CHAPTER 1

Introduction : Historical Perspective

1.1. INTRODUCTION : HISTORICAL PERSPECTIVE

Ever since human beings learnt to communicate, the goal is to send and to receive maximum information over vast distances in shortest period of time. For communication, the information signals that are mostly used are electrical in nature. The information is transmitted in the electrical form \textit{i.e.}, in the form of electrical current or electrical voltage and at the receiving end, the information is regenerated from its electrical outputs. Even now, information signal can be optical in nature. Using optical mode, information can be transmitted, received and stored as well.

The development of optical fibre technology is the milestone in the global telecommunications and information technology revolution. Besides voice communication, to-days' telephone companies are serving their customers' ever expanding demands like:

- Audio, video, fax and data transmission
- Internet and multimedia services
- e-mail
- Video conferencing

The optical information can be transmitted through optical fibre as optical fibre can guide light. Apart from optical communication, optical fibres are being used in many different types of applications including optical inspection/surgery, non-contact sensing, traffic signs, museum illumination, etc.

Information can be stored in magnetic form such as magnetic tapes and computer hard discs etc. Information can be stored using optical mode as well. Nowadays compact disk (CD) is used for storing of information like data, sound, music, audio and video. Information are stored in CD by using a very special type of light \textit{i.e.}, laser. Again, the reading of information from CD is performed using laser. That means the information signals are converted into their optical equivalent and stored in CD using a special technique with laser. Besides, various other applications of laser are there like, laser show, laser surgery, laser printer, holography and so on.
To have the broader coverage on optical mode of transmission, discussion on its two major components *i.e.*, optical fibre and laser are essential. Chapter 2 covers the discussion about optical fibre. The chapter 3 includes short information about the principle of laser, different types of laser, various applications and hazards. Chapter 4 includes discussion about optical communication system in some more detail. As a background, this introductory chapter includes discussions on electromagnetic spectrum, the history about different types of communication, different optical communication systems, analog *vs*. digital communication, bandwidth, the measuring capacity and the need for optical communication. Chapter 5 illustrates the various types of experiments based on either laser or fibre or both fibre and laser. The contents of this book has covered a broader overview. In this respect, some theoretical discussions are included on physical properties of light in the Appendix. These are Dual nature of light, Electromagnetic wave, Interference, Diffraction and Polarization. For better understanding of optical telecommunication, some basic information are also included on Propagation Modes through Optical Fibre Waveguide, Basic Digital Communication and Networking in Telecommunication.

### 1.2. ELECTROMAGNETIC SPECTRUM

Electromagnetic waves come from a large variety of sources. They differ greatly in their wavelengths and in their effects, but they have certain fundamental properties in common, like velocity and physical properties like reflection, refraction, interference, diffraction and polarization. The various electromagnetic waves if arranged according to their wavelength/frequency represent the electromagnetic spectrum. Regions are indicated and these regions do not have sharp boundaries, they generally overlap. Electromagnetic radiation exhibits both wavelike and particle-like characteristics. From the point of view of its wavelike characteristics, electromagnetic radiation is known to exhibit wavelengths from less than $10^{-13}$ m to over $10^{15}$ m. Included in this range, in order of increasing wavelength, are gamma rays ($\gamma$), X-rays, ultraviolet waves (UV), visible light, infrared (IR) light, microwaves, radio waves. The term light is used loosely to refer to radiation from UV through IR. Radio waves and X-rays are similar types of radiant energy but are not classified as light. The light waves which human eyes can see is only a very narrow part of this electromagnetic spectrum. Except visible light, the other forms of energy in the electromagnetic spectrum normally cannot be detected by our eyes. We are using these electromagnetic waves in various applications as shown in Fig. 1.1

**Radio Waves.** These were discovered by Hertz in 1887. The electromagnetic waves with the lowest frequencies and longest wavelengths are Radio Waves. Their frequencies may be as low as 10 Hz and their wavelengths can go up to millions of meters long. Therefore, radio waves can be of extremely high frequency (EHF), super high frequency (SHF), ultra high frequency (UHF), very high frequency (VHF), high frequency (HF), medium frequency (MF), low frequency (LF), very low frequency (VLF), extremely low frequency (ELF). Surface wave EHF and SHF are used for radar and space communication. UHF and VHF are used in TV transmission and line of sight communication. Sky wave HF and ground wave MF have applications in radio communication. Surface wave LF and VLF are also used in radio navigation and ELF has application in sub-surface communication.
Microwaves. Radio waves with wavelengths ranging from a few tenths to about one thousandth of a meter are known as Microwaves. These are produced by specially designed oscillators. This is also for radar and TV communications.

