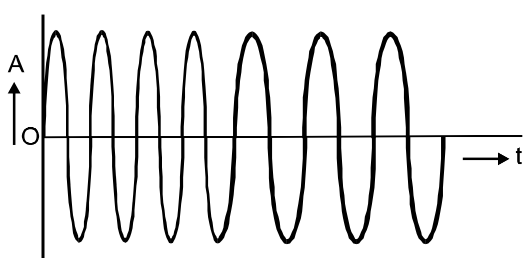


Fig.(c) FM Wave (exaggerated)

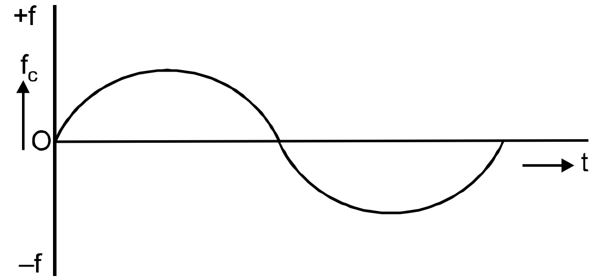


Fig.(d) Frequency vs time in FM wave

In frequency modulation, the amount by which carrier frequency is varied from its unmodulated value ($f_c = \omega_c/2\pi$) is called the **deviation.** This deviation is made proportional to the instantaneous value of the modulating voltage. The rate at which the frequency variation takes place is equal to the modulating frequency. Fig.(c) represents an exaggerated view of frequency modulated wave. Fig.(d) shows the frequency variation with time in the FM wave. This is identical to the variation of the modulating voltage with time, Fig.(b). Note that

(i) All signals having same amplitude will change the carrier frequency by the same amount, whatever be their frequencies

(ii) All modulating signals of same frequency, say 1 kHz, will change the carrier frequency at the same rate of 1000 times, per second-whatever be their individual amplitudes

(iii) The amplitude of the frequency modulated wave remains constant at all times, being equal to the amplitude of the carrier wave

If f is frequency of FM wave at any instant t and f_c is constant frequency of the carrier wave, then

deviation (in frequency), $\delta = (f - f_c)$ ....(17)

By definition of frequency modulation,

$$\delta \propto e_m$$

or $\delta \propto E_m \sin \omega_m t$

$$\delta = k\, E_m \sin \omega_m t \qquad ....(18)$$

where k is a constant of proportionality, Using (17), we get

$$\delta = f - f_c = k\ E_m \sin \omega_m t$$

or $f = f_c + k\ E_m \sin \omega_m t$ ....(19)

The deviation will be maximum, when

$$(\sin \omega_m t)_{max} = \pm 1$$

$\therefore$ From (19), $f_{max} = f_c \pm k\ E_m$ ....(20)

or $d_{max} = f_{max} - f_c = \pm k\ E_m$ ....(21)

The **modulation index** (m_f) of a frequency modulated wave is defined as the ratio of maximum frequency deviation to the modulating frequency i.e.

$$m_f = \frac{\delta_{max}}{f_m} = \frac{\pm k\ E_m}{f_m} \quad ....(22)$$

Clearly, modulating index increases, as modulating frequency (f_m) decreases. m_f has no units, it being the ratio of two frequencies.

The instantaneous amplitude of frequency modulated wave is given by

$$A = A_0 \sin \theta$$

where θ is the function of carrier angular frequency (ω_c) and modulating angular frequency (ω_m). Infact,

$$\theta = \left(\omega_c t + \frac{\delta}{f_m} \sin \omega_m t \right) \quad ....(23)$$

The **frequency spectrum** of FM wave is far more complex than the frequency spectrum of AM wave. Infact,

(i) The output of an FM wave consists of carrier frequency (f_c) and almost an infinite number of side bands, whose frequencies are ($f_c \pm f_m$), ($f_c \pm 2f_m$), ($f_c \pm 3f_m$),... and so on. The sidebands are thus separated from the carrier by f_m, $2f_m$, $3f_m$ ....etc i.e. they have a recurrence frequency of f_m.

