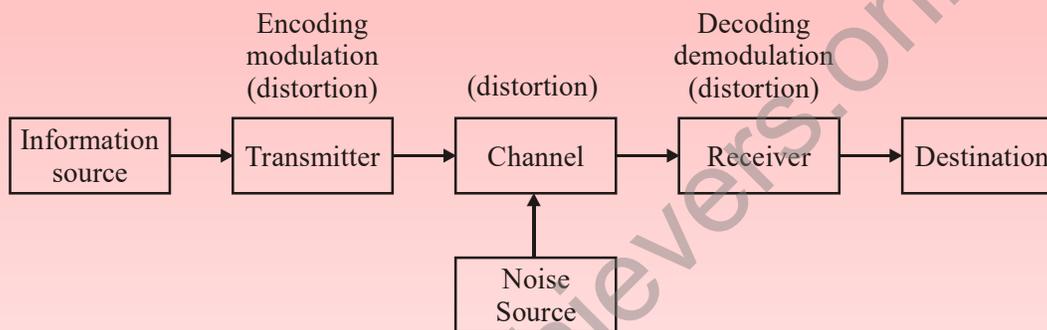# COMMUNICATION SYSTEMS

Communications

The term communication refers to the transmitting, receiving and processing of information by electronic means.

Block diagram of communications system

(i) Information: The idea/message that is to be conveyed is information. The amount of information contained in a message is measured in bits. The message may consist of individual messages or a set of messages. The message may be a symbol, code, group of words or any pre-decided unit.

(ii) Transmitter: A transmitter processes and encodes the incoming information so as to make it suitable for transmission and subsequent reception. In a transmitter information is impressed on a high frequency carrier wave, a process called modulation.

(iii) Receiver: A signal to be transmitted is first superposed on a carries wave during modulation and then it is amplified before applying on a transmitting antenna. The most important function of receiver is demodulation and some times decoding as well, the reverse of modulation in a transmitter.

❖ **ANALOG AND DIGITAL COMMUNICATIONS**

(i) Analog communication

(ii) Digital communication

In an analog communication signal current or voltage value varies continuously with time, *e.g.*, consider a sinusoidal analog voltage signal.

Modulation

➤ The radiation of electrical energy is practicable only at high frequencies, *e.g.*, above 20 kHz. The high frequency signals can be sent over large distances even with comparatively small power. This is achieved by superimposing electrical audio signal on high frequency carrier. The resultant waves are known as modulated waves or radio wave and the process is called modulation.

Amplitude Modulation

When the amplitude of high frequency carrier wave is changed in accordance with the intensity of the signal, it is called amplitude modulation. The frequency of the modulated wave remains the same, i.e., carrier frequency.

Signal

Carrier   A.M. Wave
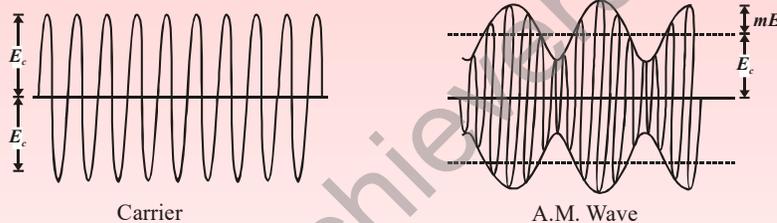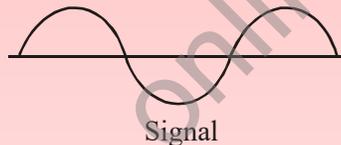
The following points are worth noting in amplitude modulation:

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

(ii) The amplitude variation 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**

Modulation factor, $m = \dfrac{\text{Amplitude change or carrier wave}}{\text{Amplitude of normal carrier wave (unmodulated)}}$.\

❖ **ANALYSIS OF AMPLITUDE MODULATED WAVE**

A carrier wave may be represented by

$v_c = V_c \cos \omega_c t$

where v_c = instantaneous voltage of carrier

V_c = amplitude of carrier

$\omega_c = 2\pi f_c$ = angular velocity of carrier wave

If the modulation factor is m, the signal produces a maximum change of mV_c in the carrier wave amplitude. Therefore, the amplitude of signal is mV_c. The signal can be represented by

$v_m = mV_c \cos \omega_m t$

$= V_c \cos \omega_c t + \dfrac{mV_c}{2} \cos(\omega_m + \omega_c)t + \dfrac{mV_c}{2} \cos(\omega_c - \omega_m)t$

where mV_c = amplitude of signal

$\omega_c = 2\pi f_m$ = angular frequency of signal

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

$$= V_c + mV_c \cos\omega_m t = V_c(1 + m\cos\omega_m t)$$

The instantaneous voltage of AM wave is

E = Amplitude $\times \cos\omega_c t$

$$= V_c(1 + m\cos\omega_m t)\cos\omega_c t$$

$$= V_c \cos\omega_c t + mV_c \cos\omega_m t \cos\omega_c t$$

$$= V_c \cos\omega_c t + \frac{mV_c}{2}(2\cos\omega_m t \cos\omega_c t)$$

$$= V_c \cos\omega_c t + \frac{mV_c}{2}[\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)t]$$

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

❖ POWER IN AM WAVE

The power dissipated in any circuit depends on the square of r.m.s. voltage across the circuit and the effective resistance of the circuit. The amplitude of three components of an AM wave are V_c, $mV_c/2$ and $mV_c/2$. Power output is distributed among these components.

Carrier power, $\quad P_c = \dfrac{\left(\dfrac{V_c}{\sqrt{2}}\right)}{R} = \dfrac{V_c^2}{2R}$ \hfill …(i)

Total power of sidebands, $\quad P_s = \dfrac{\left(\dfrac{mV_c}{2\sqrt{2}}\right)^2}{R} + \dfrac{\left(\dfrac{mV_c}{2\sqrt{2}}\right)^2}{R}$

$$= \frac{m^2 V_c^2}{8R} + \frac{m^2 V_c^2}{8R} = \frac{m^2 V_c^2}{4R} \hspace{2cm} …(ii)$$

Total power of AM wave, $\quad P_T = P_c + P_s$

$$= \frac{V_c^2}{2R} + \frac{m^2 V_c^2}{4R} = \frac{V_c^2}{2R}\left[1 + \frac{m^2}{2}\right]$$

or $\quad P_T = \dfrac{V_c^2}{2R}\dfrac{[2 + m^2]}{2} \qquad = P_c \dfrac{(2 + m^2)}{2}$ \hfill …(iii)

Fraction of total power carried by sidebands, $\dfrac{P_s}{P_T} = \dfrac{m^2}{2 + m^2}$ …(iv)

Example 1: **When a broadcast AM transmitter is 50% modulated, its antenna current is 10A. What would be the carrier current?**

***Solution:*** Here, $I_t = 10\text{A}, I_c = ? m = \dfrac{50}{100} = \dfrac{1}{2}$

As $\quad I_c = \dfrac{I_t}{\sqrt{1 + m^2/2}}$

$\therefore \quad I_c = \dfrac{10}{\sqrt{1 + 1/8}} = \dfrac{10 \times 2\sqrt{2}}{3} = \dfrac{28.28}{3} = 9.43\text{A}.$

Example 2: **An audio signal 15 sin 2π(1500t) amplitude modulates a carries 60 sin 2π(100,000t)**

(a) Sketch the audio signal.

(b) Sketch the carrier.

(c) Construct the modulated wave.

(d) Determine the modulation factor and percent modulation.

(e) What are the frequencies of the audio signal and the carrier?

(f) What frequencies would show up in a spectrum analysis of the modulated wave?

Solution: Given: Audio signal = 15 sin 2π (1500t)

Carrier = 60 sin 2π (100,000t)

(A)   (B)   (C)
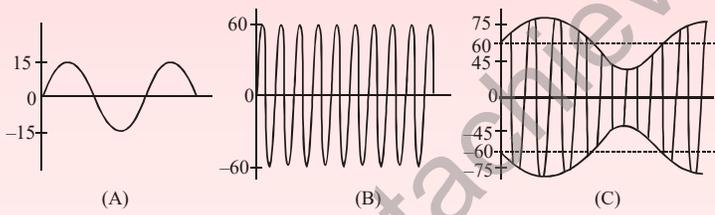
Frequency Modulation

➢ When the frequency of carrier wave is changed in accordance with the intensity of the signal, then it is called frequency modulation. In frequency modulation the amplitude of the modulated wave remains the same, *i.e.*, carrier wave amplitude. The frequency variations of carrier wave depend upon the instantaneous amplitude of the signal as shown in figure. When the signal voltage is zero as at *A*, *C*, *E*, the carrier frequency is unchanged. When the signal approaches its positive peaks as at *B* the carrier frequency is increased to maximum as shown by the closely spaced cycles.
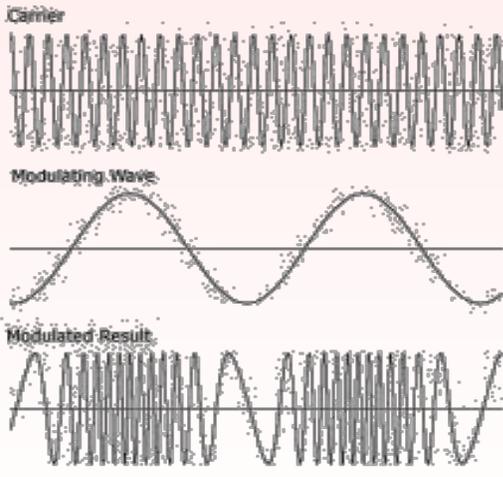
> When the modulating signal attains its negative peak, the carrier frequency is reduced to minimum as shown by the widely spaced cycles. It gives noiseless reception. Since noise is a form of amplitude variation, a FM receiver will reject such signals.

