CHAPTER : 28
COMMUNICATION SYSTEMS

Communication is a basic characteristic of all living beings. Communication entails transmitting and receiving information from one individual/place to another. In the world of animals, communication is made by mechanical, audio and chemical signals. You may have observed how sparrows begin to chirp loudly on seeing an intruder, who can put their life in danger. However, human beings are blessed with very strong means of communication – speech. We can express what we see, think and feel about whatever is happening around us. That is to say, we use sound (an audible range, 20Hz - 20kHz) and light (in visible range, 4000 Å – 7000 Å), apart from mechanical (clapping, tapping) and opto-mechanical signals (nodding, gesturing), for communication. You must realise that language plays a very significant role in making sense out of spoken or written words.It comes naturally to us. Prior to the written alphabet, the mode of communication was oral. The second era of communication began with the invention of printing press. Invention of the telegraph in the early nineteenth century marked the beginning of the third stage. Revolutionary technological developments enabled as rapid, efficient and faithful transfer of information. Using tools and techniques such as telegraph, fax, telephone, radio, mobiles, satellites and computers, it is possible to communicate over long distances. The oceans and mountain ranges no longer pose any problem and the constraints of time and distance seem to be non-existent. On-line learning, (education), publishing (research), banking (business) which were topics in science fiction not too long ago, are now routine activities. In fact, combination of computers with electronic communication techniques has opened a very powerful and fertile field of information and communication technologies (ICT_s).

Have you ever thought about the technology that has made all this development possible? You will discover answers to this question in this lesson.

OBJECTIVES

After studying this lesson, you will be able to:

- list the elements of a long distance communication system;
- explain the terms analogue and digital signals;
- describe how electromagnetic waves act as carriers of information;
- Specify the bandwidth of signals (speech, TV and digital data);
- list variouis transmission media and state bandwidths specific to them;
- explain importance of ground, sky and space wave propagation;
- state need for modulation; and
- explain production and detection of amplitude modulation wave.

30.1 A MODEL COMMUNICATION SYSTEM

Communication systems endeavour to transmit information from

– one to one, i.e., point-to-point communication;

– one to many, i.e., broadcast communication; and

– many to many, i.e., telephone conference call or a chat room.

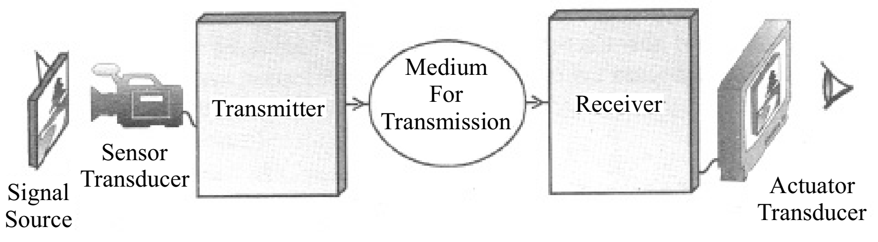


Fig. 30.1 : A schematic arrangement for the communication system.

In a typical modern day communication system, the information is in the form of electrical signals (voltage or current), spread over a range of frequencies called the signal **bandwidth**. (Some **noise** gets added to the signal and tries to obscure the desired information.) For scientific analysis of any system, we model the system into its basic components. You will now learnt about these.

30.1.1 Elements of a Communication System

Refer to Fig. 30.1. It shows building blocks of a typical communication system. As may be noted, the essential elements of a communication system are:

- a source of signal, a sensor transducer and a **transmitter,** which launches the signal carrying information,
- an intervening **medium/channel** to guide and carry the signal over long distances, and
- a signal **receiver** and an actuator transducer to intercept the signal and retrieve the information.

30.2 TYPES OF SIGNALS – ANALOGUE AND DIGITAL

You now know that communication of information involves use of signals, which are classified on the basis of their origin and nature. Accordingly we have

- continuous time (analog) end discrete time (digital) signals;
- coded and uncoded signals;
- periodic and aperiodic signals;
- energy and power signals; and
- deterministic and random signal.

Of these, we will consider only analog and digital systems. The sound produced by human being in conversation/interaction or photograph are converted into continuously varying electrical analog signal [Fig. 30.2(a)]. But in modern electronic communiction systems, these are converted into discrete form, which has finite values at different instances of time and zero otherwise [Fig. 30.2 (b), (c)] form Fig. 30.2, you will note that the waveforms used to represent correspond to a particular frequency and are periodic; while one of these is sinusoidal, the another is pulsed. In fact these may be viewed as a sub-class of sine and square waveforms.

Information can be packaged in both analog (or continuous) and digital (or discrete) forms. Speech, for example, is an analog signal which varies continuously with time. In contrast, computer files consist of a symbolic "discrete-time" digital signal.

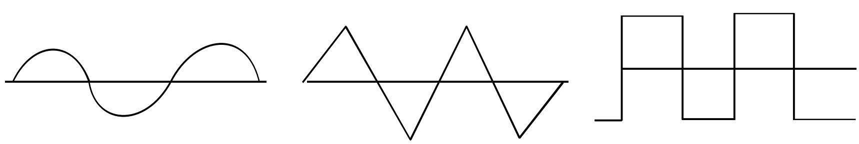


Fig. 30. 2 : *Examples of (a) continuous (sinusoidal) and (b) discrete signals.*

In the digital format, signals are in the form of a string of **bits** (abbreviated from **bi**nary digi**ts**), each bit being either 'ON' or 'OFF' (1 or 0). The **binary** system refers to a number system which uses only two digits, 1 and 0 (as compared to the **decimal** system which uses ten digits from 0 to 9). We can convert all information-bearing signals into discrete-time, amplitude-quantised digital signals. In a compact disc (CD), the audio is stored in the form of digital signals, just as a digital video disc (DVD) stores the video digitally.

Communication systems can be either fundamentally analog, such as the amplitude modulation (AM) radio, or digital, such as computer networks. Analog systems are in general, less expensive than digital systems for the same application, but digital systems are more efficient give better performance (less error and noise), and greater flexibility.

30.3 BAND WIDTH OF SIGNALS

The most crucial parameter in communication systems is the signal bandwidth, which refers to the frequency range in which the signal varies. However, it has different meaning in analog and digital signals. While analog bandwidth measures the range of spectrum each signal occupies, digital bandwidth gives the quantity of information contained in a digital signal. For this reason, analog bandwidth is expressed in terms of frequency, i.e. Hz, the digital bandwidth is expressed in terms of bits per second (bps). The frequency range of some audio signals and their bandwidths are given in Table 30.1. Note that human speech has bandwidth of nearly four kilo hertz. The bandwidth is about 10kHz in amplitude modulated (AM) radio transmission and 15kHz in frequency molulated (FM) transmission. However, the quality of signal received from FM broadcast is significantly better than that from AM. The bandwidth of a video signal is about 4.2MHz and television broadcast channel has bandwidth of 6MHz. The bandwidth of a typical modem, a device used for communication of digital signals over analog telephone lines, are 32kbps, 64 kbps or 128 kbps.