(ii) The number of sidebands depends on the modulation index (m_f). The number of sidebands increases, when frequency deviation (δ) is increased, keeping (f_m) constant. Similarly, number of sidebands decreases, when frequency of modulating signal (f_m) is increased keeping frequency deviation constant

(iii) The sidebands are disposed symmetrically about the carrier. Further, sidebands at equal distances from the carrier have equal amplitudes.

(iv) As the distance of sidebands from carrier frequency increases, their amplitude decreases. Therefore, number of significant sideband pairs is limited

(v) In frequency modulated wave, the information (audio signal) is contained in the sidebands only. Since the sidebands are separated from each other by the frequency of the modulating signal (f_m), therefore,

Band width = $2n \times (f_m)$ ....(24)

where n is the number of the particular sideband pair.

Solved Examples

Ex.3 As audio signal of 2.8 kHz modulates a carrier of frequency 84 MHz and produces a frequency deviation of 56 kHz. Calculate

(i) frequency modulation index

(ii) frequency range of FM wave

Sol. Here, $f_m = 2.8$ kHz, $f_c = 84$ MHz

$\delta = 56$ kHz

(i) Frequency modulation index

$$= m_f = \frac{\delta}{f_m} = \frac{56}{2.8} = 20$$

(ii) Frequency range of FM wave

$= f_c \pm f_m$

$= (84 \pm 2.8 \times 10^{-3})$ MHz

= 84.0028 MHz and 83.9972 MHz

COMPARISON OF AMPLITUDE MODULATION AND FREQUENCY MODULATION

Following are some of the **advantages of frequency modulation** over the amplitude modulation :

(i) FM transmission is far more efficient compared to AM transmission. This is because amplitude of FM wave is constant, whatever be the modulation index. Therefore, transmitted power is constant. Amplifiers used in FM transmission handle constant power and are more efficient. Further, all the power transmitted in FM is useful, whereas in AM transmission, most of the power goes waste in the transmitted carrier, which contains no useful information.

(ii) FM reception is almost immune to noise as compared to AM reception. This is because noise is a form of amplitude variation in transmitted signal. Therefore, by using amplitude limiters in the FM receivers, we can almost eliminate noise. Noise can also be reduced by increasing the frequency deviation in FM wave. This feature is not available in the AM wave.

Further, FM broadcasts operate in VHF and UHF frequency ranges—where the noise is much less than in MF and HF ranges for AM broadcasts.

(iii) With the use of space wave in FM broadcasts, radius of operation is limited to slightly more than the line of sight transmission. This reduces the chances of adjacent channel interference.

The chances of interference reduce further by standard frequency allocations by the International Radio Consultative Committee (IRCC). This provides a guard band between commercial FM stations.

Some of the **disadvantages of frequency modulation** are :

(i) The channel width required in FM transmission is almost 10 times as large as that needed in AM transmission. Therefore, much wider frequency channel is required in FM transmission

(ii) The equipment used in FM transmission and reception is far more complex than the equipment used in AM transmission and reception

(iii) As FM reception is limited to 'line of sight', the area of reception of FM is much smaller than that for AM

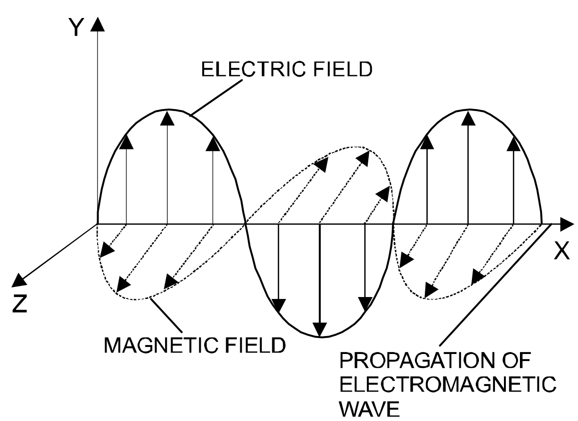
Range of frequencies allotted for commercial FM radio and T.V. broadcasts is given in Table.