❖ FREQUENCY MODULATION INDEX

The frequency modulation index is defined as the ratio of frequency deviation of modulation frequency and is denoted by m_f or δ.

$$i.e., \quad \delta = \frac{\Delta f}{f_m} = \frac{K_f V_m}{\varepsilon_m}$$

for a given frequency deviation (Δf) or for a constant amplitude of modulating voltage, the modulation index varies inversely as the modulating frequency f_m. Unlike amplitude modulation, the frequency modulation index can exceed unity.

Example 3: **Determine the modulation index of an FM carrier having a frequency deviation of 25 kHz and a modulation signal of 5 kHz. Also determine the carrier swing.**

Solution: Frequency deviation, $\Delta f = 25$ kHz

Frequency of modulating signal, $f_m = 5$ kHz

Modulation index, $m_f = \dfrac{\Delta f}{f_m} = \dfrac{25}{5} = 5$

Carrier swing $= 2 \times \Delta f = 2 \times 25$ kHz $= 50$ kHz.

Example 4: **Calculate modulation index of an FM signal in which the modulating frequency is 2 kHz and maximum deviation in frequency is 500 Hz.**

Solution: Here, $f_m = 2\text{kHz} = 2000\text{Hz}$ and $\delta_{max} = 500\text{Hz}$

As $\qquad m_f = \dfrac{\delta_{max}}{f_m}$

$\therefore \qquad m_f = \dfrac{500}{2000} = 0.25.$

Pulse Modulation

- Pulse modulation is the process of transmitting signals in the form of pulse (discontinuous signals) by using special techniques. Pulse modulation is mainly subdivided in two groups.

  (i)   Analog pulse modulation and

  (ii) Digital pulse modulation.

- Analog pulse modulation may be used to send continuous information such as speech or data in regular intervals by using a special technique known as sampling. In pulse modulation, information in the form of the signal is not supplied continuously but during sampling time only. In this type of modulation, there may be infinite variations in the sample amplitude. This type of modulation is further of three types.
  (a)   Pulse – amplitude modulation (PAM)
  (b)   Pulse – width modulation (PWM) and
  (c)   Pulse – position modulation (PPM).

  In digital pulse modulation, codes are used to indicate the sample amplitude to the closest prefixed level. This type of pulse modulation is further of two types.
  (d)   Pulse – code modulation and
  (e)   Delta modulation.

(a)   Pulse amplitude modulation (PAM)

- It is the simplest form of pulse modulation. In this type of modulation, the signal is sampled at regular intervals such that each sample is proportional to the amplitude of the signal at the sampling instant.
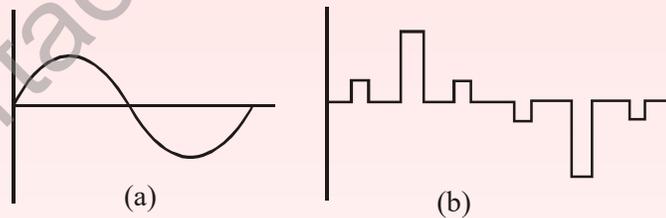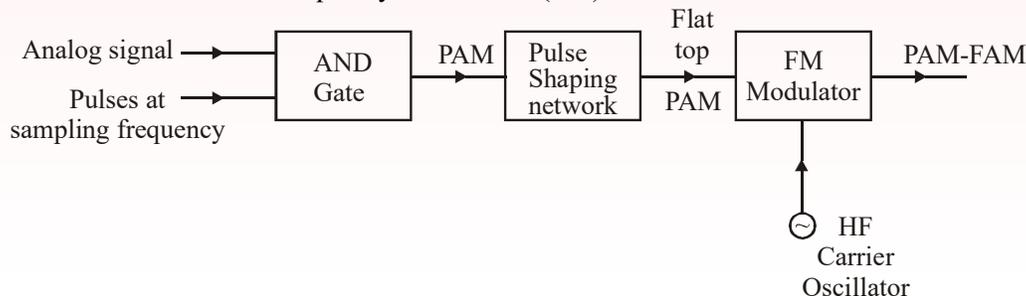
(a)   (b)

  Figure (a) shows an analog signal and figure (b) shows a sample pulse. This pulse is used to give frequency modulation by using a high frequency carrier wave.

  - Figure shows the block diagram of a set up to obtain pulse-amplitude modulation (PAM) which is further frequency modulation (FM).

Analog signal → AND Gate → PAM → Pulse Shaping network → Flat top PAM → FM Modulator → PAM-FAM

Pulses at sampling frequency →

HF Carrier Oscillator

- Sampling can be full of errors if sampling theorem is not followed. Sampling theorem states that for minimum distortion, the sampling rate in any pulse modulation should be more than twice of the signal frequency. For example, the voice frequency signal is of the order of 300 Hz to 4000 Hz so the standard sampling rate is 8000 samples per second.
- It is quite easy to produce and detect pulse-amplitude modulation but it is not popularly used because it does not involve pulses of fixed amplitude.

(b) Pulse Width Modulation (PWM)

➢ It is a type of pulse-time modulation in which sampling involves pulse of fixed amplitude. It is also known as pulse-length modulation (PLM) or pulse duration modulation (PDM). In this type of modulation, the starting time and amplitude of each pulse are constant but the duration or width or length of each pulse is made proportional to the instantaneous amplitude of the analog signal.

Figure (a) shows an analog signal and figure (b) shows pulse width modulated signal in which width of pulse is proportional to the instantaneous amplitude of the signal.

Pulse width modulation has a disadvantage that its pulses are of varying width and thus handle different powers. The circuits therefore have to be designed to handle the maximum power of maximum width pulse whereas the normal power of average width pulse may be much less.
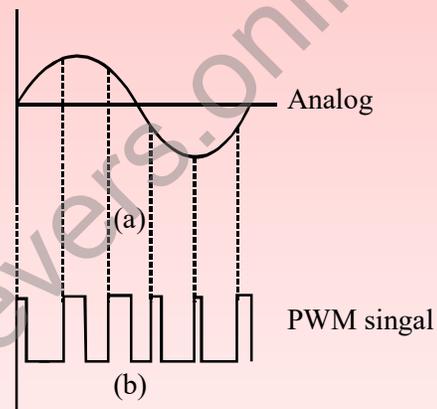
(c) Pulse Position Modulation (PPM)

➢ In this type of modulation, the sampled waveform has fixed amplitude and width whereas the position of each pulse is varied as per instantaneous value of the analog modulation signal. In fact PPM is a further modification of a PWM signal. PPM has positive thin pulse corresponding to the starting edge of a PWM pulse and negative thin pulse corresponding to the ending edge of a pulse.

Figure (a) shows an analog signal and figure (b) shows a PWM signal.

Pulse position modulation has an advantage that it requires constant transmitter power.

(d) Pulse Code Modulation (PCM)

➢ Pulse code modulation is an inherent digital process. In PCM instead of a train of sampled pulses, a series of binary digits or code is sent. Each digit represents only an approximate instantaneous value of the amplitude of the sample signal. In this type of modulation, value of the amplitude of the sample signal. In this type of modulation, a signal is continuously sampled, converted to nearest standard amplitude (i.e., quantised) and then to corresponding binary number (i.e., coded) before sending.

PCM is preferred because of noise free transmission. It is used in space communication also

e) Delta Modulation

It is also a digital modulation system which can be compared to PCM. It involves simpler coding and decoding methods. A simple delta modulation used just 1 bit (either 0 or 1) per sample.

Modem

➤ The term modem is a contraction of the term Modulator and Demodulator. In the transmitting mode the modem accepts digital data and converts it to analog signals for use in modulating a carrier signal. The modem demodulates the carrier at the receiving end of the system. Modems as placed at the both end of the communication circuits, as shown in the figure.

A modem which provides transmission in only one direction is referred to as operating in the simpler mode. It uses only one transmission channel so that from receiver to transmitter no signaling is used. In some modems data transfer can take place in both the directions, but the data flow takes turns, with flow in one direction at one time and in the opposite direction next time. This type of modem operation is called half-duplex. It requires only one bi-directional transmission channel. The speed of transmission is reduced because of necessity of sharing the same circuit. Full-duplex operation permits transmission in both directions.

Generally, the data circuits utilize telephone channels. For the type of service, the hard-wired modem and the acoustically coupled data set are used. Hard-wired modem remains connected to the circuit terminals hence they are not mobile.