Infrared (IR). Infrared frequencies are intermediate between those of microwaves and red visible light. We sense infrared light as heat. Infrared radiation can affect photographic plate coated with special chemicals.
**Visible light waves.** The next band of frequencies in the electromagnetic spectrum is Visible light. Visible light occupies only a small part of this spectrum and it produces the sensation of vision. White light is composed of a mixture of many different wavelengths each of which can be seen on its own by the human eye as a COLOUR. It consists of different colours, they are violet, blue, green, yellow, orange, red. When ordinary white light is passed through a prism, it is separated into the rainbow of colours known as Visible spectrum. The band of colour and their corresponding frequencies and wavelengths are shown in the Table 1.1 below.

**Ultraviolet light (UV).** Just above visible light in the electromagnetic spectrum is ultraviolet light (UV). This invisible light can be detected by photographic plate. Ultraviolet radiation is very useful in medical science as it is producing chemical effect on our body.

**X-rays.** Frequencies higher than UV are X-rays. This radiation was discovered by Rontgen in 1895. These rays find several applications in medical science and industry.

**Gamma rays (γ).** Frequencies higher than X-rays are Gamma rays. These rays can affect photographic plates and cause ionisation.

The sources of gamma rays are nuclear transitions involving radioactive decay. X-rays are produced through electronic transitions deep in the electronic structure of the atom. Also ultraviolet (UV) waves, visible radiation and infrared (IR) radiation result from electronic transitions of different energy ranges. Microwaves and radio waves are produced by various types of electronic oscillations.

<table>
<thead>
<tr>
<th>Colour</th>
<th>Frequency (THz)</th>
<th>Wavelength (nm) in Vacuum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>380–480</td>
<td>790-625</td>
</tr>
<tr>
<td>Orange</td>
<td>480–500</td>
<td>625-600</td>
</tr>
<tr>
<td>Yellow</td>
<td>500–520</td>
<td>600-577</td>
</tr>
<tr>
<td>Green</td>
<td>520–610</td>
<td>577-492</td>
</tr>
<tr>
<td>Blue</td>
<td>610–660</td>
<td>492-455</td>
</tr>
<tr>
<td>Violet</td>
<td>660–770</td>
<td>455-390</td>
</tr>
</tbody>
</table>

An electromagnetic wave travels with a speed $c$ such that $c = \nu \lambda$. Thus, higher the frequency ($\nu$) of the electromagnetic wave, lower is its wavelength ($\lambda$). Different forms of radiant energy travel as electromagnetic waves. It is associated with electric (E) and magnetic (M) fields. Radiant energy travels through space as waves much like the waves produced in still water if we toss a pebble into it. The waves radiate in every direction away from the point of origin.

The rough representation of Electromagnetic Spectrum is depicted in tabular form in Table 1.2. Properties common to all of the above waves are:

- They travel through free space in straight lines at a speed of $\sim 3 \times 10^8$ m/s.
- They are associated with oscillating electric and magnetic fields and transverse in nature.
- Waves emitted from a point source in free space obey an inverse square law.
Different forms of energy travel with longer or shorter waves and any energy form can be defined by either its wavelength or frequency. Wavelength is the more common system used for our purposes and this can vary tremendously according to the energy involved. For example radio waves in the long band can have a wavelength of one kilometre, while at the other end of the spectrum cosmic waves can be as short as one picometer (one million millionths of a metre).

Wavelength is the distance from the crest of one wave to the crest of the next one, while frequency is a measure of the number of wave cycles performed in the space of one second. Frequency is used to be described as cycles per second, but is more commonly known nowadays as Hertz (Hz). The frequency (ν) is expressed in Hz [or kilohertz (kHz) or megahertz (MHz) or gigahertz (GHz) or terahertz (THz) or pentahertz (PHz)] while the wavelength (λ) is expressed in metre (m) [or micron (micrometre i.e., mm) or nanometre (nm) or Angstroms (Å)]. Table 1.3 illustrates the interrelations between different units of frequency and wavelength.