Table 30.1: Typical audiobandwidths

Source	Frequency range(H_E)	Bandwidth (kHz)
Guitar	82–880	... 0.8
Violin	196–2794	... 2.6
Vowels (a,e,i,o,u)	250–5000	... 4.0
consonants		
Telephone signal	200–3200	... 3.0

30.3.1 Electromagnetic Waves in Communication

In communication, we use different ways to transport the electrical signal from the transmitter to the receiver. From Modules on electricity and magnetics, you may recall that current passes through a metal conductor in the form of current signal or voltage drop, through air in the form of electromagnetic radiation or converted into light signal and sent through an optical fibre. Irrespective of the mode transmission of signal is governed by the classical theory of electromagnetic wave propagation, given by Maxwell.

As the name suggests, e.m. waves consist of electric and magnetic fields, which are inseparable. An electric field varrying in time produces a space-time varrying magnetic field, which, inturn, produces electric field. This mutually supporting role results in propagation of electromagnetic waves according to e.m. laws. The pictorial representation of a plane e.m. wave is shown in Fig. 30.3.

Mathematically we can express these as $E = E_0 \sin(kz - \omega t)$ and $H = H_o \sin(kz - \omega t)$. The direct experimental evidence for the existence of e.m. waves came in 1888 through a series of brilliant experiments by Hertz. He found that he could detect the effect of e.m. induction at considerable distances from his appparatus.

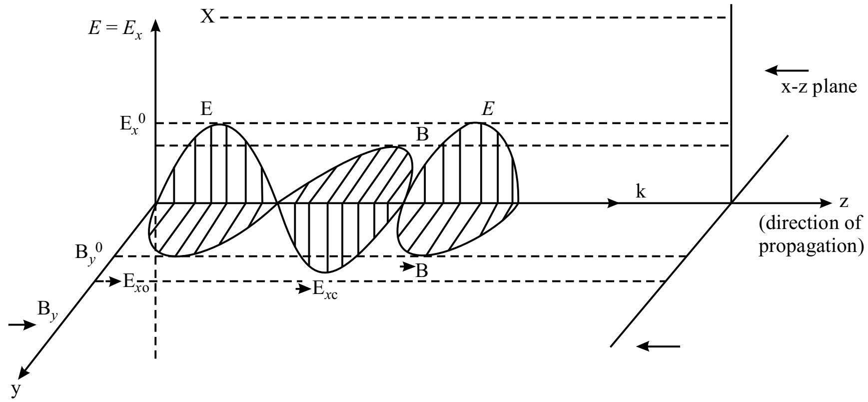


Fig. 30. 3: *Propagation of electromagnetic waves*

By measuring the wavelength and frequency of e.m. waves, he calculated their speed, which was equal to the speed of light. He also showed that e.m. waves exhibited phenomena similar to those of light. The range of wavelengths, as we now know is very wide from radio waves (λ is 1m to 10m) to visible light (400nm) as shown in Fig. 30.4. This generated a lot of interest and activity. In 1895 Indian physicist Jagadis Chandra Bose produced waves of wavelength in the range 25mm to 5m and demonstrated the possibility of radio transmission. This work was put to practical use by Guglielmo Marconi who, succeeded in transmiting e.m. waves across the Atlantic Ocean. This marked the beginning of the era of communication using e.m. waves. Marconi along with Carl Ferdinand Braun, received the 1909 Nobel Prize in physics for their work on wireless telegraphy.

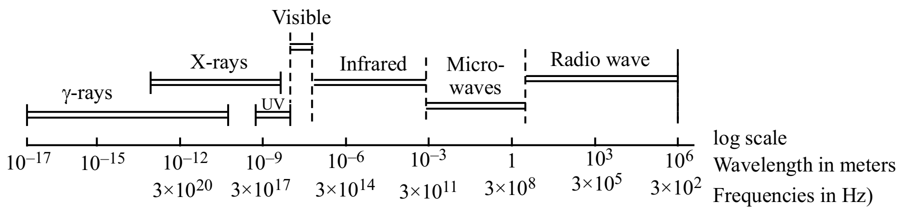


Fig. 30.4: *The electromagnetic spectrum: The wave values of length correspond to vacuum (or air) The boundaries between successive regions of the spectrum are not sharply defined.*

In a communication system, a transmitter radiates electromagnetic waves with the help of an antenna. These waves propagate in the space and captured by the receiver. At the receiver, another antenna extracts energy (information) from the electromagnetic waves. Now we use radio waves for different purposes television (TV) broadcasts, AM (amplitude modulated) and FM (frequency modulated) radio broadcasts, police and fire radios, satellite TV transmissions, cell phone conversations, and so on. Each such signal uses a different frequency, and that is how they are all separated.

You will learn the details of the mechanism of these transmissions and working of some common communication devices in the following two lessons. In Table 30.2, we have listed internationally accepted electromagnetic spectrum relevant for radio and TV broadcast, popular band names, and their application.

(Frequencies ν in Hz are related to wavelengths λ in m in vacuum through the relationship $c = \nu\lambda$, where $c = 3 \times 10^8$ m/s is the speed of electromagnetic waves in vacuum.)

Table 30.2: Radio frequency bands

Band	Frequency Range	Wavelength Range	Application
Extremely Low Frequency (ELF)	< 3 kHz	> 100 km	Mains electricity
Very Low Frequency (VLF)	3 - 30 kHz	100 – 10 km	SONAR
Low Frequency (LF)	30 - 300 kHz	10 – 1 km	Marine navigater
Medium Frequency (MF)	300 kHz - 3 MHz	1 km – 100 m	Medium wave radio
High Frequency (HF) Very High Frequency (VHF)	3 - 30 MHz 30 – 300 MHz	100 – 1 m 10 – 1 m	short wave radio FM radio
Ultra High Frequency (UHF)	300 MHz – 3 GHz	1 m – 10 cm	commercial, TV, Radio, Radar
Super High Frequency (SHF)	3 – 30 GHz	10 – 1 cm	Satellite communiction, cellular mobile, commercial TV

AM radio is broadcast on bands, popularly known as the Long wave: 144 - 351 kHz (in the LF), the Medium wave: 530 - 1,700 kHz (in the MF), and the Short wave: 3 – 30 MHz (HF). **Medium wave** has been most commonly used for commercial AM radio broadcasting. **Long wave** is used everywhere except in North and South Americas, where this band is reserved for aeronautical navigation. For long- and medium-wave bands, the wavelength is long enough that the wave diffracts around the curve of the earth by ground wave propagation, giving AM radio a long range, particularly at night. **Short wave** is used by radio services intended to be heard at great distances away from the transmitting station; the far range of short wave broadcasts comes at the expense of lower audio fidelity. The mode of propagation for short wave is ionospheric.