TABLE

Nature of Broadcast	Frequency Band
FM radio	88–108 MHz
VHF T.V	47–230 MHz
UHF T.V	470–960 MHz

ELECTROMAGNETIC WAVES

Electromagnetic waves are those waves in which there is a sinusoidal variation of electric and magnetic field vectors at right angles to each other as well as at right angles to the direction of propagation of waves. In electromagnetic waves, both the field vectors ($\vec{E}$ and $\vec{B}$) vary with time and space and have the same frequency and same phase. In Fig., the electric field vector ($\vec{E}$) and magnetic field vector ($\vec{B}$) are vibrating along Y and Z directions and propagation of electromagnetic wave is shown in X-direction.



According to Maxwell the electromagnetic waves are of transverse in nature and they can pass through vacuum with the speed of light ($= 3 \times 10^8$ ms^{-1}).

The velocity of eletromagnetic wave in a medium is given by

$$\nu = \frac{1}{\sqrt{\mu_0 \mu_r \in_0 \in_r}}$$

where, μ_0, μ_r = absolute permeability of space and relative permeability of medium,

$\in_0$, $\in_r$ = absolute permittivity of space and relative permittivity of medium

The velocity of electromagnetic waves of different frequency in vacuum is same but in a medium is different. It is more for red light and less for violet light.

Examples of electromagnetic waves are radiowaves, microwaves, infrared rays, light waves, ultraviolet rays, X-rays and γ-rays.

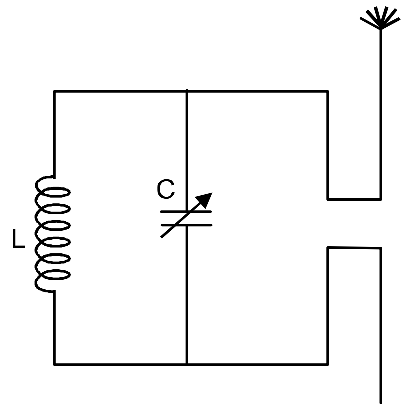
The electromagnetic waves were first produced by Hertz in 1888 with the help of Hertz oscillator, which were of wavelength 6 m. In 1895, an Indian Physicist Jagdish Chander Bose produced electromagnetic waves of wavelength 5 mm to 25 mm. In 1896, Marconi was first to establish a wireless communication across the English channel, a distance of about 50 km.

In electromagnetic waves, the energy is shared equally between electric field vector and magnetic field vector. The total average energy associated with electric field is equal to the total average energy associated with magnetic field, given by

$$U_{av} = \frac{1}{2} \in_0 E_0^2 = \frac{1}{2} \frac{B_0^2}{\mu_0}.$$

It has been found that the velocity (c) of electromagnetic wave in free space is equal to the ratio of amplitude of electric field vector (E_0) and magnetic field vector (B_0) i.e. $c = E_0/B_0$.

It was found that the accelerated charge or oscilating charge is a source of electromagnetic waves. A simple experimental arrangement shown in Fig. is used to transmit electromagnetic waves produced by L–C circuit, using half wave antenna.



When L–C circuit produces oscillations, the charge oscillates on capacitor. Due to which the two ends of the antenna become alternatively positive and negative. As a result of it, the electric field vector is always parallel to the plane of antenna, while the magnetic field vector is at right anlge to it. Since the electric field vector is oriented in one particular direction with respect to the surface of earth, hence there is polarisation of electromagnetic wave.