**Table 1.2 : Rough Representation of Electromagnetic Spectrum**

<table>
<thead>
<tr>
<th>E.M. Radiation</th>
<th>Frequency (Hz) (ν)</th>
<th>Wavelength (m) (λ)</th>
<th>How produced</th>
</tr>
</thead>
<tbody>
<tr>
<td>γ-rays</td>
<td>(5 \times 10^{20} - 3 \times 10^{19})</td>
<td>(6 \times 10^{-12} - 1 \times 10^{-10})</td>
<td>Radioactive nucleus</td>
</tr>
<tr>
<td>X-rays</td>
<td>(3 \times 10^{19} - 1 \times 10^{16})</td>
<td>(1 \times 10^{-10} - 3 \times 10^{-8})</td>
<td>Bombardment of high atomic weight nucleus with energetic electrons</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>(1 \times 10^{16} - 8 \times 10^{14})</td>
<td>(3 \times 10^{-8} - 4 \times 10^{-7})</td>
<td>Excited atoms</td>
</tr>
<tr>
<td>Visible (Violet-Red)</td>
<td>(8 \times 10^{14} - 4 \times 10^{14})</td>
<td>(4 \times 10^{-7} - 8 \times 10^{-7})</td>
<td>Excited atoms</td>
</tr>
<tr>
<td>Infrared</td>
<td>(4 \times 10^{14} - 3 \times 10^{11})</td>
<td>(8 \times 10^{-7} - 1 \times 10^{-3})</td>
<td>Hot bodies</td>
</tr>
<tr>
<td>Microwave</td>
<td>(3 \times 10^{11} - 3 \times 10^{9})</td>
<td>(1 \times 10^{-3} - 3 \times 10^{-1})</td>
<td>Oscillating current</td>
</tr>
<tr>
<td>Radio wave (EHF, SHF, UHF, VHF, HF, MF, LF, VLF, ELF)</td>
<td>(3 \times 10^{9} - 3 \times 10^{4})</td>
<td>(1 \times 10^{-1} - 1 \times 10^{4})</td>
<td>Oscillating current</td>
</tr>
<tr>
<td>Power Frequencies</td>
<td>Below (3 \times 10^{4})</td>
<td>Above (1 \times 10^{4})</td>
<td>AC circuit</td>
</tr>
</tbody>
</table>

**Table 1.3 : The Interrelations between Different Units of Frequency and Wavelength**

<table>
<thead>
<tr>
<th>Units of Frequency</th>
<th>Units of Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kHz = (10^{3}) Hz</td>
<td>1 μm = (10^{-6}) m</td>
</tr>
<tr>
<td>1 MHz = (10^{6}) Hz</td>
<td>1 nm = (10^{-9}) m</td>
</tr>
<tr>
<td>1 GHz = (10^{9}) Hz</td>
<td>1 Å = (10^{-10}) m</td>
</tr>
<tr>
<td>1 THz = (10^{12}) Hz</td>
<td>1 pm = (10^{-12}) m</td>
</tr>
<tr>
<td>1 PHz = (10^{15}) Hz</td>
<td></td>
</tr>
</tbody>
</table>
1.3. HISTORY ABOUT DIFFERENT TYPES OF COMMUNICATION

The basic components of a communication technology are:
- Transmitter of Information signal
- Carrier of signal
- Receiver of signal

Considering different types of communication, the broad types can be cited, like, Radio, Television, Satellite and optical communication.

Radio Communication

In this respect the first stepping stone was Radio Communications. Guglielmo Marconi (1874–1937) is known as the father of wireless communication. He was fascinated by the idea of using radio waves to communicate. He discovered a way to transmit and receive radio waves and perfected it during the 1890s. On December 1901, Marconi proved to the world that it was possible to send messages across continents.

To communicate by radio, we need a radio transmitter and a radio receiver. Sound waves (Speech/Music) are converted into electrical signals in the microphone. These signals are combined with a radio wave with a particular frequency called a carrier wave into the transmitter. By this process called modulation, the resulting signal is passed to the transmitting aerial and is transmitted through free space as electromagnetic radio waves. The electromagnetic radio wave is picked up by the antenna of a radio receiver. The carrier wave is tuned and information signal is separated by a detector in the radio receiver by the process called demodulation. The loudspeaker of the radio converts the electrical signals back to sound. These processes are depicted in Fig. 1.2. Therefore, for radio wave communication, we have transmission station which transmit the signal by modulation process. The information signal is carried as electromagnetic wave and the signal is picked up by radio receiver by the process of

![Radio Communication Diagram](image-url)
demodulation. The modulation processes can be of different types such as Amplitude Modulation (amplitude of the carrier wave is influenced by the signal amplitude), Frequency Modulation (frequency of the carrier wave is influenced by the signal frequency) and so on.

New inventions such as the use of semiconductor brought about the improvement of radio and at the same time, telephone networks began to spread as well. Ultimately, the radio transmission opened the way to many technological innovations like, television, satellite, mobile phone, etc.

**The Television**

After transmitting sound through radio communication, next came the concept of transmitting images which led to television. The television was first developed during the 1920s and perfected in the 1930s. The first “successful” colour television was invented in 1953. Of all the communication-related inventions, none has so much impact on society as television.

Television broadcasting works in a way similar to radio broadcasting. The image signal recorded by the camera is made of the red, green and blue signals. These signals are converted into electrical signals. These electrical signals are in turn modulated and transmitted by electromagnetic waves. On reaching the TV aerial, the signals are demodulated and displayed on the TV screen, while the sound signal is passed to the loudspeaker.

**The Satellite**

Many satellites were developed and launched in the late 1950s and in the 1960s, for observation. In July 1962, NASA launched the first public telecommunications satellite “Telstar” and broadcast the first live television pictures across the Atlantic.