Table 30. 3 : Frequency ranges for commercial FM-radio and TV broadcast

Frequency Band	Nature of Broadcast
41 – 68 MHz	VHF TV
88 – 104 MHz	FM Radio
104 – 174 MHz	S Band (Sond-erkanal meaning Special Channel) for cable TV networks
174 – 230 MHz	VHF TV
230 – 470 MHz	H (Hyper) Band for cable TV networks
470 – 960 MHz	UHF TV

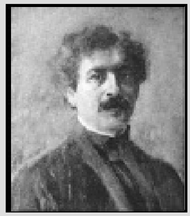
Frequencies between the broadcast bands are used for other forms of radio communication, such as walkie talkies, cordless telephones, radio control, amateur radio, etc.

You must have read about Internet enabled mobile phones and Internet Protocol Television. Have you ever thought as to which technology is enabling such empowerment? Is it fibre optic communication? Does laser play any role? You will learn answers to all such questions in the next unit.

INTEXT QUESTIONS 30.1

1. What is an electromagnetic wave?
2. Calculate the wavelength of a radio wave of frequency of 30 MHz propagating in space.
3. What is the frequency range of (i) visible light, (ii) radio waves?

Jagadis Chandra Bose
(1858 – 1937)



Jagadis Chandra Bose, after completing his school education in India, went to England in 1880 to study medicine at the University of London. Within a year, he took up a scholarship in Cambridge to study Natural Science at Christ's College – one of his lecturers at Cambridge, Professor Rayleigh had a profound influence on him. In 1884 Bose was awarded B.A degree by Cambridge university and B.Sc degree by London University. Bose then returned to India and took teaching assignment as officiating professor of physics at the Presidency College in Calcutta (now Kolkata). Many of his students at the Presidency College were destined to become famous in their own right. Satyendra Nath Bose who became well known for his pioneering work on Bose-Einstein statistics and M.N. Saha who gave revolutionary theory of thermal ionisation, which enabled physists to classify the stars into a few groups.

In 1894, J.C. Bose converted a small enclosure adjoining a bathroom in the Presidency College into a laboratory. He carried out experiments involving refraction, diffraction and polarization. To receive the radiation, he used a variety of junctions connected to a highly sensitive galvanometer. He developed the use of *galena* crystals for making receivers, both for short wavelength radio waves and for white and ultraviolet light. In 1895, Bose gave his first public demonstration of radio transmission, using these electromagnetic waves to ring a bell remotely and to explode some gunpowder. He invited by Lord Rayleigh, to give a lecture in 1897. Bose reported on his microwave (2.5 cm to 5 mm) experiments to the Royal Institution and other societies in England. But Nobel prize alluded him probably for want of vivid practical appliction of this work by him. By the end of the 19th century, the interests of Bose turned to response phenomena in plants. He retired from the Presidency College in 1915, and was appointed Professor Emeritus. Two years later the Bose Institute was founded in Kolkata. Bose was elected a Fellow of the Royal Society in 1920.

30.4 COMMUNICATION MEDIA

There are two types of communication channels: wireline (using guided media) or wireless (using unguided media). *Wireline* channels physically connect the transmitter to the receiver with a "wire," which could be a twisted pair of transmission lines, a coaxial cable or an optical fibre. Consequently, wireline channels are more private and comparatively less prone to interference than wireless channels. Simple wireline channels connect a single transmitter to a single receiver, i.e., it is a point-to-point connection. This is most commonly observed in the telephone network, where a guided medium in the form of cable carry the signal from the telephone exchange to our telephone set. Some wireline channels operate in the broadcast mode, i.e., one or more transmitters are connected to several receivers, as in the cable television network.

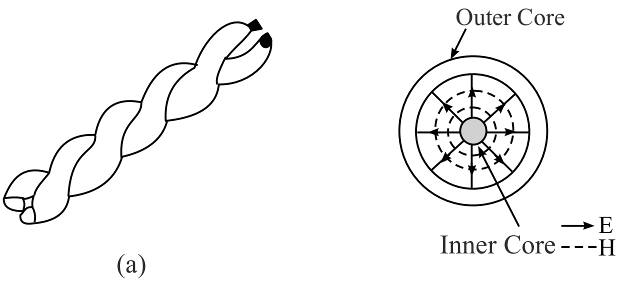
Wireless channels are much more public, with a transmitter antenna radiating a signal that can be received by any antenna tuned close by. In radio transmission, the wireless or unguided propagation of radio waves from the transmitter to the receiver depends on the frequency of the electromagnetic waves. As you will learn in this lesson, the waves are transmitted as ground (or surface) waves, sky waves, or space waves by direct line-of-sight using tall towers, or by beaming to artificial satellites and broadcasting from there. Wireless transmission is flexible endowed with the advantage that a receiver can take in transmission from any source. As a result, desired signals can be selected by the tuner of the receiver electronics, and avoid unwanted signals. The only disadvantage is that the interference and noise are more prevalent in this case.

For transmitting em signals, we use microwave frequencies, you may recall that it varies from 1GHz to 300GHz. This frequency range is further divided into various bands. Indian satellite INSAT – 4C operates in the C band (4 – 8 GHz), whereas Edusat operates in Ku bond (12–18 GHz).

30.4.1 Transmission lines

For guided signal transmission, a transmission line – a material medium forms a path. As such, the construction of a transmission line determines the frequency range of the signal that can be passed through it. Fig. 30.5 shows some typical transmission lines. The simplest form of transmission line is a pair of parallel conductors separated by air or any dielectric medium. These are used in telephony. However, such lines tend to radiate, if the separation between the conductors is nearly half of the frequency corresponding to the operating frequency. This may lead to noise susceptibility, particularly at high frequencies, and limit their utility. To overcome this problem, we use a *twisted pair of* wires. These are used in computer networking.

At high signal frequencies $(\leq 3\text{GHz})$ we minimise radiation losses by using *coaxial cables,* where one conductor is hollow and the second conductor is placed inside it at its centre throughout the length of the cable. These conductors are separated by dielectric spacer layers of polythylene and the electric field is confined in the annular space in between the conductors. These cables are used for carrying cable TV signals. It is important to note that ideally the dielectrics should have infinite resistance. But in practice, their resistance is finite and that too decreases with frequency. As a result, even coaxial cables are useful in a limited range (upto a maximum of 40GHz when special dielectric materials are used). Beyond 40GHz, we use *waveguides.* However, for frequencies greater than 300GHz, their dimensions become too small (is 4mm or so) and it presents practical problems. Above this frequency, we use optical fibres for guided wave transmission.



(a) (b)

Fig. 30.5: (a) A twisted pair **(b)** A coaxial cable

30.4.2 Optical Fibre

The 1960 invention of the **laser** (acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation) completely revolutionized communication technology. The laser, which is a highly coherent source of light waves, can be used as an enormously high capacity carrier wave for information carrying signals (voice, data or video) transmitted through an **optical waveguide**, such as an **optical fibre**. The basic principle involved in all long distance communication systems is **multiplexing**, i.e., simultaneous transmission of different messages over the same pathways. To illustrate it, let us consider transmission of an individual human voice. The frequency band required for transmitting human voice extends from v_1 = 200Hz to v_2 = 4000 Hz, i.e., the information contained in this frequency band can be transmitted in any band whose width is $v_1 - v_2$ = 3800 Hz, regardless of the region of the spectrum in which it is located. Higher frequency regions have far more room for communication channels, and hence, have a much greater potential capacity than the lower frequencies. The frequency corresponding to the visible optical region at 600 nm is 5×10^{14} Hz, while that at a wavelength of 6 cm is 5×10^9 Hz. Thus, the communication capacity of visible light in an optical fibre is about 100,000 times greater than that of a typical microwave in a metallic conductor.