If the plane of electric field is oriented horizontally in respect to the earth, the electromagnetic wave is said to be **horizontally polarised.** On the other hand, if the plane of electric field vector is oriented vertically the electromagnetic wave is said to be **vertically polarised.**

When the antenna is vertical w.r.t. earth, the electric field vector is vertically oriented w.r.t. earth, therefore, the electromagnetic wave is vertically polarised. When the antenna is held parallel to horizontal, the electromagnetic wave would be horizontally polarised. **It means the polarisation of electromagnetic wave is mainly the function of the antenna orientation.**

Our earth's atmosphere helps in the propagation of electromagnetic waves from one place to other place on the surface of earth. To understand the various modes of propagation of electromagnetic waves, we shall study about earth's atomosphere.

EARTH'S ATMOSPHERE

The gaseous envelope surrounding the earth is called earth's atmosphere. The earth atmosphre mainly consists of nitrogen 78%, oxygen 21% and with a little portion of argon, carbon dioxide, water vapour, hydrocarbons, sulphur compounds and dust particles. The density of the atmospheric air goes on decreasing as we go up. The electrical conductivity of the atmosphre has no sharp boundary. It has been divided into various regions as given below.

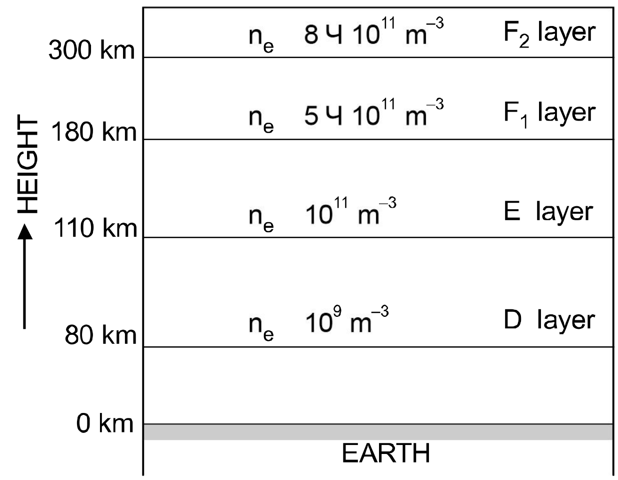
(i) **Troposphere.** It extends upto a height of 12 km. The atmospheric air in this region has maximum density which varies from 1 kg/m^3 at the surface of earth to 0.1 kg/m^3 at the top of this layer. The electrical conductivity of this region is least as compared to other regions of earth's atmosphre.

(ii) **Stratosphere.** It extends from 12 km to 50 km from the surface of earth. The density of air of this region varies from 0.1 kg/m^3 to 10^{-3} kg/m^3. There is an **ozone layer** in this region in between 30 km to 50 km from the surface of earth, which absorbs a large portion of **ultraviolet radiations** radiated by sun or coming from outer space.

(iii) **Mesosphere.** It extends from 50 km to 80 km from the surface of earth. The density of air in this layer varies from 10^{-3} kg/m^3 to 10^{-5} kg/m^3. The temperature of this region falls from 280 K to 180 K with height.

(iv) **Ionosphere.** It extends from 80 km to 400 km from the surface of the earth. The density of this region varies from 10^{-5} kg/m^3 to 10^{-10} kg/m^3. In this region temperature increases with height from 180 K to 700 K, that is why, it is called **thermosphere.** Ionosphere is the outermost part of the earth's atmosphere. It is composed of ionised matter (i.e. electrons and positive ions) which plays an important role in space communication.

There are four main layers in earth's atmosphere having high density of electrons and positive ions, produced due to ionisation by the high energy particles coming from sun, stars or cosmos. These layers play their effective role in space communication. These layers are D, E, F_1 and F_2. Fig.



(a) **D-layer** is at a virtual height of 80 km from surface of earth and having electron density ≈ 10^9 m^{-3}. The extent of ionisation of D layer depends upon the altitude of sun. This layer disappears at night. This layer reflects very low frequency (VLF) and low frequency (LF) electromagnetic waves but absorbs medium frequency (MF) and high frequency (HF) electromagnetic waves to a certain degree.