Satellite communication differs uniquely from other modes of communication owing to its ability to link all the users simultaneously on the earth’s surface (Fig. 1.3). In 1945, Dr. Arthur Clarke wrote in his book “Wireless World” that the satellites placed in geostationary

![Satellite communication](image)

**Fig. 1.3.** Satellite communication from one ground station to another.
orbit of the earth could provide worldwide communication. As it is known that the satellite in geo-stationary orbit of the earth (at an altitude of 35,786 kms) rotates at the same angular velocity as the earth and thus appears to be stationary with respect to a location on the earth and this is a big advantage for communication links (as illustrated in Fig. 1.4). Clarke’s foresight turned into reality twenty years later when the first satellite was launched in 1965. By placing a satellite in a high geostationary orbit, the satellite remains above a particular point on the Equator. Three geostationary satellites, one above the Pacific, one above the Atlantic and one above the Indian Ocean would be enough to relay signals to and from any point on the surface of the Earth. In 1965, the satellite “Early Bird” was launched on a geostationary orbit and became the first commercial satellite to provide a constant link between Europe and America.

![Figure 1.4](image)

Fig. 1.4. Three stationary satellites located in circular orbits at 120° apart from each other.

Initiatives have been taken for large number of satellites for providing high capacity local access for multimedia anywhere in the world. Satellites form an essential part of telecommunication system worldwide carrying large amounts of data and telephone traffic in addition to television signals. Gateway stations are collecting data from different routes and interfacing with the existing terrestrial infrastructure. An illustration is made in Fig. 1.5. Long-distance calls or TV programs travel by radio or along cables to the satellite ground station. The signals are amplified and beamed from a parabola antenna into space. The satellite receives the signal, amplifies it again and sends it back to the appropriate ground station. The signals are again amplified and sent by wireless radio waves or electrical wave along cables. With a “dish” connected to their TV set, people can pick up signals directly from a satellite and receive more channels which are called the satellite television.
Optical Communication

Since the boundaries of communications have been extended, multiple channels of communications are being carried out simultaneously through networks spanning the world which include cable/wire (i.e., copper cable/fibre cable) and wireless transmission.

Optical fibre has become the most popular medium for transmission of data, voice and video signals from one point to another. It is now almost a reality that optical fibres play a major role in Integrated Services Digital Network (ISDN) and also as a communicating medium in between distant telephone exchanges. The large bandwidth low attenuation characteristics of an optical fibre make it extremely popular in long haul telecommunication links. It is the optical fibres immunity to electromagnetic and radio frequency interference that makes it equally popular in local area networks (LAN), defense, railway applications and communication on the factory/office floor. In addition to vast use of optical fibre in telecommunications, some other areas of optical communication are Video link, Community Antenna Television (CATV), Computer link, Local Area Networks (LAN’s)/Wide Area Networks (WAN’s), which have been discussed in Chapter 2.

1.4. DIFFERENT OPTICAL COMMUNICATION SYSTEM

For underground Optical Telecommunication system, we need to have a pair of optical fibre for each channel of optical communication, one for transmission and the other for reception.
of information. Different types of underground cables consisting of a number of pairs of optical fibres (like 6x, 12x, 48x, 96x) are used for this purpose. Detailed discussion on optical fibre cables is made separately in chapter 2. Chapter 4 includes the discussion on optical transmitter, receiver and related advanced optical communication technology. Besides underground Optical Telecommunication system *i.e.*, land line communication system, the other types of optical communication system are Free Space Communication System and Undersea Optical Communication System.

1.4.1. Free Space Optical Communication System

This can be classified again as (A) Satellite Optical Communication System and (B)Terrestrial atmospheric Optical Communication System.

**(A) Satellite Optical Communication System**

Satellites offer a number of features not readily available with other means of communications. As a very large area of the earth is visible from a satellite, the satellite can form the star point of a communication network linking together many users simultaneously, users who may be widely separated geographically. The same feature enables satellites to provide communication links to remote centres in sparsely populated areas, which are difficult to access by other means. Of course, satellite signals ignore political boundaries as well as geographical ones. Allocating frequencies to satellite services is a complicated process, which requires international co-ordination and planning. This is carried out by International Telecommunication Union. For frequency planning, the world is divided into three regions and within these regions, frequency bands are allocated to various satellite services like broadcasting, mobile telephone, navigational, meteorological and fixed services.