Modems can operate within a signal 300 Hz to 3400 Hz (4 kHz) telephone channel. Beyond 19000 bps a wideband modem is required. Modems commonly use frequency shift keying modulation, which shifts a carrier frequency to indicate a mark or space. The frequency shifting is limited to the 4 kHz bandwidth of the voice grade channel.
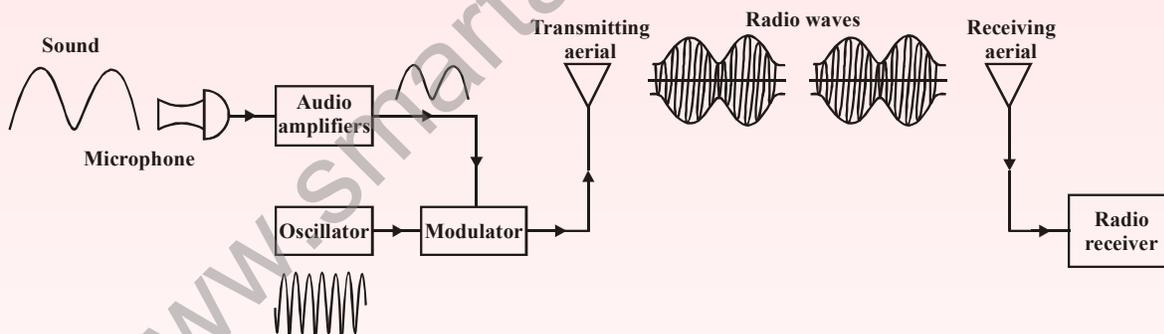

❖ LINE COMMUNICATION

Under this section we will discuss the wire systems whose properties can after signal properties. Transmission line are impedance matching circuits designed to deliver power from the transmitter to the antenna, and the maximum signal from the antenna to the receiver.

❖ COMMONLY USED TWO-WIRE LINE

(a) Parallel wire lines: The parallel-wire line is used where balanced properties are required for example, in connecting a fold-dipole antenna with the T.V. receiver set. These are in the form of a black ribbon where the spacing between the conductors and insulation is chosen according to the power to be handled.

(b) Twisted pair wire line: It consists of two insulated copper wires twisted around each other, often used to connect telephone systems. Twisting helps in minimizing electrical interference. These wire lines can transmit analog and digital signals, although they cannot transmit signals over very large distances.
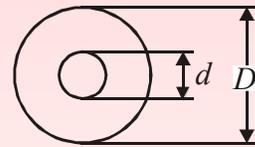
(c) Co-axial wire lines: These wires are used when unbalanced properties are needed, often used to interconnect a transmitter and an earthed antenna. A co-axial wire line consists of inner and outer conductors separated by low dielectric insulators, *e.g.* polyethylene and Teflon. Co-axial line wires can also be gas filled using nitrogen or dry air. Co-axial line wires can be used for microwaves and ultra high frequency waves (≈ 1 GHz). Any system of conductors radiates RF energy if the conductor separation becomes appreciable, approaching a wavelength half that of the operating frequency. It occurs more in the case of parallel wire lines than in a co-axial line.
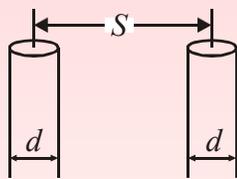

| (a) Parallel-wire | (b) Twisted wire | (c) Co-axial wire |

❖ EQUIVALENT CIRCUIT OF A TRANSMISSION LINE

A two wires line consists of conductors and dielectric between them. As such the line must have some resistance (or conductance), inductive reactance and capacitive reactance (or susceptance). A dielectric can not be an ideal insulator so some leakage current always flows through it which is considered to be due to shunt conductance *G*. All quantities shown in the equivalent diagram are the value per unit length only. At radio frequency operations, the inductance of line is more effective than the resistance of line and capacitive susceptance is also significant than shunt conductance. At RF (radio frequency) such resistance and shunt conductance's can be ignore resulting into simple LC circuit as shown in the figure.
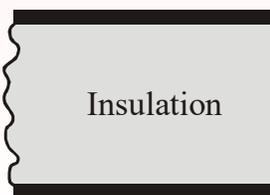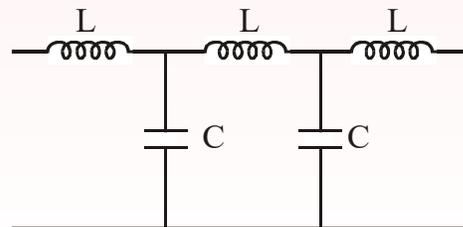
- A two wire line has some input impedance which depends upon type of line, length of line, termination at the other end etc. This input impedance is known as reference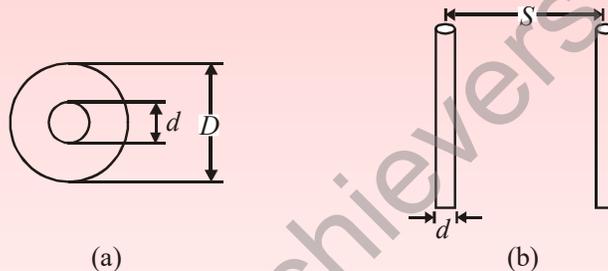 impedance or characteristic impendence (Z_0). If the length of the line is taken as infinity then termination at the other end has no effect and is ignored. Characteristic impedance can be defined as the impedance measured at the input of a line of infinite length. Practically this impedance depends upon size and spacing of the conductors as well as dielectric constant of the insulator separating them.

❖ **ADDITIONAL INFORMATION**

For coaxial line figure (a), $Z_0 = \dfrac{138}{\sqrt{k}} \log \dfrac{D}{d}$ where k is the dielectric constant.

For a parallel–wires line figure (b), $Z_0 = \dfrac{276}{\sqrt{k}} \log \dfrac{2S}{d}$

(a)   (b)

At voice frequency, expression for characteristic impedance is, $Z_0 = \sqrt{\dfrac{R + j\omega L}{G + j\omega C}} = \sqrt{\dfrac{Z}{Y}}$

Where Z is series impedance of each section and Y is the shunt impedance of each section.

At radio frequency, resistance R and conductance G become insignificant

$\therefore \quad Z_0 = \sqrt{\dfrac{L}{C}}.$

Example 5: **Calculate capacitance of a co-axial cable, when its inductance is 0.4 μH and the characteristic impedance is 160 ohm.**

Solution: Here, $C = ?; L = 0.4\mu H = 0.4 \times 10^{-6} H; Z_0 = 160$ ohm

As $\quad Z_0 = \sqrt{\dfrac{L}{C}}$

$\therefore \quad C = \dfrac{L}{Z_0^2} = \dfrac{0.4 \times 10^{-6}}{(160)^2} = 15.625 \times 10^{-12} F.$

Example 6: **A coaxial cable has nominal capacitance of 70×10^{-12} Fm^{-1}. If the characteristic impedance of the cable is 75Ω, what is the inductance of the cable per metre length?**

Solution: Using the relation $Z_0 = \sqrt{\dfrac{L}{C}}$, we get

$$\frac{L}{C} = Z_0^2 \text{ or } L = CZ_0^2$$

Here $Z_0 = 75\Omega$ and $C = 70 \times 10^{-12}\,\text{Fm}^{-1}$

∴ $L = 70 \times 10^{-12} \times 75 \times 75 = 0.39\mu\,\text{Hm}^{-1}$.

❖ VELOCITY FACTOR OF A TRANSMISSION LINE

All electromagnetic waves travel through air/vacuum with a speed $= 3 \times 10^8$ m/s. In any other medium, this velocity reduces and is given by

$$v = \frac{v_c}{\sqrt{K}} = \frac{3 \times 10^8\,\text{m/s}}{\sqrt{K}}$$

Where v_c = velocity of light in vacuum

v = velocity of light in any other medium

K = dielectric constant of the medium (= 1 for vacuum and very nearly 1 for air)

The velocity factor (V.F.) of transmission line is defined as the velocity reduction ratio, *i.e.,*

$$\text{V.F.} = \frac{v}{v_c} = \frac{1}{\sqrt{K}}.$$

❖ LOSSES IN TRANSMISSION LINE

The energy applied to a transmission line may be dissipated in the following three ways:
(i) Radiation losses, (ii) Conductor heating, (iii) Dielectric heating.

Optical Communication

❖ THE OPTICAL FIBRE AND FIBRE CABLES:

A optical fibre consist typically of a transparent core fibre of glass of index of refraction n_1 surrounded by a transparent glass or cladding of slightly lower index n_2, with both enclosed in an opaque protective jacket.

Figure shows a cross-section through the axis of an optical fibre. A ray entering the core from an external medium of index n_0 at angle θ_e will make an angle θ_t with respect to axis inside the core.
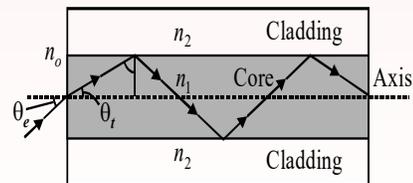
From Snell's law,

$$\sin\theta_t = \frac{n_0}{n_1}\sin\theta_e$$

The ray continuing in the core will be incident on the core-cladding boundary at an angle θ_i. If $\theta_i > \theta_{ic}$, where θ_{ic} is the critical angle, the ray will be totally internally reflected and continue to propagate inside the core.

$$\sin\theta_{ic} = \frac{n_2}{n_1} \qquad \qquad \text{…(ii)}$$

We have $\sin\theta_e = \frac{n_1}{n_0}\sin\theta_t = \frac{n_1}{n_0}\sin(90° - \theta_{ic}) = \frac{n_1}{n_0}\cos\theta_{ic}$ …(iii)

or $\quad \sin\theta_e = \dfrac{\sqrt{n_1^2 - n_0^2}}{n_0} \qquad \qquad \text{…(iv)}$

Where θ_e = entrance angle on the axis of the core
$\quad n_1$ = index of refraction of core,
$\quad n_2$ = index of refraction of cladding
$\quad n_0$ = index of refraction of external medium.