(b) **E-layer** is at a virtual height of 110 km, from the surface of earth, having electron density ≈ 10^{11} m^{-3}. The critical frequency* of this layer is about 4 MHz. This layer helps to MF surface-wave propagation a little but reflects some high frequency waves in day time. This layer exist at night.

(c) **F_1-layer** is at a virtual height of 180 km from the surface of earth, having electron density ≈ 5 × 10^{11} m^{-3}. The critical frequency for this layer is 5 MHz. It reflects some of the high frequency waves but most of the high frequency waves pass through it and they get reflected from layer F_2. This layer merges in F_2 layer at night.

(d) **F_2-layer** is at a vertical height of about 300 km in day time and about 350 km in night time. The electron density of this layer is $\approx 8 \times 10^{11}$ m^3. The critical frequency of this layer is 8 MHz in day time and 6 MHz in night time. It reflects back the electromagnetic waves of frequency upto 30 MHz but cannot reflect back the electromagnetic waves of frequency 40 MHz or more.

Thus earth's atmosphere helps in the propagation of electromagnetic waves from one place to another place, upto 30 MHz frequency.

BEHAVIOUR OF ATMOSPHERE TOWARDS ELECTROMAGNETIC WAVES

The behaviour of atmosphere is different for electromagnetic waves of different frequencies. The atmosphere is transparent to electromagnetic waves of visible region of wavelength range 4000 Å to 8000 Å, as we can see the sun and the stars through it clearly. The electromagnetic waves belonging to infrared region of wavelength range 8×10^{-7} m to 3×10^{-5} m are not allowed to pass through atmosphere rather they get reflected by atmosphere. The ozone layer of earth's atmosphere blocks the electromagnetic waves of ultraviolet region of wavelength range 6 Å to 4000 Å.

The behaviour of earth's atmosphere towards electromagnetic waves of wavelength 10^{-3} m and higher is of special interest in space communication. The lower part of atmosphere is more or less transparent to electromagnet waves of wavelength 20 m and higher used in radiocommunication but the top most layer, the ionosphere does not allow these waves to penetrate but reflects, above 40 MHz, the ionosphere bends any incident electromagnetic wave but dies not reflect it back towards earths.

RADIOWAVES

The radiowaves are the electro-magnetic waves of frequency ranging from few kilo hertz to nearly few hundred mega hertz (i.e. 3 kHz to about 300 GHz, where 1 GHz = 109 Hz). These waves are used in the field of radio communication. With reference to the frequency range and wavelength range the radiowaves have been divided into following categories ; See Table.

Table 12-1

S. No.	Frequency band	Frequency range	Wavelength range	Main use
1	Very-Low Frequency (VLF)	3 kHz to 30 kHz	10 km to 100 km	Long distance point to point communication
2	Low Frequency (LF)	30 kHz to 300 kHz	1 km to 10 km	Marine and navigational purposes
3	Medium Frequency (MF)	300 kHz to 3 MHz	100 m to 1 km	Marine and broadcasting purposes
4	High Frequency (HF)	3 MHz to 30 MHz	10 m to 100 m	Communication of all types
5	Very-High Frequency (VHF)	30 MHz to 300 MHz	1 m to 10 m	T.V., Radar and air navigation
6	Ultra-High-Frequency (UHF)	300 MHz to 3000 MHz	10 cm to 1 m	Radar and microwave commnication
7	Super-High-Frequency (SHF)	3 GHz to 30 GHz	1 cm to 10 cm	Radar,radio relays and navigation purposes
8	Extremely-High-Frequency (EHF)	30 GHz to 300 GHz	1 mm to 1 cm	Optical fibre communication

TRANSMISSION MEDIUM OR COMMUNICATION CHANNEL

The **transmission medium** or **communication channel** is a link through which information/ message signal may propagate from the source to the destination, without any noise or distorsion. It is a sort of electronic roadways along which signals travel.