In recent years, ground/aircraft to satellite and satellite to ground/aircraft optical communication links are receiving attention. It is obvious that these links are under constraints of atmospheric turbulence, weather and aircraft boundary layer effects. The attenuation of optical signal both due to absorption and scattering is primarily confined to a few hundred meters vertically up in the atmosphere. The loss from higher atmosphere is comparatively negligible. To overcome these effects high power CO$_2$ laser system is chosen at 10.6 $\mu$m. This is suitable for ground use only for its bulky size. Serious attempts are under way to modify the existing system considering the following points:

- Design of the optical source for its use in satellite
- Faster infrared detector technology at this wavelength
- Low temperature system for infrared detector in order to overcome the electronic noise problems

**(B) Terrestrial Atmospheric Optical Communication System**

Scientist Alexander Graham Bell first proposed optical communication with the atmosphere as transmission medium. This optical communication through atmosphere is greatly affected by atmospheric condition and it is always a line of sight communication, as it cannot circumvent any physical obstruction between the optical transmitter and related receiver. With proper engineering to overcome these problems, this optical link is very useful in busy and built-up areas where laying of optical fibre may not be possible for different reasons. For
its low cost and easy installation this communication is very much preferred in connecting offices in high rise buildings in metropolitan environment. An atmospheric optical communication system consists of a laser transmitter and an optical receiver. The most common method of data transmission uses pulse code modulation of a laser diode output. LEDs can also be used as source in case of short distance of the order of a few tens of meters. The receiver consists of a telescopic type optical component focusing the beam on a PIN/APD photo detector.

This atmospheric optical link can be considered as mobile data link at low cost. This can also be a part of local area network (LAN) within 500 m using low cost components. That means, besides optical fibre, wireless communication is also being used in LAN. In case of wireless LAN, sometime, Infrared technology is used. This technology is similar to the one that is used in TV set remote control. The transmitter uses simple inexpensive IR LEDs and photo diode is used as receiver. It is expected that in near future the link distance could be even several kilometers with improvements in optical source and detector. There are two types of IR LANs:

- **Direct beam IR LANs.** This is referred to as line of sight link which involves the transmission of highly focused narrow IR beam that connect one terminal to another. Obviously the receiver and transmitter must be properly aligned. It gives longer range and higher data rates up to 10 Mbps. It is best suited for fixed terminals and specially for large file transfers.

- **Diffused IR LANs.** It provides ease of installation as the transmission of signals are in all directions. Because of multiple paths involved, data transmission rate is limited to about 1Mbps. For example, sometime, laptops have in built IR transceiver chip that enables communication between portable laptop and a fixed terminal, printer or any peripheral. The main advantage of using infrared is the reduced cost. Disadvantage is the limited range, i.e., transmission is interrupted when obstacles are present because infrared does not penetrate solid matter.

### 1.4.2. Undersea Optical Communication System

The advances in digital transmission technology have provided an introduction of optical fibre as a transmission medium in underwater optical communication system. Undersea fibre cables are in direct competition with satellites. They have the great political advantage that the countries connected retain complete control over the link. This undersea i.e., underwater optical communication system can be subdivided into two groups as (A) Fibre-optic transoceanic Optical Communication Systems and (B) Optical Communication Systems with submerged bodies.

**A) Fibre-optic Transoceanic Optical Communication System**

Submarine cable technology was introduced for optical communication because of various advantages of optical fibre cable systems over conventional cables. It is important to note that it is difficult and expensive to install and maintain a submerged optical system. For long distance communication “repeater” is required for shaping and sizing the faded and distorted signal. Thus, it is particularly important to achieve much larger repeater spacing. For this, pure silica core, low loss dispersion shifted optical fibres are used with 1.55μm heterostructure light source. With the main advantages like, extended repeater spacing, wide band width,
large data transmission capacity and easy handling for smaller size and light weight, these optical systems are used for two types of links like: (a) 565 Mbps channel capacity with a repeater spacing of 80–100 km and (b) 140 Mbps channel capacity with a repeater spacing of 120–150 km.

There are several underwater fibre optic cables already installed through Atlantic and Pacific Ocean and they are working satisfactorily connecting US, France and Britain from 1988. In Japan, extensive underwater fibre optic cables also connect various islands.

(B) Optical Communication Systems with Submerged Bodies

Optical communication system with submerged body like submarine is for limited depth of 200 m. Since water is a good absorber of electromagnetic wave of all wavelengths, communication from the ground to submarines under water has always been a problem. For example, the blue green optical signal with 1W peak power could travel through water for about 300m within which it is detectable and during this path the power falls to 1 mW. Thus, it is not possible to have direct communication between ground and submarine object. This problem could be solved using modified technology. This link could be made using a mirror satellite using the following steps:

(i) atmospheric communication from ground to satellite
(ii) atmospheric communication from satellite to ocean surface
(iii) penetration of air-water interface at ocean surface
(iv) optical propagation in water from ocean surface to the submarine object.