The most extensively used optical waveguide is the step-index optical fibre that has a cylindrical central glass or plastic core (of refractive index n_1) and a cladding of the same material but slightly (about 1%) lower refractive index (n_2). There is usually an outer coating of a plastic material to protect the fibre from the physical environment (Fig. 30.6)

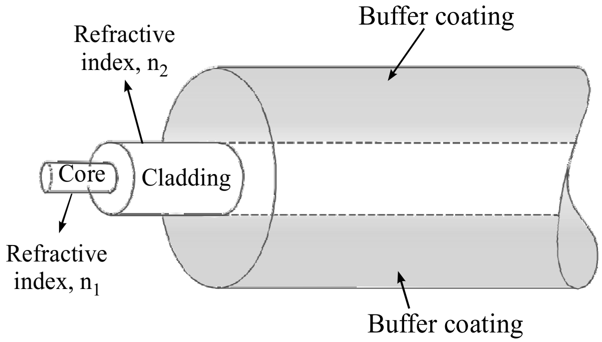


Fig. 30.6: A typical optical fibre with a doped silica core and a pure silica cladding.

When light from the core (n_1) is incident on the interface of the cladding ($n_2 < n_1$), the *critical angle* of incidence for *total internal reflection* is given by $\theta_c = \sin^{-1}(n_2/n_1)$. Thus in an optical fibre, the light ray is made to enter the core such that it hits the core-cladding interface at an angle $\theta_1 > \theta_c$. The ray then gets guided through the core by repeated total internal reflections at the upper and lower core-cladding interfaces. You may recall from wave optics that when a plane wave undergoes total internal reflection, a wave propagates in the cladding (rarer medium) along the interface, with its amplitude decreasing exponentially away from the interface. The entire energy of the wave in the core is reflected back, but there is a power flow along the interface in the cladding. Such a wave is called an *evanescent wave*, and is extensively used in integrated optics for the coupling the energy of a laser beam into a thin film waveguide (Fig. 30.7)

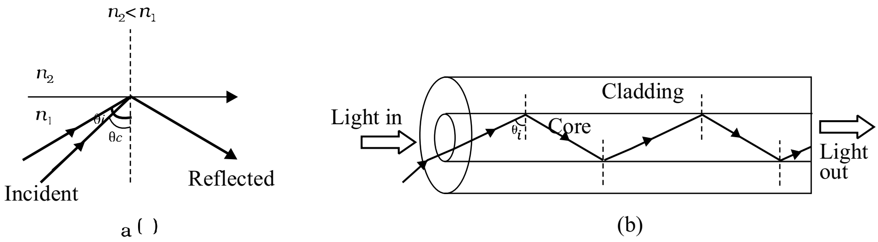


Fig. 30.7: **(a)** Total internal reflection **(b)** Ray confinement in actual optical fibre

INTEXT QUESTIONS 30.2

1. What is a coaxial cable? Write down its frequency range of operation.
2. State the basic principle used for guiding light in an optical fibre.

30.5 UNGUIDED MEDIA

The wireless communication between a transmitting and a receiving station utilising the space around the earth, i.e. atmosphere is called *space communication.* The earth's atmosphere plays a very interesting role the propagation of e.m. waves from one place to another due to change in air temperature, air density, electrical conductivity and absorption characteristics with height. For example, most of the radiations in infarred region are absorbed by the atmosphere. The ultaviolet radiations are absorbed by the ozone layer.

Five layers are considered to play main role in communicaiton:

- *C layer* at about 60km above the surface of earth reflects e.m. waves in the frequency range 3kHz – 300kHz. It is therefore used for direct long range communication.
- *D layer* at a height of about 80km reflects e.m. waves in the low frequency range (3kHz – 300kHz) but absorbs waves in the medium frequency range (300 kHz – 3MHz) and high frequency range (3 – 30MHz).
- *E layer* ata height of about 110km helps in propagation of waves in the medium frequency range but reflects waves in the high frequency range in the day time.
- F_1 *layer* at a height of about 180 km lets most of the high frequency waves to pass through.
- F_2 *layer* (at a height of 300 km in daytime and 350 km at night) reflects e.m. waves upto 30MHz and allows waves of higher frequencies to pass through.

You may recall from your easlier classes that, based on the variation of temperature, air density and electrical conductivity with altitude, the atmosphere is thought to be made up of several layers. The atmospheric layer close to the earth called the *troposphere* extends up to about 12 km above the sea level. The temperature in troposphere vary between 290K (at the equator) to 220K (at tropopause). The air density is maximum but electrical conductivity is the least compared to other layers. The next layer up to about 50 km is called the *stratosphere*. An ozone layer is in the lower stratosphere extends from about 15 km to about 30 km. The layer above the stratosphere and up to about 90 km is called the *mesosphere*. The minimum temperature in mesosphere in about 180K. Beyond mesosphere upto 350km, there is a zone of ionised molecules and electrons called the *ionosphere*. In ionosphere, temperature increases with height to about 1000k. The ionosphere affects the propagation of radio waves. It is divided into D, E, F and F_2 regions based on the number density of electrons, which increases with height from about $10^9 m^{-3}$ in Dregion to $10^{11} m^{-3}$ in region and $10^{12} m^{-3}$ in F_2 layer[1]. These variations in temperature, density and conductivity arise due to different absorption of solar radiations at different heights and changes in composition etc.

The essential feature of space communication is that a signal emitted from an antenna of the transmitter has to reach the antenna of the receives. Depending on the frequency fo radio wave, it can occur as *ground wave, space wave, sky wave* and via satellite communication. Let us now learn about these.

30.5.1 Ground Wave Propagation

In ground *wave* propagation, the electromagnetic waves travel along the surface of the earth. These can bend around the corners of the objects but are affectd by terrain. A vertical antenna is used to transmit electromagnetic waves. If electric field E is vertical, and the magnetic field B is horizontal, the direction of propagation k is horizontal but perpendicular to both E and B vectors. The material properties of the ground, such as its conductivity refractive index and dielectric constant, are seen to control propagation of such waves. That is why ground waves propagation is much better over sea than desert. In practice, ground waves are rapidly attenuated due to scattering by the curved surface of the the earth. A larger wavelength results in smaller attenuation. That is, ground waves are more useful as lower frequencies & constitute the only way to communicate into the ocean with submarines. Moreover, this mode of propagation is suitable for short range communication. For these reasons, ground wave propagation is used for radio wave (300kHz – 3MHz) transmission.