For air as the external medium ($n_0 = 1$), eqn. (iv) reduces to

$$\sin\theta_e = \sqrt{n_1^2 - n_2^2}.$$

Example 7: **A step index fiber has a relative refractive index difference of 0.88%. Estimate the critical angle at the core cladding interface.**

Solution: Here, $\dfrac{\mu_1 - \mu_2}{\mu_1} = \dfrac{0.88}{100}$ or $1 - \dfrac{\mu_2}{\mu_1} = 0.0088$ or $\quad \dfrac{\mu_2}{\mu_1} = 1 - 0.0088 = 0.9912$

critical angle, $\theta_c = \sin^{-1}\left(\dfrac{\mu_2}{\mu_1}\right) = \sin^{-1}(0.9912) = 82°24'.$

Example 8: **The velocity of light in the core of a step index fibre is 2×10^8 m/s and the critical angle at the core cladding interface is 70°. Find the numerical aperture and acceptance angle for the fibre in air. The velocity of light in vacuum is 3×10^8 ms^{-1}.**

Solution: Here, $\quad v = 2\times10^8\,\text{ms}^{-1}; \theta_c = 70°;$

$\theta_c = 3\times10^8\,\text{ms}^{-1}; \text{NA} = ?; \theta_a = ?$

$\mu_1 = \dfrac{c}{v} = \dfrac{3\times10^8}{2\times10^8} = 1.5 \qquad\qquad \theta_c = 70° = \sin^{-1}\dfrac{\mu_2}{\mu_1} = \sin^{-1}\dfrac{\mu_2}{1.5}$

or $\quad \mu_2 = 1.5\sin 70° = 1.5 \times 0.9397 = 1.41$

$\text{NA} = \sqrt{\mu_1^2 - \mu_2^2} = \sqrt{1.5^2 - 1.41^2} = 0.51$

$\theta_a = \sin^{-1}(\text{NA}) = \sin^{-1}(0.51) = 30°40'.$

❖ SPONTANEOUS AND STIMULATED EMISSION – MASER AND LASER

An isolated atom can exist either in its state of lowest energy, the ground state whose energy is, say, E_0, or in a state of higher energy (an excited state), whose energy is E_x. There are three processes by which the atom can move from one of these states to the other. These processes are shown in figure. We shall now discuss them one by one.

(a)

(b)

(c)
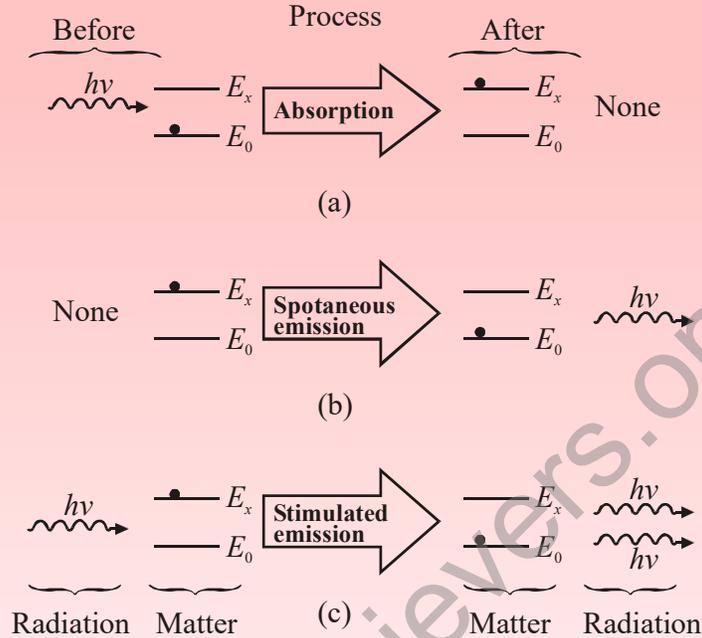
(i) Absorption: Figure (a) shows that the atom is initially in its ground state. Now, if an electromagnetic radiation of frequency v is incident on the atom, the atom can absorb an energy hv (a photon) from the radiation and move to the higher energy state. From the principal of conservation of energy we have

$hv = E_x - E_0$ …(i)

We call this process absorption.

(ii) Spontaneous emission: Figure (b) shows that the atom is in its excited state and no external radiation is present. It comes to his state after absorbing a photon of energy hv or by some other inelastic collision. The atom has now become an excited atom. A short time later, the atom will move of its own accord to its ground state, emitting a photon of energy hv. We call this process spontaneous emission – spontaneous because the energy was not triggered by any outside influence. The direction and phase of each a sodium or mercury lamp is generated in this manner. Normally, the mean-life of excited atoms before spontaneous emission takes place is about 10^{-8}s. However, for some of the excited states, this mean-life can be as mush as 10^5 times longer. Such long-lived states are called meta stable states; as we shall see they play an important role in laser operation.

(iii) Stimulated emission: In figure (c) the atom is in its excited state but this time a radiation with a frequency given by the equation (i) is also simultaneously present. Under these circumstances a photon of energy hv can stimulate the atom to move to its ground additional photon, whose energy is also hv. We call this process stimulated emission – stimulated because the event is triggered by the external photon. The emitted photon is in every way identical to the stimulating photon. It has the same energy, phase, polarization, and direction of travel.

As we shall see, the process of stimulated emission is the key to laser operation.
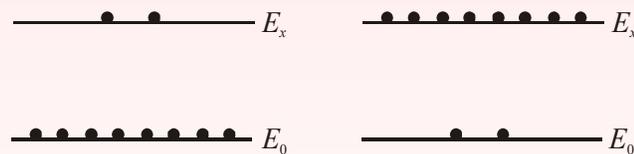
Laser

- The work LASER is an acronym and stands for light amplification by stimulated emission of radiation, which sums up the operation of an important optical and electronic device. The laser is a source of highly directional, monochromatic, and coherent light.
- The action of laser is based on the principle of stimulated emission. Figure (c) describes stimulated emission for a single atom. Consider an absorption cell containing a large number of atoms of the type described by figure (c) above in thermal equilibrium at temperature T. Before any radiation is directed at the sample, a number N_0 of these atoms are in the ground state with energy E_0, and a number N_x are in a state of higher energy E_x, Boltzmann showed that N_x is given in terms of N_0 by

$$N_x = N_0 e^{-(E_x - E_0)/kt} \qquad …(i)$$

Where k is the Boltzmann's constant.

- The quantity kT is the mean kinetic energy of the atom at temperature T. Thus, higher the temperature, more atoms will be thermally excited to the higher state. Also because $E_x > E_0$, equation (i) requires that $N_x < N_0$: that is, there will always be fewer atoms in the excited state than in the ground state. This is expected if the level populations N_0 and N_x are determined only by the action of thermal excitation. Such a situation is illustrated in figure (a) below.
- If we now flood the atoms, represented in figure (a), by photons of energy $E_x – E_0$, state atoms, and will be generated largely via stimulated emission of the excited state. It can be shown that the probabilities per atom of these two processes are identical. Since there are more atoms in the ground state, the net effect will be the absorption of photons.
- To have laser action, we must have more photons emitted than absorbed. Therefore, we must have a situation in which stimulated emission dominates.
- A direct way to bring this about is to start with more atoms in the excited state than in the ground state, as shown in figure. (b)

(a)   (b)

- Such a situation is termed as population inversion. However, such a population inversion is not consistent with thermal equilibrium. Therefore, to create and maintain such a situation we have to think of some clear way.

Let us now consider a system of atoms in which most of the atoms are initially in their ground state of energy E_0. These atoms has an excited level designated by energy E_3, as shown in figure. The system is now irradiation by photons of energy $E_3 - E_0$ or excited by electron collisions in a discharge tube. As a result of this process, more and more atoms are excited to the state designated by the energy E_3. This state is highly unstable and the atoms decay rapidly to a state designated by energy E_2. The energy difference $E_3 - E_2$ is given up in the form of heat. Now, suppose the state E_2 has a long mean life (say, of the order of 5 MS). Such a state is called a metastable state. The level E_2 is very important for the stimulated emission process since the atoms in this state have a mean life of ~5 MS before they fall to the ground state. If the atoms are excited from E_0 to E_3 at a rate faster than the rate at which the atoms in state E_2 fall back to the ground state E_0, the population of the metastable state E_2 becomes larger than that of the ground state E_0. This is now reversal of the state of thermal equilibrium, where there are always fewer atoms in the higher energy states than the lower ones. Thus, a situation of population is crucial for laser action. Let us now consider what happens when a photon of energy $E_2 - E_0$ enters this system and interacts with one of the inverted population atoms. This photon can now actually stimulate the atom to fall from state E_2 to E_0 and emit a photon of energy $E_2 - E_0$. The first photon has stimulated the emission of another photon of same energy. This amounts to multiplying the number of photons in the system by a factor of two, and so on. We, therefore, have light amplification by stimulated emission of radiation or LASER.