Broadly, transmission media have been divided into two types :

(i). Guided Transmission Medium

(ii) Unguided Transmission Medium

(i) Guided Transmission Medium. It is that communication medium or channel which is used in signal communication, for point to point contact between the transmitter and receiver. For example, parallel wire lines, twisted pair and co-axial cable are guided transmission media. Optical fibres are other examples of guided transmission medium. Guided transmission medium is used in **line communication.**

(ii) Unguided Transmission Medium. It is that communication medium which is used, where there is no point to point contact between the transmitter and receiver. Free space is an example of unguided transmission medium. It is used in **space communication** and **satellite communication.**

The characteristics and quality of transmission medium depend upon

(a) nature of transmission medium,

(b) nature of signal

Thus, basically there are two types of communications (1) Space communication

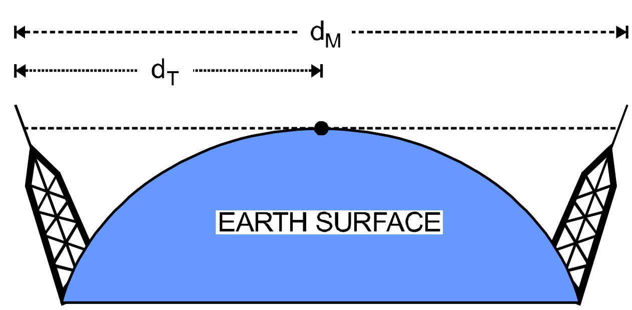
(2) Line communication.

SPACE WAVE PROPAGATION

It is that mode of propagation in which the radiowaves emitted from the transmitting antenna reach the receiving antenna through space. These radiowaves are called space waves. The space waves are the radiowaves of frequency range from 54 MHz to 4.2 GHz. The space waves travel in straight line from transmitting antenna to receiving antenna. Therefore, the space waves are used for the **line of sight communication** as well as for the **satellite communication.** The space wave propagation is used for **television broadcast, microwave link** and **satellite communication.**

If the frequency of the radiowaves is greater than 54 MHz ; then the waves can not travel along the surface of earth as they get absorbed by the earth. Hence, their propagation cannot be like ground wave propagation. Morcover, these waves cannot be reflected by ionosphere, hence their propagation cannot be like sky wave propagation.

The communication through space wave between transmitter and receiver is limited to line of sight path. The line of sight communication is limited by (i) the line of sight distance and (ii) the curvature of the earth. The space waves following the line of sight propagation get blocked at some point by the curvature of the earth as illustrated in Fig. Here, d_T is called the radio horizon of the transmitting atenna, d_M is called the maximum line of sight distance between the two antennas.



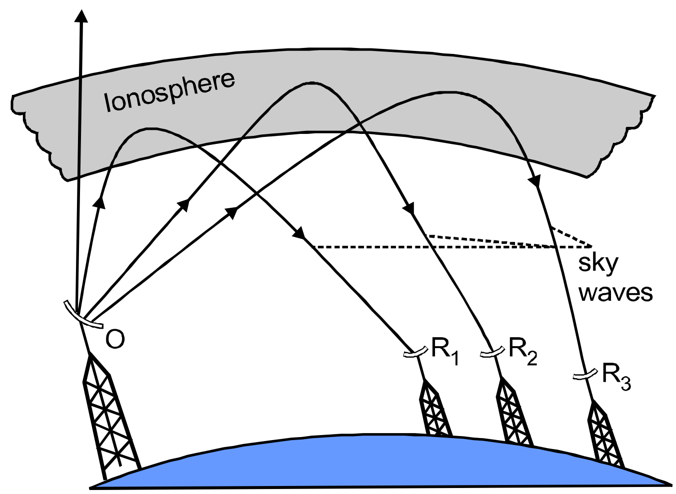
The line of sight distance is that distance between transmitting antenna and receiving antenna at which they can see each other. It is also called **range of communication (d_M).** The range of space wave communication can be increased by increasing the heights of transmitting antenna and receiving antenna.