Considering optical signal from ground to satellite and from satellite to ocean surface, it has been found that the attenuation factor is around 0.36. The reason for this attenuation of optical signal is due to both absorption and scattering which is primarily confined to a few hundred meters vertically up in the atmosphere. The loss from higher atmosphere is nearly negligible. Again, in the third step, the optical signal penetration of ocean surface is considerably low due to presence of random ocean waves. Research studies have indicated that if the illuminated ocean surface diameter is more than twice the typical wavelength in ocean wave spectra, the intensity of the beam received at the submarine detector is not much less than half of the intensity that would have been received in the absence of waves. The important factor is that the intensity of light will fluctuate with ocean waves and that will destroy any factual information that the amplitude of the optical signal may process. To avoid this, techniques other than amplitude modulation should be adopted. Another most serious attenuation is due to the beam divergence which, of course, cannot be avoided. Any way, this communication is feasible only using a high power pulsed laser like Nd:YAG (532 nm wavelength and power output $10^6$ W) and using pulse modulation. Actually, the bit rate is so small that even a single voice channel cannot be transmitted satisfactorily for communication to submarine which is 200 m inside the ocean. With the expected future development of new lasers, we are hopeful about the success of this type of optical communication in days to come.
1.5. ANALOG VS. DIGITAL COMMUNICATION

Fig.1.6(a) and Fig.1.6(b) illustrate schematically the analog and digital formats of communication signal. People speak in an analog format. Therefore, spoken words are transmitted as analog waves. Until recently, all telephone calls were transmitted in an analog form. Now much of the public telephone network is digital. The phones operate with digital signals, made up of one’s and zero’s just like our computers, with the analog-to-digital conversion done at the local telephone office.

![Fig. 1.6. Different types of signals (a) Analog (b) Digital.](image)

The analog signal can be thought of as the time varying voltage. At each instant of time, the magnitude of the voltage has a specific value. This voltage can be represented by a decimal number (i.e., base 10), say N. If this decimal number N be converted into binary number system (whose base is 2), then it can be represented as a series of “ones” and “zeros”. For example, if N = 57, then

\[ 57 = 32 + 16 + 8 + 1 = (1 \times 2^5) + (1 \times 2^4) + (1 \times 2^3) + (0 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) \]

So, the binary representation of 57 is 111001. Here, “1” and “0” indicate respectively the appropriate power of 2 which is present and the appropriate power of 2 which is not present. In Table 1.4, examples are given for decimal number and its binary equivalent. These ‘zero’ and “one” are called binary digit or simply bit. If the values of voltages of the analog signal are taken at equal time intervals, and if the corresponding values are converted into their binary form, then a continuous binary representation of the original analog signal can be obtained. This is called analog to digital conversion (A/D). Once information has been digitized, it can be transmitted from the source of message to the destination without distortion and noise.

Electrical digital signal means signal consisting of series of voltage on and off state, similarly digital optical signal consists of series of light on and off states to make ‘one’ and ‘zero’ state of digital mode of communication.

### Table 1.4 : Decimal Number and Corresponding Binary Equivalent

<table>
<thead>
<tr>
<th>Decimal Value [Base 10]</th>
<th>Corresponding Binary Equivalent [Number Representation Base 2 format]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 ((1 \times 2^0))</td>
</tr>
<tr>
<td>2</td>
<td>10 ((1 \times 2^1) + (0 \times 2^0))</td>
</tr>
<tr>
<td>3</td>
<td>11 ((1 \times 2^1) + (1 \times 2^0))</td>
</tr>
<tr>
<td>4</td>
<td>100 ((1 \times 2^2) + (0 \times 2^1) + (0 \times 2^0))</td>
</tr>
</tbody>
</table>
### Decimal Value [Base 10] | Corresponding Binary Equivalent [Number Representation Base 2 format]
---|---
5 | 101
6 | 110
7 | 111
8 | 1000
9 | 1001
10 | 1010
11 | 1011
12 | 1100
13 | 1101
14 | 1110
15 | 1111
16 | 10000
31 | 11111
32 | 100000
63 | 100001
64 | 100000
65 | 100001

The sources of different digital signal are shown in Fig. 1.7. The advantages of digital signal over analog are like, higher speeds, clearer voice, video quality, fewer data errors etc.

![Digital Data](image1.png)

![Analog to Digital converter](image2.png)

Fig. 1.7. Examples of Digital Sources.
Analog intensity modulation is usually easier to apply but requires comparatively large signal to noise ratio. Reason is that for long distance communication repeater is required for shaping the faded signal and in the process the noise is amplified in analog transmission. But in digital transmission, noise is eliminated as shown in Fig. 1.8. The amplified noises destroy the originality of the analog signal whereas for digital communication the noise does not interfere with the data transmitted. Therefore even though relatively narrow bandwidth is required for analog transmission, it is limited to short distance applications and most long haul fibre optical systems use digital intensity modulation. Considering different properties, the comparison between analog and digital communication are explained in tabular form in Table 1.5.