(a)

(b)
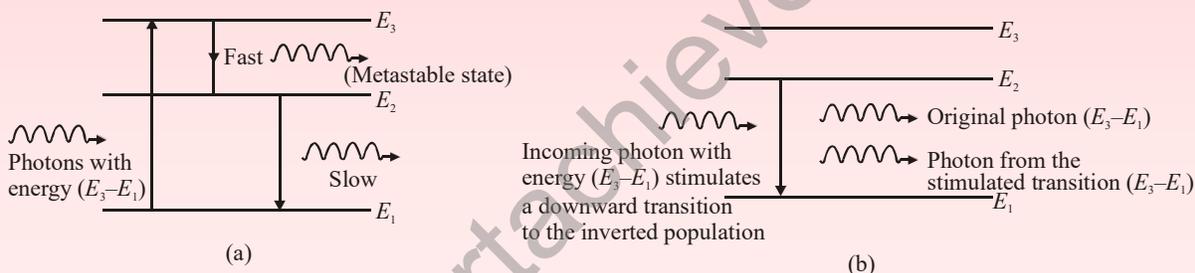
❖ PROPERTIES OF LASER LIGHT

(i) Laser light of highly monochromatic: Light from an ordinary incandescent lamp is spread over a continuous range of wavelengths. The light from a fluorescent mercury lamp has several wavelength; even light from a neon is monochromatic to only 1 part about 10^6. However, the sharpness, $\dfrac{\Delta v}{v}$, of laser light is many times greater, as much as 1 part is 10^{15}.

(ii) Laser light is highly coherent: When two separated beams, originating from the same source, that have travelled long distances (over several hundred kilometers) over separate paths, are recombined, they 'remember' their common origin and are fringes. The corresponding coherence length for light originating from a light bulb is typically less than a metre.

(iii) Laser light is highly directional: A laser beam spreads very little; it departs from parallelism only because of diffraction at the exit aperture of the laser. For example, a laser beam used to measure the distance to the Moon generates a spot on the Moon's surface with a diameter of only a few metre The laser beam has an extremely small angular divergence.

(iv) **Laser light can be sharply focused:** If two light beams transport the same amount of energy, the beam that can be focused to the smaller spot will have the greater intensity at the spot. For laser light the focused spot can be so small that intensity of the order of 10^{17} W/cm^2 is readily obtained. An oxyacetylene flame has an intensity of only 10^3 W/cm^2.

❖ APPLICATIONS OF LASER LIGHT

➤ In recent years, lasers have found a wide variety of applications. The high intensity of a laser beam makes it a convenient drill. A very small hole can be drilled in a diamond for use as a die in drawing very small-diameter wires. The ability of a laser beam to travel long distances without appreciable divergence make it a very useful tool for surveyors, especially when great precision is required over long distances, as in the case of a long tunnel being drilled from both ends. The smallest lasers, used for voice and data transmission over optical fibres, have as their active medium a semiconducting crystal about the size of a pinhead. Small as they are, they can generate about 200 mW of power. The largest lasers used for nuclear fusion research and for astronomical and military applications, fill a large building.

Among the many uses of lasers are reading bar codes, manufacturing and reading compact discs, cutting cloth in garment industry, welding auto bodies, etc.

Lasers are finding increasing applications in medical science. A laser can produce a intensity, high enough to vaporize anything in its path. This property is used in the treatment of a detached retina: a short burst of radiation damages a small area of the retina, and the resulting scar tissue 'welds' the retina detached. Laser beams are also used in surgery; blood vessels cut by laser beam tend to seal themselves off, making it easier to control bleeding.

Semiconductor lasers, as laser diodes, are finding wide application in optical communication.

❖ PHASE MODULATION

➤ It is the process of variation of phase of the carrier wave in accordance with the modulating signal. Just like frequency modulation, amplitude of the carrier wave remains constant in phase modulation also but phase modulation is not important in analog communication.

Let a carrier wave be represented by equation, $e_c = E_c \sin(\omega_c t + \phi)$

Where e_c = instantaneous voltage of carrier wave,

         E_c = amplitude of carrier wave,

         ω_c = angular frequency of carrier wave and

         ϕ = phase angle.

On variation of the phase of the carrier wave such that its magnitude is proportional to the instantaneous amplitude of the modulation wave then expression for phase modulated wave is

$e_c = E_c \sin(\omega_c t + \phi_m \sin \omega_m t)$.

$e_c = E_c \sin(\omega_c t + m_p \sin \omega_m t)$

where m_p the modulation index for phase modulation and is equal to ϕ_m, the maximum value of phase change brought by the modulating signal *i.e.*, $m_p = \phi_m$.

The most important difference between frequency modulation and phase modulation is that in phase modulation the change in phase angle is proportional to the amplitude of the modulating signal and is independent of the frequency of the modulating signal but the modulation index is proportional to the modulation voltage only whereas in the case of frequency modulation the modulation index is also inversely proportional to the frequency of modulation.

❖ SKY WAVE PROPAGATION OR IONOSPHERIC PROPAGATION

➤ This mode of propagation is shown in figure. A transmitted wave going up in the sky is reflected back from the ionized region of the earth's atmosphere, the ionosphere. The UV and other high energy radiations coming from sun are absorbed by air molecules which get ionized and form an ionized layer of electrons and ions around the earth. The ionosphere extends from a height of ~ 80 to 300 km above the earth's surface.

Without going into the mathematical details, we can easily understand the reflection of electromagnetic waves from the ionosphere. The oscillating electric field of electromagnetic wave (frequency ω) changes the velocity of the electrons in ionosphere (negligible change for ions because they are heavy and electromagnetic wave field is weak). This changes the effective dielectric constant (ε'), and hence the refractive index (n'), as compared to free space values of ε_0 and n_0. The effective dielectric constant ε' and the corresponding refractive index n' are related to ε_0 and n_0 as

$$n' = \sqrt{\varepsilon'\mu_0} = \sqrt{\varepsilon_0\mu_0[1-(Ne^2/\varepsilon_0 m\omega^2)]}$$

or $\quad n' = n_0[1-(Ne^2/\varepsilon_0 m\omega^2)]^{1/2}$

where e is the electronic charge, m is the mass of the electron and N is the electron density in the ionosphere.

It is clear that the refractive index of ionosphere is less than its free space value of n_0. That is, it behaves as a rarer medium. Therefore, the wave will turn away from the normal when it enters the ionosphere. As we go deep into the ionosphere (N is large), the refractive index keeps on decreasing. The refraction or bending of the beam will continue till it reaches critical angle after which it will be reflected back. It is clear from equation, that different frequency ω will be reflected from different regions of the ionosphere having different values of N.
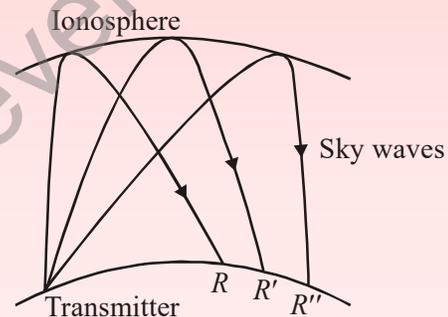
Therefore, the different points on earth receive signals reflected from different depths of the ionosphere. If the frequency ω is too high, then after a certain value, the electron density N may never be so high as to produce enough bending for attainment of critical angle or condition of reflection. This is called critical frequency. If maximum electron density of the ionosphere is N_{Max} per m^3. then the critical frequency f_c is approximately given by $f_c = 9 (N_{Max})^{1/2}$

The f_c range approximately from 5 to 10 MHz Frequencies higher than this cross the ionosphere and do not return back to the earth.

Long distance communication beyond 10 to 20 MHz was not possible before 1960 because all the three modes of communication failed (ground waves due to conduction losses, space wave due to limited line of sight, sky wave due to the penetration of the ionosphere by the high frequencies beyond f_c) Now, this is possible with the advent of the new concept of satellite communication.

Example 9: A ground receiver station is receiving a signal at (a) 5MHz, and (b) 100 MHz, transmitted from a ground transmitter at a height of 300 m located at a distance of 100 km. Identify whether it is coming via space wave or sky wave propagation or satellite transponder. Radius of earth = 6.4×10^6 m; N_{Max} of ionosphere = 10^{12} m².

Solution: Maximum distance covered by space wave communication

$$= \sqrt{2rh} = \sqrt{2 \times 6.4 \times 10^6 \times 300} = 62 \text{ km}$$

Since receiver–transmitter distance is 100 km, this is ruled for '*a*' and '*b*'.

Further, $f_c = 9(N_{max})^{1/2} = 9 \times (10^{12})^{1/2} = 9 \text{MHz}$

So, the '*a*' signal of 5 MHz ($< f_c$) comes via ionospheric mode while the '*b*' signal of 100 MHz comes via the satellite mode.

Example 10: If frequencies higher than 10 MHz are not reflected by ionosphere, calculate its electron density N_{Max} per m³.