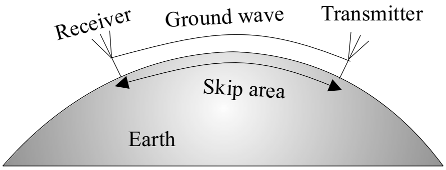


Fig. 30.8: Ground wave propagation

30.5.2 Sky Wave or Ionospheric Propagation

In **sky wave** or **ionospheric** propagation, the electromagnetic waves of frequencies between 3MHz – 30MHz launched by a transmitting antenna travel upwards, get reflected by the ionophere and return to distant locations. In this mode, the reflecting ability of the ionosphere controls the propagation characteristics of the sky wave. The ionosphere acts as an invisible electromagnetic "mirror" surrounding the earth – at optical frequencies it is transparent, but at radio frequencies it reflects the electromagnetic radiation back to earth.

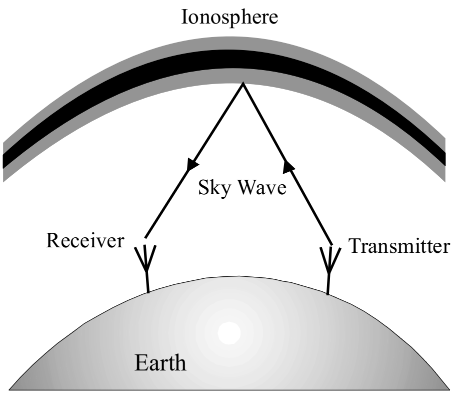


Fig. 30.9: Skywave propagation

The maximum distance along the surface of the earth that can be reached by a single ionospheric reflection ranges between 2010 and 3000 km depending on the altitude of the reflecting layer. The communication delay encountered with a single reflection ranges between 6.8 and 10 ms, a small time interval. This mode of propagation is used for long-distance (short wave) communication in the frequency range approximately between 5 and 10 MHz. Above 10 MHz, the waves pass through the ionosphere and do not reflect back to the earth. It is, however, subject to erratic daily and seasonal changes due to variations in the number density and height of the ionized layers in the ionosphere. The composition of the ionosphere at night is different than during the day because of the presence or absence of the sun. That is why international broadcast is done at night because the reflection characteristics of the ionosphere are better at that time.

30.5.3 Space Wave Propagation

You may have seen very high antennas at radio station. These are used for broadcasting. In space wave propagation, some of the VHF radio waves (30 MHz – 300MHz) radiated by an antenna can reach the receiver travelling either directly through space or after reflection by the curvature of the earth. (Note that earth reflected waves are different from ground waves.)

In practice, direct wave mode is more dominant. However, it is limited to the so-called *line-of-sight* transmission distances and curvature of earth as well as height of antenna restrict the extent of coverage.

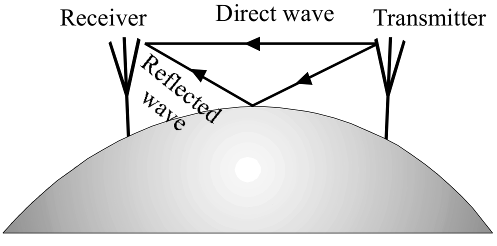


Fig. 30.10: Space-wave propagation

So far you have learnt that ground waves suffer conduction losses, space waves have limitations due to line of sight and sky waves penetrate the ionisalion beyond a certain frequency. Some of these difficulties were circumvented with the launch of communication satellities in the 1950s. Satellite communication has brought about revolutionary changes in the form and format of transmission and communication. We can now talk is real time at a distance. Let us now learn about it.

30.5.4 Satellite Communication

The basic principle of satellite communication is shown in Fig. 30.11. The modulated carrier waves are beamed by a transmitter directly towards the satellite.

The satellite receiver amplifies the received signal and retransmits it to earth at a different frequency to avoid interference.

These stages are called uplinking and down-linking.

As we have seen already in connection with communication with light waves, the capacity of a communication channel can be increased by increasing the frequency of communication. How high up can we go in frequency? You now know that the ionosphere does not reflect waves of frequencies above 10 MHz, and for such high frequencies we prefer space wave propagation with direct transmission from tall towers. But this line-of-sight transmission also has a limited range or reach. Hence for long-range wireless communication with frequencies above 30 MHz, such as for TV transmission in the range of 50-1000 MHz, communication through a satellite is used.

The gravitational force between the earth and the satellite serves as the centripetal force needed to make the satellite circle the earth in a f*reefall* motion at a height of about 36,000 km. An orbit in which the time of one revolution about the equator exactly matches the earth's rotation time of one day is called a *geostationary* orbit, i.e., the satellite appears to be stationary relative to the earth. Ground stations transmit to orbiting satellites that amplify the signal and retransmit it back to the earth. If the satellites were not in geostationary orbits, their motion across the sky would have required us to adjust receiver antenna continually. Two other orbits are also currently being used for communication satellites: (i) *polar circular orbit* at a height of about 1000 km almost passing over the poles (i.e., with an inclination of 90^0), and (ii) *highly elliptical inclined orbit* (with an inclination of 63°) for communications in regions of high altitudes.

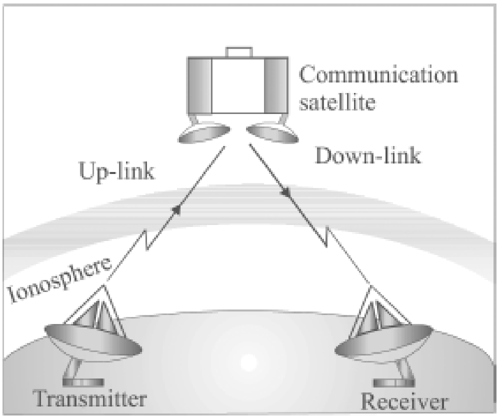


Fig. 30.11: Satellite communication.

INTEXT QUESTIONS 30.3

1. Why do you hear some radio stations better at night than in the day?
2. Choose the correct option in each case:
   (a) Frequencies in the UHF range normally propagate by means of
      (i) Ground Waves
      (ii) Sky Waves
      (iii) Surface Waves
      (iv) Space Waves.
   (b) Satellites are used for communication
      (i) With low (< 30 MHz) frequencies and for a small range
      (ii) With low (< 30 MHz) frequencies and for a long range
      (iii) With high (> 30 MHz) frequencies and for a small range
      (iv) With high (> 30 MHz) frequencies and for a long range.

EDUSAT

The Indian Space Research Organisation (ISRO), Department of Space, Government of India, launched an exclusive education satellite EDUSAT in Sept. 2004. The satellite has its footprints all over the country and operates in KU band. It is designed to provide services for seven years. This satellite has capability for radio and TV broadcast, Internet-based education, data broadcasting, talk-back option, audio-video interaction, voice chat on Internet and video conferencing. It has opened up numerous possibilities: a teacher of a leading educational institution in a city may video-conference with students of a remote school, or school drop-outs in villages may receive Internet-based education support and get back into mainstream education system. EDUSAT has the capability of telecasting 72 channels. A large number of networks have been created by state governments and national institutions including NIOS. Such networks are being successfully used to impart education even in regional languages.