**Table 1.5 : Comparison between Analog and Digital Communication**

<table>
<thead>
<tr>
<th>Properties</th>
<th>Digital</th>
<th>Analog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission</td>
<td>simple</td>
<td>Not so simple</td>
</tr>
<tr>
<td>Cost</td>
<td>Cost effective</td>
<td>Not so cost effective</td>
</tr>
<tr>
<td>Modulation</td>
<td>On/Off modulation removes most non-linearity problem</td>
<td>Introduction of non-linearity reduces the transmission bandwidth</td>
</tr>
<tr>
<td>Speed</td>
<td>Higher</td>
<td>Slower</td>
</tr>
<tr>
<td>Quality</td>
<td>Clearer voice quality</td>
<td>Not so clear</td>
</tr>
<tr>
<td>Error</td>
<td>Fewer errors</td>
<td>Error more</td>
</tr>
<tr>
<td>Equipment</td>
<td>Less complex peripheral equipment required</td>
<td>complex peripheral equipment required</td>
</tr>
</tbody>
</table>
The speed of analog signal is expressed in frequency and its unit is Hertz, whereas digital signal’s speed is expressed as bits per second (bps). In telephone communication, laser, used as light source, can be turned on and off billions of times per second. Optical fibre typically carry 32,000 digital phone signals and in the new system 500,000 channels would be possible.

1.6. BANDWIDTH, THE MEASURING CAPACITY

In any communication, bandwidth refers to capacity. Bandwidth is expressed differently in analog and digital communications. For analog communications, the bandwidth of a signal is the range of frequencies required to represent the information contained in the signal. It is expressed in hertz or Hz. The bandwidth required to send a signal or to transmit data depends on the type of signal. As for example, let us look at some typical signals and required bandwidths as depicted in Table 1.6. Voice signal needs 4 kHz bandwidth, Audio signal needs approximately 10 kHz bandwidth. In case of FM, high quality audio and television transmission, the required bandwidths are respectively 200 kHz and 6 MHz. The analog service consists of so many signals transmitting together. Thus the bandwidth of an analog service is the difference between the highest and lowest frequencies within which the media carries traffic. For example, cabling that carries data between 200 MHz and 300 MHz has a bandwidth, or frequency, of 100 MHz. The higher the frequency, the greater the capacity or bandwidth.

Table 1.6 : Various Types of Signals and Corresponding Required Bandwidth

<table>
<thead>
<tr>
<th>Signal</th>
<th>Bandwidth Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telephone (Voice)</td>
<td>4 kHz</td>
</tr>
<tr>
<td>AM Radio (Audio)</td>
<td>10 kHz</td>
</tr>
<tr>
<td>FM Radio (High quality Audio)</td>
<td>200 kHz</td>
</tr>
<tr>
<td>Television (Video + Audio)</td>
<td>6 MHz</td>
</tr>
</tbody>
</table>

In digital communication, bandwidth means the transmission speed or bit rate and it is measured in bits per seconds (bps). The bandwidth required to send a signal or to transmit data depends on the type of signal. The slogan of communication technology is speed. Technology is being developed to serve the demand of more and more data service rate, namely from bits per second (bps) to kilo bits per second (kbps) to million bits per second (Mbps) to giga bits per second (Gbps) and finally to tera bits per second (Tbps). It is roughly defined as the inverse of the minimum seperation in time allowable in successive pulses without overlapping.

On different digital services, such as ISDN, T-1, T-3, SONET and ATM, speed is stated in bits per second. That means, it is the number of bits that can be transmitted in one second. Modem (Modulation and Demodulation) converts analog signals into digital signals and vice-versa. Earlier modems transmitted signals at 300 or 1,200 bps. With time, modems with higher transmission rates like 14.4 kbps, 28.8 kbps, 64 kbps got developed. An idea of bandwidth in terms of bits per second (bps) for different digital services are as follows:
• Individual ISDN channels have a bandwidth of 64 Kbps
• T-1 circuits have a bandwidth of 1.54 Mbps
• One version of ATM has the capacity for 13 Gbps

where,

Kbps = kilo (thousand = 10^3) bits per second
Mbps = mega or million (10^6) bits per second
Gbps = Giga (billion = 10^9) bits per second
similarly, Tbps = Tera (10^12) bits per second

In addition to bits per second (in digital transmission) and hertz (in analog transmission), speed is sometimes referred to as narrowband and wideband. Similar to wide pipe which can carry more water, wideband lines can carry more information than the narrowband lines. Thus the term narrowband refers to slower speed services and wideband refers to higher speed services. Examples for narrowband services are analog telephone lines at 3 kHz, T-1 at 1.54 Mbps as 30 voice or data conversations on fibre optics etc., whereas wideband services include TV broadcast services at 6 MHz per channels, ATM services at 622 Mbps capable of sending voice, video and data, etc.