Solution: Using $f_c = 9N_{max}^{1/2}$ we get

$$N_{max} = \frac{f_c^2}{9^2} = \frac{10 \times 10 \times 10^{12}}{81} = 1.25 \times 10^{12}.$$

PRACTICE QUESTIONS

1. Consider telecommunication through optical fibres. Which of the following statements is not true?
   a) Optical fibres may have homogeneous core with a suitable cladding.
   b) Optical fibres are subject to electromagnetic interference from outside.
   c) Optical fibres can be of graded refractive index
   d) Optical fibres have extremely low transmission loss

2. This question has statement-1 and statement -2. Of the four choices given after the statements, choose the one that best describes the two statements.

   Statement - 1: Sky state of signals are used for long distance radio communication. These signals are in general, less stable than ground wave signals.
   Statement -2: The state of ionosphere varies from hour to hour, day to day and seasons to seasons.
   a) Statement-1 is true, statement-2 is false.
   b) Statement-1 is true, statement-2 is true, statement-2 is the correct explanation of statement-1.
   c) Statement-1 is true, statement-2 is true, statement-2 is not the correct explanation of statement-1.
   d) Statement-1 is false, statement-2 is true.

3. A radar has a power of 1 kW and is operating at a frequency of 10 GHz. It is located on a mountain top, of height 500 m. The maximum distance up to which it can detect object located on the surface of the earth is:
   (Radius of earth $=6.4\times10^6$ m)
   a) 80 km
   b) 16 km
   c) 40 km
   d) 64 km

4. Approximately how many photons are emitted per second by a 10 kw transmitter emitting radio waves with a wavelength of 500 m?
   a) 10^{37} b) 10^{31} c) 10^{25} d) 10^{43}

5. A radio transmitter transmits at 830kHz. At a certain distance from the transmitter magnetic field has amplitude 4.82×10^{-11} T. Find the electric field and wavelength.
   a) 0.014 N/C,36 m
   b) 0.14 N/C,36 m
   c) 0.14 N/C,360 m
   d) 0.014 N/C,360 m

6. This question has statement-1 and statement-2. Of the four choices given after the Statements, choose the one that best describes the two statements.
   Statement 1: Short wave transmission is achieved due to the total internal reflection of the e-m wave from an appropriate height in the ionosphere.
   Statement 2: Refractive index of a plasma is independent of the frequency of e-m waves.
   a) Statement 1 is true, Statement 2 false.
   b) Statement 1 is false, Statement 2 is true
   c) Statement 1 is true, Statement 2 is true but statement 2 is not the correct of statement 1.
   d) Statement 1 is true, statement 2 is true and statement 2 is the correct explanation of statement 1.

7. Which of the following statement is NOT correct?
   a) Ground wave signals are more stable than the sky wave signals
   b) The critical frequency of an ionospheric layer is the highest frequency that will be reflected back by the layer when it is vertically incident
   c) Electromagnetic waves of frequencies higher than about 30MHz cannot penetrate the ionosphere
   d) Sky wave signals in the broadcast frequency range are stronger at night than in the daytime

8. What is the maximum distance between a transmitting antenna, located at the top of a tower with a height of 32 m, and a receiving antenna at a height of 50 m, to ensure satisfactory communication in Line of Sight (LOS) mode?
   a) *55.4 km*   b) *45.5 km*   c) *54.5 km*   d) *455 km*

9. For sky wave propagation, the radio waves must have a frequency range in between:
   a) 1 MHz to 2 MHz
   b) 5 MHz to 25 MHz
   c) 35 MHz to 40 MHz
   d) 45 MHz to 50 MHz

10. In order for long-range radio transmission to occur through ionospheric reflection, the frequency of the radio waves must fall within which range?
    a) 80-150 MHz
    b) 8-25 MHz
    c) 1-3 MHz
    d) 150-500 kHz

11. The characteristic impedance of a co-axial cable is of order of:
    a) 50Ω   b) 200Ω   c) 270Ω   d) none of these

12. A TV transmission tower has a height of 140 m and the height of the receiving antenna is 40 m. What is the maximum distance up to which signals can be broad casted from this tower in LOS (Line of Sight) mode?

a) 80Km   b) 48Km   c) 40Km   d) 65Km

13. What should be done to the height of a T.V. transmitter tower in order to double its covering range?

a) $1/\sqrt{2}$

b) $\sqrt{2}$

c) 4

d) 2

14. For a line of sight radio communication, the transmitting and receiving antennas maintain a distance of approximately 50 km. If the height of the receiving antenna is 70 m, what is the minimum height required for the transmitting antenna? (Radius of the Earth = 6.4×10^{6} m)

a) 40 m   b) 32 m   c)20 m   d)51 m

15. Given below in the left column are different modes of communication using the kinds of waves given the right column.

A.	Optica fiber communication	P.	Ultrasound
B.	Radar	Q.	Infrared Light
C.	Sonar	R.	Microwaves
D.	Mobile phones	S.	Radio Waves

From the options given below, find the most appropriate match between entries in the left and the right column.

a) A−Q, B−S, C−R, D−P

b) A−Q, B−S, C−P, D−R

c)A−S, B−Q, C−R, D−P

d) A−R, B−P, C−S, D−Q

16. Which of the following four alternatives is not correct? We need modulation:

a) to increase the selectivity

b) to reduce the time lag between transmission and reception of the information signal

c) to reduce the size of antenna

d) to reduce the fractional band width, i.e., the ratio of the signed band width to the centre frequency

17. Given the electric field of a complete amplitude modulated wave as
$$E = \hat{i} \, E_C \left(1 + E_m/E_c \cos\omega_m t\right) \cos \omega_c t.$$

Where the subscript c stands for the carrier wave and m for the modulating signal. The frequencies present in the modulated wave are
a) ω_c and $\omega_c2 + \omega_m2$
b) $\omega_c, \omega_c + \omega_m$ and $\omega_c - \omega_m$
c) ω_c and ω_m
d) ω_c and $\omega_c \, \omega_m$

18. Among the following modulated signals, which one exhibits the highest noise-tolerance?
a) Long-wave
b) Short-wave
c) Medium-wave
d) Amplitude-modulated
e)

19. A diode detector is used to detect an amplitude modulated wave of 60% modulation by using a condenser of capacity 250pF in parallel with a load resistance 100 kilo ohm. Find the maximum modulated frequency which could be detected by it.
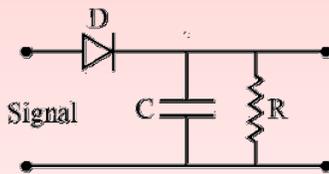
a) 10.62 MHz   b) 10.62 kHz   c) 5.31 MHz   d) 5.32 kHz

20. Laser light is considered to be coherent because it consists of
a) waves of several wavelengths.
b) incoherent waves of a single wavelength.
c) coherent waves of several wavelengths
d) coherent waves of a single wavelength.

21. When a signal with a frequency of 5 kHz is amplitude modulated onto a carrier wave with a frequency of 2 MHz, what are the frequency or frequencies present in the resultant modulated signal?
a) 2 MHz only
b) 2005 kHz, 2000 kHz and 1995 kHz
c) 2005 kHz, and 1995 kHz
d) 2000 kHz and 1995 kHz

22. Choose the correct statement:
a) In amplitude modulation the frequency of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.
b) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.
c) In frequency modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the frequency of the audio signal.
d) In amplitude modulation the amplitude of the high frequency carrier wave is made to vary in proportion to the amplitude of the audio signal.

23. For the modulated signal Cm(t)=30sin(300πt) +10(cos(200πt) −cos(400πt)), determine the values of the carrier frequency fc, the modulating frequency (message frequency) fω, and the modulation index μ.
   a) fc=200Hz; fw=50Hz; μ=12
   b) fc=150Hz; fw=50Hz; μ=23
   c) fc=150Hz; fw=30Hz; μ=13
   d) fc=200Hz; fw=30Hz; μ=12

24. If n audio signal comprises two distinct sounds—a human speech signal in the frequency band of 200 Hz to 2700 Hz, and a high-frequency music signal in the range of 10200 Hz to 15200 Hz—determine the ratio of the AM signal bandwidth required to transmit both signals simultaneously to the AM signal bandwidth required for transmitting just the human speech signal.
   a) 2   b) 5   c) 6   d) 3

25. In amplitude modulation, sinusoidal carrier frequency used is denoted by ωc and the signal frequency is denoted by ωm. The bandwidth ($\triangle\omega m$) of the signal is such that $\triangle\omega m << \omega c$. Which of the following frequencies is not contained in the modulated wave?
   a) $\omega c - \omega m$
   b) ωm
   c) ωc
   d) $\omega m + \omega c$

26. A signal of frequency 20 kHz and the peak voltage of 5 Volt is used to modulate a carrier wave of frequency 1.2 MHz and peak voltage 25 Volts. Choose the correct statement.

   a) Modulation index = 5, side frequency bands are at 1400 kHz and 1000 kHz.
   b) Modulation index = 0.8, side frequency bands are at 1180 kHz and 1220 kHz.
   c) Modulation index = 5, side frequency bands are at 21.2 kHz and 18.8 kHz.
   d) Modulation index = 0.1, side frequency bands are at 1220 kHz and 1180 kHz.