30.6 MODULATION – ANALOGUE AM AND FM, DIGITAL (PCM)

The process of processing a signal to make it suitable for transmission is called *modulation.* Most of the information-bearing signals in day-to-day communication are audio signals of frequency less than 20 kHz. For small distances, we can form direct link. But it is not practical to transmit such signals to long distances. This is because of the following two reasons:

- The signal should have an antenna or aerial of size comparable to the wavelength of the signal so that the time variation of the signal is properly sensed by the antenna. It means that for low-frequency or long-wavelength signals, the antenna size has to be very large.
- The power carried by low frequency signals is small and can not go far. It is because of cantinuous docline or attemation due to absorption/radiation loss. It means that for long distance transmission high frequencies should be used. But these can not carry useful information. We are therefore confronted with a situation analogous to the following:

On a front port, Indian army spots advancing enemy forces. To minimise loss of life and save the post from falling to enemy, they need reinforcement from the base camp. But by the time an army jawan goes, conveys the message and the reinforcement reaches, the port would have fallen. Therefore, it wants a carrier, say a horse, which can run fast. But the horse can not deliver the message. The way out is: Put the jawan on the horseback; let the horse run and jawan convey the message.

For signal transmission, audio signal acts as jawan and high (radio) frequency acts as the horse (carrier). So we can say that by super imposing a low frequency signal on a high frequency carrier wave, we process a signal and make it suitable for transmission. We convert the original signal into an electrical signal, called the *base band signal* using a signal generator. Next we super impose the base band signal over carrier waves in the modulator. The change produced in the carrier wave is known as modulation of the carrier wave and the message signal used for modulation is known as *modulating signal*. The carrier wave can be continuous or pulsed. Since a sinusoidal wave, is characterised by amplitude, frequency and phase it is possible to modulate (i.e. modify) either of these physical parameter.

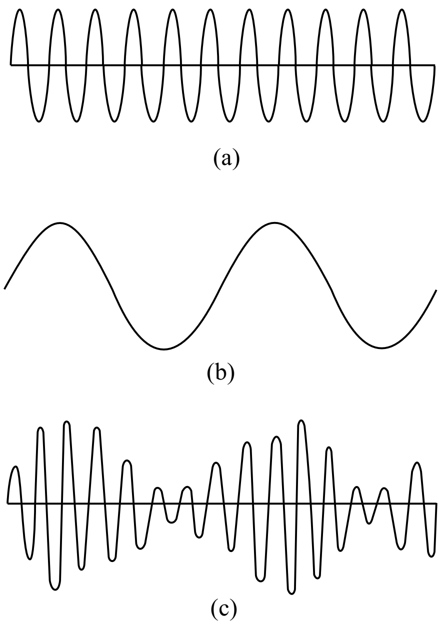


Fig. 30.12: Modulation of a carrier wave by a modulating signal: **(a)** a sinusoidal carrier wave of high frequency, **(b)** a modulating signal (message or information signal) of low frequency, **(c)** amplitude modulated carrier wave.

This is known as analog modulation. There are different types of analog modulation: **Amplitude Modulation** (**AM**); **Frequency Modulation** (**FM**); and **Phase Modulation (PM),** respectively For pulsed carrier waves, **Pulse Code Modulation** (**PCM**) is the preferred scheme.

In Amplitude modulation, the amplitude of a high-frequency carrier wave (Fig. 30.12a) is modified in accordance with the strength of a low-frequency audio or video modulating signal (Fig.30.12.b). When the amplitude of the modulating wave increases, the amplitude of the modulated carrier also increases and vice-versa — the envelope of the modulated wave takes the form depending on the amplitude and frequency of modulating signal (Fig. 30.12.c) .

To understand this, we write expressions for instantaneous amplitudes of audio signal and carrier wave:

$$\upsilon_a(t) = \upsilon_{ao} \sin\omega_a t \qquad (30.1a)$$

and

$$\upsilon_c(t) = \upsilon_{co} \sin\omega_c t \qquad (30.1b)$$

where w_a and w_c are the angular frequencies and $\boldsymbol{\upsilon}_{ao}$ and $\boldsymbol{\upsilon}_{co}$ denote of audio and carrier waves, respectively. denote the amplitudes. In amplitude modulation the modulationg (audio) signal is superimposed on the carrier wave, so that the amplitude of the resultant modulated wave can be expressed as

$$A(t) = \upsilon_{co} + \upsilon_a(t) = \upsilon_{co} + \upsilon_{ao} \sin\omega_a t$$

$$= \upsilon_{co}\left[1 + \frac{\upsilon_{ao}}{\upsilon_{co}} \sin\omega_a t\right] \qquad (30.2)$$

Hence the modulated wave can be expressed as

$$\upsilon_c^{\text{mod}}(t) = A\sin\omega_c t = \upsilon_{co}\left[1 + \frac{\upsilon_{ao}}{\upsilon_{co}} \sin\omega_a t\right] \sin w_c t \qquad (30.3)$$

From Eqn. (30.3) we note that the instantaneous amplitude of the modulated wave is determined by the amplitude and frequency of the analog audio signal. The ratio $\upsilon_{ao}/\upsilon_{co}$ gives us a measure of the extent to which carrier amplitude is varied by the analog modulating signal and is known as amplitude modulation index. We will denote it by m_a. In terms of modulation index, we can rewrite Eqn. (30.3) as

$$\upsilon_c^{\text{mod}} = \upsilon_{co}(1 + m_a \sin\omega_a t)\sin\omega_c t$$

$$= \upsilon_{co}\sin\omega_c t + \upsilon_{co} ma \sin\omega_a t \sin\omega_c t$$

$$= \upsilon_{co}\sin\omega_c t + \frac{\upsilon_{co} m_a}{2}\cos(\omega_c - \omega_a)t - \frac{\upsilon_{co} m_a}{2}\cos(\omega_c + \omega_a)t \qquad (30.4)$$

From Eqn. (30.4) we note that

- the modulated wave shown in Fig. 30.12(c) has three components. The first term represents carrier wave the second term whose frequency is lower than that of the carrier wave, constitutes the lower side band, and the third term with frequency higher than the carrier wave is the upper side band; and
- the frequency of the modulating signal is not directly contained in the amplitude modulated wave.