SKY WAVE PROPAGATION

It is a mode of wave propogation in which the radiowaves emitted from the transmitter antenna reach the receiving antenna after reflection by the ionosphere.

In sky wave propagation, the radiowaves of frequency range from generally 1710 kHz to 54 MHz are used. This mode of propagation is used by short wave broadcast service.

Ionosphere is the uppermost layer of earth's atmosphere extending from a height of 65 km to about 400 km, above the surface of earth. The density of atmosphere decreases with height. The ultraviolet radiations and other high energy radiations coming from sun on entering ionosphere of earth's atmosphere, are largely absorbed by the molecules of that layer of atmosphere. Due to it, the molecules get ionised. The degree of ionisation varies with the height. At great height, the solar radiations intensity is high but the density of earth's atmosphere is low, hence there are few air molecules to be ionised. On the other hand, close to the earth, the density of earth's atomosphere is high but the radiation intensity is low. Due to it, the ionisation is low. However, at some intermediate heights, there occurs maximum ionisation of earth atmospheric molecules, resulting ionised layers of maximum electrons and ions which are formed at different heights. Due to it, we get various ionised layers ; D, E, F_1 and F_2 having different number density of electrons and ions at different height as discussed in Art. Fig. Each ionised ionospheric layer acts as a reflector for a certain range of radiowaves (between 1.71 MHz to 54 MHz). The electromagnetic waves of frequencies greater than 54 MHz penetrate the ionosphere and escape. The Fig.15 shows the mode of the sky wave propagation.



IMPORTANT TERMS FOR SKY WAVE PROPAGATION

(a) Plasma frequency and critical frequency. Plasma frequency is an important parameter in radiocommunication via the ionosphere. The plasma frequency ν is related to the electron density N (in m^{-3}) of a layer of ionosphere by a relation $\nu = 9\sqrt{N}$

The plasma frequency at the peak of a layer is called **critical frequency** (ν_c).

Critical frequency ν_c. It is that highest frequency of radio wave, which when sent straight (i.e. normally) towards the layer of ionosphere gets reflected from ionosphere and returns to the earth. If the frequency of the radiowave is more than critical frequency, it will not be reflected by ionosphere. The critical frequency of a sky wave for reflection from a layer of atmosphere is given by $\nu_c = 9(N_{max})^{1/2}$, where N_{max} is the maximum number density of electron/m^3. The number density per cubic metre of electrons for D, E, F_1 and F_2 layers are 10^9, 10^{11}, 5×10^{11} and 8×10^{11} respectively.

(b) **Maximum usable frequency (MUF). It is that highest frequency of radio waves which when sent at some angle towards the ionosphere, gets reflected from that and returns to the earth.**

$$\text{Quantitatively, MUF} = \frac{\nu_c}{\cos i} = \nu_c \sec i$$

where i is the angle between normal and the direction of incidence of waves. The frequency normally used for ionosphere transmission is known as **optimum working frequency** (OWF), which is taken to be 15% of MUF.

(c) **Skip distance.** It is the smallest distance between the transmitting antenna and the point R_v where the sky wave of a fixed frequency, but not more than critical frequency is first received after reflection from ionosphere. In Fig.15, OR_1 = skip distance. If the angle of incidence of sky wave on the layer of ionosphere is large, then after reflection they will be reaching the earth at longer distance from the transmitting antenna. It means, the larger is the angle of incidence of sky wave, the greater is the value of skip distance on the surface of earth. This shows that the transmission path of sky waves is limited by the skip distance. The skip distance is given by the relation

$$D_{skip} = 2h\sqrt{\left(\frac{\nu_{max}}{\nu_c}\right)^2 - 1}$$

where h is the height of reflecting layer of atmosphere, ν_{max} is the maximum frequency of electromagnetic waves and ν_c is the critical frequency for that layer of ionosphere.