27. What should be the peak voltage of the modulating signal to achieve an 80% modulation index when using a carrier wave with a peak voltage of 14 V for transmission?
   a) 7V
   b) 28V
   c) 11.2V
   d) 22.4V

28. At a carrier frequency of 10 GHz, a telephonic communication service is operating, utilizing only 10% of the available bandwidth for transmission. If each telephonic channel requires a bandwidth of 5 kHz, determine the maximum number of telephonic channels that can be transmitted simultaneously.
   a) 2×10^3
   b) 2×10^4
   c) 2×10^5
   d) 2×10^6

29. The carrier frequency of a transmitter is provided by a tank circuit of a coil of inductance 49µH and a capacitance of 2.5nF. It is modulated by an audio signal of 12kHz. The frequency range occupied by the side bands is:
   a) 18kHz−30kHz
   b) 63kHz−75kHz
   c) 442kHz−466kHz
   d) 13482kHz−13494kHz

30. Given a 300 kHz bandwidth for amplitude modulated broadcast stations and a maximum modulating frequency of 15 kHz, calculate the number of broadcast stations that can be accommodated within this bandwidth.
   a) 20   b) 10   c) 8   d) 15

31. In a communication system, the operating wavelength is 800 nm, and only one percent of the source frequency is available as signal bandwidth. The system is used to transmit TV signals with a bandwidth of 6 MHz. Calculate the number of channels that can be accommodated for transmitting these TV signals. (Take the velocity of light $=3\times10^8$ m/s and Planck's constant $h=6.6\times10^{-34}$ J.s).

   a) 3.75×10^6 b) 4.87×10^5 c) 3.86×10^6 d) 6.25×10^5

32. The modulation frequency Of an AM radio station is 250 KHz, which is 10% of the carrier wave. If another AM station approaches you for licence, what broadcast frequency will you allot?
   a) 2750 KHz
   b) 2250 KHz
   c) 2900 KHz
   d) 2000 KHz

33. An amplitude modulated signal is given by
   $V(t)=10[1+0.6\cos(2.2\times10^4 t)\sin(5.5\times10^5)t]$. Here t is in seconds. The sideband frequencies (in kHz) are [Given $\pi=\frac{22}{7}$]
   a) 1785 and 1715
   b) 178.5 and 171.5
   c) 91 and 84
   d) 892.5 and 857.5

34. An amplitude modulated signal is plotted given:
   Which one of the following best describes the given signal?
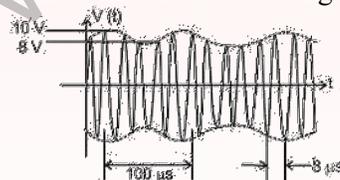
   a) $(9+\sin(2.5\pi\times10^5 t))\sin(2\pi\times10^4 t)$ V
   b) $(9+\sin(4\pi\times10^4 t))\sin(5\pi\times10^5 t)$ V
   c) $(1+9\sin(2\pi\times10^4 t))\sin(2.5\pi\times10^5 t)$ V
   d) $(9+\sin(2\pi\times10^4 t))\sin(2.5\pi\times10^5 t)$ V

35. A 100 V carrier wave is made to vary between 160 V and 40 V by a modulating signal. What is the modulation index?

a) 0.3   b) 0.5   c) 0.6   d) 0.4

36. The wavelength of the carrier waves in a modern optical fibre communication network is close to

a) 600 nm
b) 900 nm
c) 2400 nm
d) 1500 nm

37. A signal A cos ωt is transmitted using v0 sinω0t as carrier wave. The correct amplitude modulated (AM) signal is

a) v0 sin [ω0(1+0.01 A sin ωt) t]
b) v0sinω0t+Acosωt
c) v0sinω0t+A/2[sin (ω0−ω) t + sin (ω0+ω) t]
d) (v0+A) cos ωt sinω0t

38. The physical sizes of the transmitter and receiver antenna in a communication system are?

a) Proportional to carrier frequency
b) Inversely proportional to modulation frequency
c) Inversely proportional to carrier frequency
d) Independent of both carrier and modulation frequency

39. For amplitude modulation, a message signal with a frequency of 100 MHz and a peak voltage of 100 V is used to modulate a carrier wave with a frequency of 300 GHz and a peak voltage of 400 V. Determine the modulation index and find the difference between the two sideband frequencies.

a) $0.25; 2\times10^8$ Hz
b) $4; 1\times10^8$ Hz
c) $4; 2\times10^8$ Hz
d) $0.25; 1\times10^8$ Hz

40. In an amplitude modulator circuit, the carrier wave is given by,
C(t)=4sin(2000πt) while modulating signal is given by, m(t)=2sin(200πt). the values of modulation index and lower side band frequency are:

a) 0.5 and 9kHz
b) 0.5 and 10kHz
c) 0.3 and 9kHz
d) 0.4 and 10kHz

-----------------------ANSWER KEY-----------------------------

1)	c	2)	d	3)	b	4)	b
5)	b	6)	c	7)	d	8)	c
9)	d	10)	b	11)	a	12)	a
13)	b	14)	b	15)	b	16)	c
17)	b	18)	d	19)	b	20)	c
21)	d	22)	a	23)	a	24)	a
25)	a	26)	d	27)	c	28)	b
29)	b	30)	b	31)	a	32)	a
33)	c	34)	d	35)	d	36)	d
37)	d	38)	c	39)	c	40)	c

HINTS AND SOLUTIONS

1. **(b)**
Optical fibre cables are immune to electromagnetic interference because they transmit signals as light pulses through a glass or plastic core, without the use of electrical current. Unlike traditional electrical cables, there are no generated magnetic fields, and fluctuations in the induced magnetic field outside the conductor cannot interfere with the transmitted signals. This inherent immunity makes optical fibre cables highly reliable and efficient for high-speed data transmission over long distances.

2. **(a)**
Sky state of signal are used for long distance communication. The sky state signals are less stable than ground wave signals because of the variation of state of ionosphere.

3. **(a)**
Maximum distance to
$$\text{detect} = \sqrt{(h + R)^2} - R^2$$
$$= \sqrt{2Rh + h^2}$$
$$= \sqrt{2Rh}$$
$$= \sqrt{2 \times 6.4 \times 10^3 \times 12}$$
$$= 80 \text{ km}$$

4. **(b)**
Energy emitted by the transmitter per sec, $E_t = 10kW$
Energy of the wave, $E_w = hc/\lambda$
where $\lambda = 500m$
Plugging the values gives
$E_w = 3.96 \times 10^{-28}$
No of photons emitted per sec,
$n = E_t / E_w = 10000 / 3.96 \times 10^{-28}$
$$= 2.5 \times 10^{31}$$

5. **(d)**

Frequency of EM wave $v = 830kHz$
$= 830 \times 10^3$ Hz
Magnetic field, $B = 4.82 \times 10^{-11}$ T
As we know, frequency, $v = \lambda c$
or $\lambda = v c = 830 \times 10^{33} \times 108$
$\lambda \simeq 360$ m
And, E
$BC = 4.82 \times 10^{-11} \times 3 \times 10^8$
$= 0.014$ N/C

6. **(a)**
Theory

7. **(c)**
Above critical frequency (fc), an electromagnetic wave penetrates the ionosphere and is not reflected by it.

8. **(b)**
Calculation
$\sqrt{2} \times 64 \times 105 \times 32 + \sqrt{2} \times 64 \times 105 \times 50 = 64 \times 102 \times \sqrt{10} + 8 \times 103 \times \sqrt{10}m = 144 \times 102 \times \sqrt{10} = 45.5$ km

9. **(b)**
Refer the notes

10. **(b)**
In a broadcast system, there is one transmitter and multiple receivers. The transmitter processes the incoming signal to make it suitable for transmission through a specific channel. On the receiving end, the receiver captures the signal and extracts the message or contents.
Broadcasting systems operate within different frequency bands. For example, standard AM broadcast uses frequencies from 540 kHz to 1600 kHz, while FM broadcast operates within 88 MHz to 108 MHz. Television broadcasting systems cover frequencies ranging from over 50 MHz to 900 MHz.

shortwave broadcast services utilize sky wave propagation in the frequency range of 3 MHz to 40 MHz. This method allows for long-distance communication as radio waves are reflected from the ionosphere. Effective reflection occurs within the 8 MHz to 25 MHz frequency range, enabling long-range radio transmission.

11. (a)
The characteristic impedance of a coaxial cable is typically of the order of 50 to 75 ohms. It can vary depending on the specific design and application of the coaxial cable, but these values are commonly used for various communication and transmission systems.

12. (d)

13. c)
Use formula of range

14. (c)
The maximum line of sight of both the antennas is,

$$LOS = \sqrt{2}hTR + \sqrt{2}hRR$$

$$50 \times 10^3 = \sqrt{2} \times hT \times 6.4 \times 10^6$$
$$+ \sqrt{2} \times 70 \times 6.4 \times 10^6$$

On solving, we get, HT=32 m

15. (d)
Optical Fibre Communication - Infrared Light
For Optical fibre communication system we use light in the range of 850~ 1550 nm (infrared region).
Radar - Radio Waves
Radar uses radio waves to determine the range or velocity of the objects.
Sonar - Ultrasound
Sonar is a technique that uses sound propagation to navigate, measure distances, communicate with objects on or under the surface of the water, and uses ultrasonic waves.