1.7. NEED FOR OPTICAL COMMUNICATION

Nearly exponential increase in usage of voice, video and data communications, nationally and internationally, demands new requirements on the transmission media. The need for low loss, low dispersion, ultra-wide bandwidth, and high dynamic range, durability, upgradability, and low cost communications networks, have shifted the focus from traditional copper cable to optical fibre links.

One channel telephone speech takes only a few kHz of bandwidth, whereas one channel of television broadcast needs at least several MHz. The greater the amount of information and/or the greater its necessary transfer rate, greater the bandwidth required. Table 1.7 shows the communication frequency band of the electromagnetic waves for various types of signals. The important fact is that the TV transmission utilizes VHF/UHF (very/ultra high frequency ~30–3000 MHz) waveband while normal radio broadcasts (voice and music) utilize lower frequencies (~300 kHz–30 MHz) of the electromagnetic spectrum. The reason for this is that the information content in TV signals are much more compared to that of radio broadcasts, and TV signals cannot be sent effectively by using radio frequencies as the carrier. Indeed, the higher one goes up in the electromagnetic spectrum in the frequency scale, the higher would be the information carrying capacity of such communications system.
Table 1.7: Communication Frequency Bands for different Information Signals

<table>
<thead>
<tr>
<th>Communication Frequency Band</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 kHz</td>
<td>Telephone (voice)</td>
</tr>
<tr>
<td>0.5 MHz—1.6 MHz</td>
<td>AM radio (Audio)</td>
</tr>
<tr>
<td>88 MHz—108 MHz</td>
<td>FM radio (High quality Audio)</td>
</tr>
<tr>
<td>174 MHz—254 MHz</td>
<td>VHF Television (broadcast) (video + audio)</td>
</tr>
<tr>
<td>470 MHz—860 MHz</td>
<td>UHF Television (broadcast) (video + audio)</td>
</tr>
<tr>
<td>800 MHz—900 MHz</td>
<td>Cellular phones</td>
</tr>
<tr>
<td>1 GHz—40 GHz</td>
<td>Communication satellites</td>
</tr>
</tbody>
</table>

For example, since the frequency of the speech signal may lie anywhere between 0 and 4000 Hz, in the upper side band transmission, we must transmit frequencies between 100,000 and 104,000 Hz. Thus, a band of at least 4000 Hz must be reserved for one speech signal. Hence, between carrier frequencies of 100,000 and 500,000 Hz, we can at least send 100 independent speech signals simultaneously as obtained from simple calculation as described in Table 1.8. Since the same bandwidth of 4000 Hz is required irrespective of the value of the carrier frequency, it becomes clear that, in a higher carrier frequency channel between \((10^{10} - 5 \times 10^{10})\) Hz and \((10^{15} - 5 \times 10^{15})\) Hz one can send \(10^7\) and \(10^{12}\) speech signals respectively. Thus switching the carrier frequency from radio to microwave and then to optical wave, the option for number of telephone channels changes from \(10^2\) to \(10^7\) and ultimately to \(10^{12}\). This is an enormous capacity indeed. The bandwidth of 4000 Hz that we have considered is enough for speech transmission. But for music the bandwidth is about 20 kHz. For television, the bandwidth is about 6 MHz. Thus for increasing more number of Telephone/Audio/Video channels, higher frequency carrier wave is required. Since optical frequencies are extremely large (~ \(10^{15}\) Hz), as compared to the conventional radio waves (~\(10^6\) Hz) and microwaves (~\(10^{10}\) Hz), a light beam acting as a carrier wave is capable of carrying far more information than radio waves and microwaves.

Table 1.8: Option for Number of Channels Depending on Carrier Wave Frequency

<table>
<thead>
<tr>
<th>Carrier wave</th>
<th>For Carrier wave frequency Range</th>
<th>Number of Telephone voiceChannels possible (Theoretically)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio Wave</td>
<td>(10^5 - 5 \times 10^5)</td>
<td>((5 – 1) \times 10^5/4000 = 10^2) Channels</td>
</tr>
<tr>
<td>Microwave</td>
<td>(10^{10} - 5 \times 10^{10})</td>
<td>((5 – 1) \times 10^{10}/4000 = 10^7) Channels</td>
</tr>
<tr>
<td>Optical wave</td>
<td>(10^{15} - 5 \times 10^{15})</td>
<td>((5 – 1) \times 10^{15}/4000 = 10^{12}) Channels</td>
</tr>
</tbody>
</table>
The idea of using light waves for communication i.e., to transmit voice information was first developed by Alexander Graham Bell and demonstrated in 1880 with his experiment called the photophone. After the invention of laser in 1960, the optical communication started taking shape using Graham Bell’s photophone principle. The modern impetus for telecommunications with carrier waves at optical frequencies of the electromagnetic spectrum through optical fibre owes its origin to the discovery of laser. It is expected that in the not too distant future, the demand for flow of information traffic will be so high that only a light wave will be able to cope with it.