Note. Skip zone in radio communication is that range where there is no reception of either ground wave of sky wave.

(d) **Fading.** It is the variation in the strength of a signal at a receiver due to interference of waves. Fading is more at high frequencies. Fading causes an error in data transmission and retrieval.

The signals received due to sky wave propagation are subjected to **fading** in which the strength of the signal varies with time. It is so because, at the receiver, a large number of waves reach, following different number of paths.

(e) **Refractive index μ** of a layer in sky wave propagation is given by

$$\mu = \sqrt{1 - \frac{81.45\ N}{\nu^2}}$$

where N is the number density of electrons/m^3 of the layer of atmosphere under study and ν is the frequency of electromagnetic wave in Hz).

Relative permittivity or dielectric constant of the layer of atmosphere under study is given by

$$\in_r = 1 - \frac{81.45\ N}{\nu^2}$$

RELATION BETWEEN COVERAGE DISTANCE AND HEIGHT OF TRANSMITTING ANTENNA

Suppose PQ is a T.V. transmitting angenna of height h located at P on the surface of earth. Due to finite curvature of earth, the T.V. signal transmitted from Q cannot be received beyond the tangent points T and S on earth (Fig.16). The effective reception range of the T.V. broadcast is essential the region from S to T on earth which is covered by the line of sight during T.V. transmission.

Let SP = TP = d (distance to the horizon). This distance is limited by the curvature of earth. Therefore, the T.V. signals will be received on earth in a circle of radius d.

Here, R = radius of earth

= OS = OT = OP ;

PQ = h

and OQ = OP + PQ = R + h

In rt. angled triangle QPS

$$SQ^2 = SP^2 + PQ^2 + d^2 + h^2$$

In rt. angled triangle OSQ

$$OQ^2 = OS^2 + SQ^2$$

or $(R + h)^2 = R^2 + (d^2 + h^2)$

or $R^2 + 2hR + h^2 = R^2 + d^2 + h^2$

or $2hR = d^2$

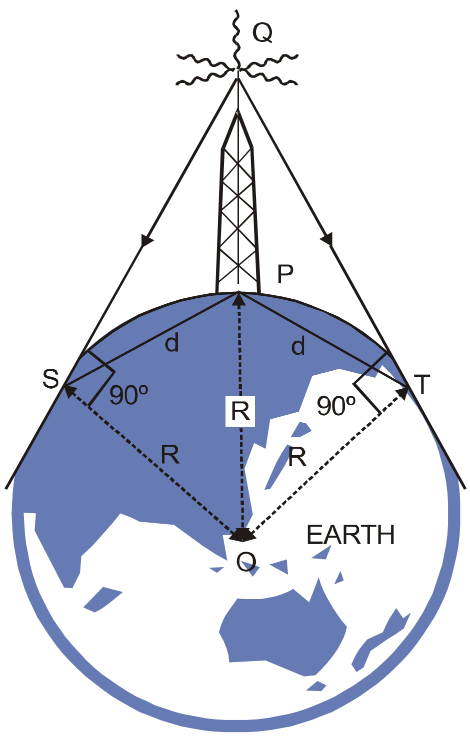
or $d = \sqrt{2hR}$

For T.V. signals, area covered

$$= \pi d^2 = \pi \, 2Rh$$

Population covered = population density

× area covered



Solved Examples

Ex.4 What should be the height of transmitting antenna if the T.V. telecast is to cover a radius of 128 km ? $R_e = 6.4 \times 10^6$ m. If the average population density around the tower is 1000/ km^2,

how much population is covered ?

Sol. Height of transmitting antenna

$$h = \frac{d^2}{2R} = \frac{(128 \times 10^3)^2}{2 \times 6.4 \times 10^6} = 1280 \text{ m}$$

Total population covereds

$= \pi d^2 \times$ population density

$= 3.14 \times (128)^2 \times 1000 = 5.14 \times 10^7$