If the modulating signal in an AM system is given by

$\upsilon_a = 4\sin 6283t$ and frequency of the lower side band is 3.5×10^5Hz, the angular frequency of the carrier wave is given by

$$\omega_C = \omega_a + 2\pi \times (3.5) \times 10^5$$

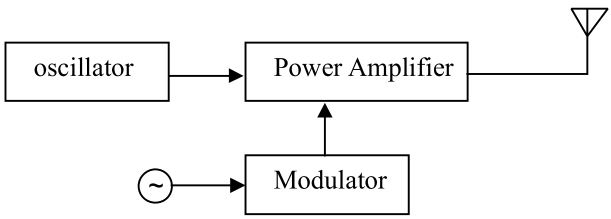
$$= 6283 + 22 \times 10^5$$

$$= (2200 + 6.283) \times 10^3 \text{rad}$$

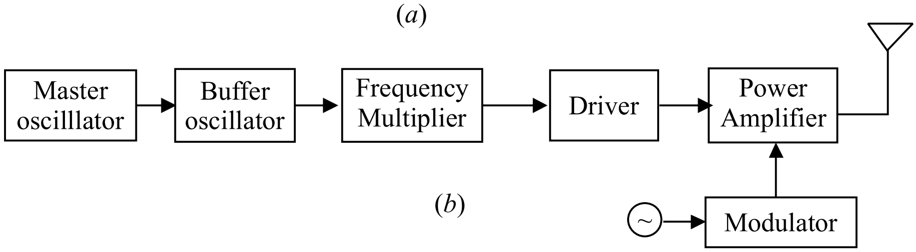
$$= 2.206 \times 10^6 \text{rad}$$

It is important to appreciate that the most efficient information transfer takes place when maximum power transmitted by the comunication system is contained in the side bands.

The block diagram of a basic analog AM transmitter is shown in Fig. 30.13 (a). The oscillator provides a fixed frequency and the power amplifier modulates the signal.



(*a*)



(*b*)

Fig. 30.13 Block diagram of **(a)** a basic and **(b)** practical AM transmitter

For any broadcast, the maximum power that can be radiated is controlled by the GOI. It is in the range 500W to 50kW for radio transmitters. Every broadcaster is allocated a definite frequency, which has to be observed strictly to avoid interfrence with other signals. To ensure this, undesirable frequencies are filtered out by using coupling circuits. We will not go into these details further.

The most popular form of radio communiction in India over the past 50 years had been medium wave (520 – 1700kHz) and short wave (4.39 – 5.18MHz; 5.72 – 6.33MHz) analog AM broadcast. It continues to have the widest spread, though analog FM broadcast is now being preferred because of better quantity. Moveover, radio waves are now comparatively free and private broadcasters are also entering the field in a big way. FM radio stations are also being created by educational institutions for education as well as empowerment of rural youth and homemakers. In TV transmission, audio is frequency modulated whereas the video (picture) is amplitude modulated.

In **frequency modulation**, the amplitude of the carrier wave remains constant, but its frequency is continuously varied in accordance with the instantaneous amplitude of the audio or video signal. When the amplitude of the modulating signal voltage is large, the carrier frequency goes up, and when the amplitude of the modulating signal is low, the carrier frequency goes down, i.e., the frequency of the FM wave will vary from a minimum to a maximum, corresponding to the minimum and maximum values of the modulating signal (Fig. 30.14).

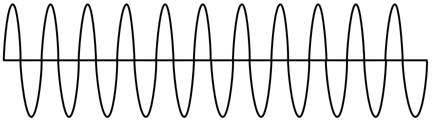


Fig. 30.14: Frequency modulated career wave

An FM Transmitter essentially contains an oscillator, whose frequency of the carrier is varied depending on the input audio signal. (It is usually accomplished by varying capacitance in an LC oscillator or by changing the charging current applied to a capacitor, for example, by the use of a reverse biased diode, since the capacitance of such a diode varies with applied voltage.) After enhancing the power of the modulated signal, it is fed to the transmission antenna. Low-frequency radio broadcast stations use amplitude modulation, since it is a simple, robust method.

Phase modulation involves changing the phase angle of the carrier signal is accordance with the modulating frequency. Analog pulse modulation is either amplitude modulated or time modulated. Similarly, digital pulse modulation is of two types: pulse code modulation and pulse delta modulation.

In **pulse code modulation**, the modulating signal is first sampled, and the magnitude (with respect to a fixed reference) of each sample is quantised. (It is a digital representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals of duration T_s. The binary code is transmitted usually by modulating an analog current in a transmission medium such as a landline whereas pulse code modulation is used in digital telephone systems and for digital audio recording on compact discs.

30.7 DEMODULATION

The modulated signal carrying the information, once radiated by the antenna, travels in space. Since there are so many transmitting stations, thousands of signals reach our antenna.

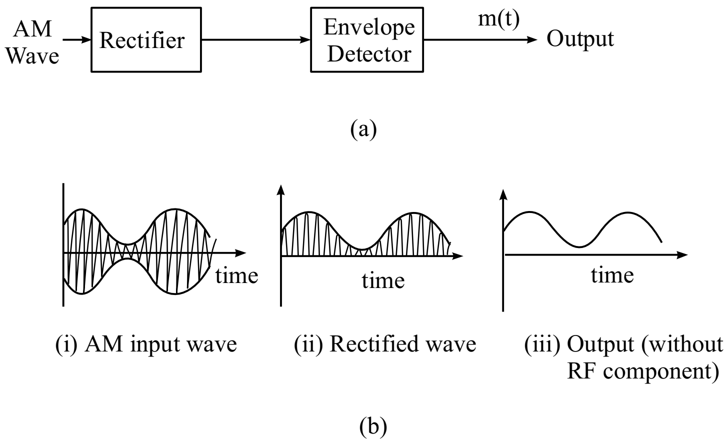


Fig. 30.15: (a) Block diagram of a detector for AM signal. (b) (i) AM modulated input wave (ii) Rectified wave (iii) output demodulated wave

We have to choose the desired signal and decouple the carrier wave and the modulating signal. This process is known as *demodulation*. The modulated signal of the form shown in Fig. is passed through 30.15(a) a rectifier to produce the output shown in Fig. 30.15(b). This envelop of the signal (b) is the message signal. In order to rereavel the message signal, the signal is passed through a envelop detectors (demodulator) which may consists of a simple RC circuit.

INTEXT QUESTIONS 30.4

1. Choose the correct option in each case:

   (a) Modulation is used to

   (i) reduce the bandwidth used

(ii) separate the transmissions of different users

(iii) ensure that information may be transmitted to long distances

(iv) allow the use of practical antennas.

(b) AM is used for broadcasting because

(i) it is more noise immune than other modulation systems

(ii) it requires less transmitting power compared to other systems

(iii) it avoids receiver complexity

(iv) no other modulation system can provide the necessary bandwidth for faithful transmission.

2. What is the optimum size of a radio antena.

COMMUNICATION APPLICATIONS

In recent years, the world of communication has advanced rapidly from printed texts to the telegraph, the telephone, the radio, the television, mobiles, Internet and computer conferencing (Audio and video). Countries all over the world are striving to achieve high standards of national and international communications. Radio and TV broadcasting through communication satellites is routinely achieved to reach out to the majority of the population even in remote corners of the globe. The domestic system of automatic telephone exchanges is usually connected by modern networks of fibre-optic cable, coaxial cable, microwave radio relay, and a satellite system.

Cellular or mobile telephone services are now widely available and include roaming service, even to many foreign countries. The cellular system works as a radio network of base stations and antennas. (The area of a city covered by one base station is called a cell, whose size ranges from 1 km to 50 km in radius.) A cell phone contains both a low-power transmitter and a receiver. It can use both of them simultaneously, understand different frequencies, and can automatically switch between frequencies. The base stations also transmit at low power. Each base station uses carefully chosen frequencies to reduce interference with neighbouring cells.