Mobile Phones - Microwaves
Microwave are used for the mobile phones.

16. (a)
Modulation does not change time lag between transmission and reception.

17. (**b**)
The frequencies present in amplitude modulated wave are
Carrier frequency $=\omega c$
Upper side band frequency $=\omega c + \omega m$
Lower side band frequency $=\omega c - \omega m$.

18. (b)
Noise tolerance refers to the vulnerability of an individual to noise. The order of noise tolerance is
Short wave> medium wave> long wave. Short wave has best noise-tolerance.

19. (b)
20. (d)
Laser is the short form of light amplification by stimulated emission of radiation. Laser beam is intense, monochromatic (that is of the single wavelength) collimated and highly coherent.

21. (b)
$$fc = 2MHz = 2000KHz$$
$$fm = 5KHz$$
The resultant frequencies are: $fc -fm$, fc, $fc + fm$.
Thus, the frequencies are 1995, 2000 and 2005 KHz.

22. (d)
By definition

23. (b)
Amplitude modulated wave is represented as:
$$y(t) = A\sin(2\pi fct)$$
$$+ A\mu\sin(2\pi fct)\sin(2\pi fwt)$$
$$= A\sin(2\pi fct) + \frac{A\mu}{2}[\cos(2\pi(fc - fw)t)$$
$$- \cos(2\pi(fc + fw)t)]$$

Comparing this with the given equation gives:
$$2\pi fc = 300\pi, \Longrightarrow fc = 150 \text{ Hz}$$
$$2\pi(fc - fw) = 200\pi, \Longrightarrow fw = 50 \text{ Hz}$$
$$A = 30$$
$$\frac{A\mu}{2} = 10, \Longrightarrow$$
$$\mu = \frac{2}{3}$$

24. (c)
Band width for both signals
$$15200 \text{ Hz} - 200 \text{ Hz} = 15000 \text{ Hz}$$
Band with for human speech
$$2700 \text{ Hz} - 200 \text{ Hz} = 2500 \text{ Hz}$$
The ratio $= 15000 / 2500 = 6$

25. (c)
In amplitude modulation, the frequencies ωc + ωm and ωc - ωm are referred to as the upper side and lower side frequencies, respectively. The modulated signal comprises the carrier wave with a frequency of ωc, along with two sinusoidal waves, each slightly different in frequency from ωc. These two waves are known as sidebands.
The frequency spectrum of the amplitude-modulated signal is depicted in the figure. From this, we can infer that the transmitted frequency lies between ωc - ωm and ωc + ωm. As a result, ωm is not present within the modulated wave.

26. (d)
Frequency of signal =20 kHz
Peak voltage =5 V
Frequency of carrier wave =1.2 Hz
Peak voltage A_C= 25 V
Modulation index =c=525=0.2
Lower side band frequency
=1200−20=1180 kHz
Upper side band frequency=
=1200+20=1220 kHz

27. (c)
Amplitude of carrier wave is =14
Index is =80%=0.80μ
Amplitude of modulating signal is given by
=AcAm
Am=μ Ac
=0.8×14=11.2
Am=0.8×14=11.2V

28. (c)
Carrier frequency=10HGz
10% is used in transmission
(10/100) ×10GHz=1GHZ
Each channel requires 5kHz
Number of channels=1GHz/5kHz
$=2\times10^5$

29. (c)
The frequency of an LC tank circuit is given as:
$$\omega = \frac{1}{\sqrt{LC}}$$

Putting the values of C and L, we get the frequency to be:
$$\omega = \frac{1}{\sqrt{49 \times 10^{-6} \times 2.5 \times 10^{-9}}}$$
$$= 2857142.86 \text{Hz}$$

$$fC = \frac{\omega}{2\pi}$$
$$= 454728.409 \text{Hz} \simeq 454.728 \text{kHz}$$

Now using this value of carrier frequency, we can calculate the side-band frequencies:

$$(fC + fm) = 454.728 + 12 = 466.728 \text{kHz}$$
$$(fC - fm) = 454.728 - 12 = 442.728 \text{kHz}$$

30. (b)

As band width= 2 x n x highest modulation frequency
Here n is the number of amplitudes modulated broadcast stations.
Band width = 300 kHz
Highest modulation frequency = 15 kHz
so, 300 kHz = 2n15 kHz
300 = 30n
n = 10
Hence the number of stations will be 10.

31. (d)

$$f = \frac{C}{\lambda} = 3.75 \times 10^{14} \, hz$$

$$1\% \text{ of } f = 3.75 \times 10^{12} \, hz = 3.75 \times 10^{6} \, Mhz$$

$$\text{Number of channels} = \frac{3.75 \times 10^{6}}{6}$$

$$= 6.25 \times 10^{5}$$

32. (b)

According to the given question, the modulation frequency is 250 kHz, which is 10% of the carrier wave frequency:
Carrier wave frequency (fc) = 2500 kHz
Modulation frequency (FM) = 10% of fc = 0.1 * 2500 kHz = 250 kHz

The range of the signal will be 2500 ± 250 kHz = 2250 kHz to 2750 kHz for a carrier frequency of 2500 kHz.
However, this range might lead to overlapping waves, which is undesirable. Therefore, to avoid overlapping, let's consider a different scenario:
Carrier frequency (fc) = 2000 kHz
Modulation frequency (FM) = 200 Hz
The range of the signal will be 2000 ± 200 kHz = 1800 kHz to 2200 kHz.
Hence, the required frequency in this scenario is 2000 kHz.

33. (d)

$$V(t) = 10 + \frac{3}{2}[2\cos A \sin B]$$
$$= 10 + \frac{3}{2}[\sin(A + B) - \sin(A - B)]$$
$$= 10 + \frac{3}{2}[\sin(57.2 \times 10^{4}t) - \sin(52.8 \times 10^{4}t)]$$
$$\omega_1 = 57.2 \times 10^{4} = 2\pi f_1$$
$$f_1 = \frac{57.2 \times 10^{4}}{2 \times \left(\frac{22}{7}\right)} = 9.1 \times 10^{4}$$
$$\simeq 91 KHz$$
$$f_2 = \frac{52.8 \times 10^{4}}{2 \times \left(\frac{22}{7}\right)}$$
$$\simeq 84 KHz$$

Side band frequency are

$$f_1 = f_c - f_w = \frac{52.8 \times 10^{4}}{2\pi} \approx 85.00 kHz$$
$$f_2 = f_c + f_w = \frac{57.2 \times 10^{4}}{2\pi} \approx 90.00 kHz$$

34. (d)

As + Ac = 10 and Ac − As = 8
After solving, we get, As = 1, Ac = 9
And, Ts = 100 μs, Tc = 8 μs
$$\Rightarrow fs = \frac{2\pi}{T}s = 2\pi \times 10^{4} \text{ Hz}$$
And, $$fc = \frac{2\pi}{Tc} = 25\pi \times 10^{4} \text{ Hz}$$

The general equation of an AM wave is,

$$cm(t) = Ac(1 + \frac{As}{Ac}\sin\omega st)\sin\omega ct$$

$$\therefore cm(t) = (9 + \sin(2\pi \times 10^4 t))\sin(25\pi \times 10^5 t)$$

35. (c)

Maximum amplitude $= Em + Ec = 160$

$Em + 100 = 160$

$Em = 160 - 100 = 60$

Modulation index is given by,

$$\mu = Em \, Ec = \frac{60}{100}$$

$$\mu = 0.6$$

36. (d)

To minimise attenuation, wavelength of carrier waves is close to 1500 nm.

37. (c)

The equation of amplitude modulated wave

$m = (v0 + A\cos\omega t)\sin\omega 0t$

$m = v0\sin\omega 0t + A\cos\omega t \sin\omega 0t$

$$= v0\sin\omega 0t$$
$$+ \frac{A}{2}[\sin(\omega 0 - \omega)t$$
$$+ \sin(\omega 0 + \omega)t]$$

$[\because 2\sin A\cos B = \sin(A + B) + \sin(A - B)]$

38. (c)

$$\lambda = \frac{c}{f}$$
$$\Rightarrow l \propto 1/f$$

39. (d)

Range of frequency = (fc − fm) to (fc + fm)

$\therefore$ Band width $= 2fm = 2 \times 100 \times 10^6$ Hz $= 2 \times 10^8$ Hz

Modulation index $= \frac{Am}{Ac} = \frac{100}{400}$
$$= 0.25$$

40. (a)

Modulation index is given by

$$m = \frac{Am}{Ac} = \frac{2}{4} = 0.5$$

(a) carrier wave frequency is given by
$$= 2\pi fc = 2 \times 10^4 \pi$$
$$fc = 10kHz$$

(b) modulation wave frequency (fm)
$$2\pi fm = 2000\pi$$
$$\Rightarrow fm = 1kHz$$

lower side band frequency
$$\Rightarrow fc - fm$$
$$\Rightarrow 10kHz - 1kHz = 9kHz$$