In a situation where multiple personal computers are used, as perhaps in your local study centre, it helps to get all the computers connected in a network so that they can "talk" to each other, and we can

- share a single printer between computers;
- share a single Internet connection among all the computers;
- access shared files and documents on any computer;
- play games that allow multiple users at different computers; and
- send the output of a device like a DVD player to other computer(s).

To install such a network of personal computers, there are three steps:

- Choose the technology for the network. The main technologies to choose between are standard Ethernet, phone-line-based, power-line-based and wireless.
- Buy and install the hardware.
- Configure the system and get everything talking together correctly.

The Internet is a vast network of computers throughout the world. It combines many different forms of communications. As the technology advances it could replace all other forms of communication by combining them into one. Magazines and newspapers are already being put online along with libraries, art, and research. Unlike most forms of communication, it facilitates access to vast store of information through the World Wide Web (WWW). The World Wide Web is the multimedia part of the Internet and combines text with sound, photos, drawings, charts, graphs, animation, and even video. New innovations such as Java, a web-based programming language, allow simple tasks to be performed inside the document. The more widespread the Internet becomes, the more important and powerful type of communication it will become. In India, several hundred thousand schools are being provided access to computers and Internet to impure the quality of education. The MHRD is developing a one stop portal –Sakshat– which can be accessed by you. The National Institute of open schooling is also contributing for it.

You may be aware of variouis complex communication systes in use around us; like: radio, TV, fax machine, internet etc.

A cathode-ray tube in a television set, has a “cathode” which emits a ray of electrons in a vacuum created inside a glass “tube”. The stream of electrons is focused and accelerated by anodes and hits a screen at the other end of the tube. The inside of the screen is coated with phosphor, which glows when struck by the beam. The cathods beam carries the vedio signals from the object and forms the image an the screen accordingly.

In a fax machine, the document to be transmitted is scanned by a photo sensor to generate a signal code before it is transmitted through a telephone line.

A modem (modulator/demodulator) can convert a digital bit stream into an analog signal (in the modulator) and vice-versa (in the demodulator). It is used as a transmitter to interface a digital source to an analogue communication channel, and also as a receiver to interface a communication channel to a digital receiver

WHAT YOU HAVE LEARNT

- In a typical modern-day long distance communication system, the information is in the form of electrical signals (voltage or current).
- The essential elements of a communication system are (i) a transmitter (ii) a medium or mechanism to carry the signal over long distances, and (iii) a receiver to intercept the signal and retrieve the information.
- An antenna or aerial is essentially a system of conductors, which is an effective radiator and absorber of electromagnetic waves in the desired radio frequency region.
- Analog signals are physical signals that vary continuously with time while digital signals have the form of discrete pulses.
- Digital communication systems are more efficienct, give better performance, and greater flexibility than their analog counterparts.
- AM radio is broadcast on three bands, the Long wave at 144 – 351 kHz (in the LF), the Medium wave at 530 – 1,700 kHz (in the MF), and the Short wave at 3 – 30 MHz (HF). FM radio is broadcast on carriers at 88 – 104 MHz (in the VHF). Commercial TV transmission is in the VHF-UHF range.
- Electrical communications channels are wireline (using guided media) or wireless (using unguided media).
- Multiplexing refers to the process of simultaneous transmission of different messages (each with some frequency bandwidth) over the same path way. The higher the frequency of the carrier, the higher is its message-carrying capacity.
- Comparing the different r ine h nel e c m ica c visible light (of frequency of about 10^{14} Hz) in an optical fibre is thus much larger than that of typical microwave (of frequency of about 10^9 Hz) in a metallic conductor.
- An optical fibre guides a light beam (from a laser) from its one end to the other by the process of total internal reflection at the interface of the inner core (of refractive index n_1) and the cladding (of refractive index $n_2 > n_1$).
- In the wireless radio transmission, a system of conductors called antenna or aerial launches the carrier radio waves in space and also detects them at the receiver location. The propagation of radio waves in the atmosphere depends on the frequency of the waves. Low and medium frequency radio waves up to about 1 MHz are used in ground (or surface) wave communication. Medium frequency (MF) waves of 300 kHz – 3 MHz are largely absorbed by the ionosphere. The high-frequency (HF) waves of 3 – 30 MHz are, however, reflected back by the ionosphere. VHF and UHF waves are transmitted either

by direct line-of-sight using tall towers (space wave or tropospheric propagation), or by beaming to artificial satellites and broadcasting from there.

- The cellular or mobile telephone system works as a radio network in which a city is divided into 'cells' of 1 km to 50 km in radius, and each cell is covered by one base station. A cellular phone contains a low-power transmitter and a low-power receiver.
- An analogue signal is completely described by its samples, taken at equal time intervals T_s, if and only if the sampling frequency $f_s = 1/T_s$ is at least twice the maximum frequency component of the analogue signal.
- Low frequencies can not be transmitted to long distances using aerials or antennas of practical dimensions. Low-frequency messages are loaded on a high frequency carrier signal by a process called modulation. In amplitude modulation (AM), the amplitude of a high-frequency carrier wave are modified in accordance with the strength of a low-frequency information signal. In frequency modulation (FM), the amplitude of the carrier wave remains constant, but its frequency is continuously varied in accordance with the instantaneous amplitude of the information signal, i.e., the frequency of the modulated carrier wave varies from a minimum to a maximum corresponding to the minimum and maximum values of the modulating signal.
- In the digital pulse code modulation (PCM) technique, the modulating signal is first sampled, the magnitude (with respect to a fixed reference) of each sample is quantised, and then the binary code is usually transmitted modulating an analogue current in a landline.

ANSWERS TO INTEXT QUESTIONS

30.1

1. E.M. waves are time varying electrical and magnetic field travelling in space with a speed of 3×10^8 ms^{-1} at right angles to each other.

2. $\lambda = \frac{C}{\nu} = \frac{3\times10^8 ms^{-1}}{30\times10^6 s^{-1}} = 10 \text{ m}$

3. (i) frequency range of visible light is 10^{14} Hz–10^{15} Hz

   (ii) frequency range of radio waves is 30 kHz–300 MHz

30.2

1. Co-axial cable is a pair of point to point connector where in one conductor is in the form of hollow cylinder and the other a solid wire at the axis of the first conductor the two being separated by an insulator. The one used for frequency range 3.0 GHz-40 GHz.
2. The basic principle used in optical fibre is total internal reflecion due to which light beam may move along an optical fibre without any loss in energy.

30.3

1. Sky wave communication is normally better during night, because in absence of sun ionosphere's composition is settled so that it acts as a better reflector.
2. (a) iv, (b) (iii)

30.4

1. (a) (iii), (b) (iii)
2. The minimum size of a transmitting antenna is comparable to wavelength of signal to be transmitted. For maximum power transmission size of antenna should be at least $\lambda/4$.